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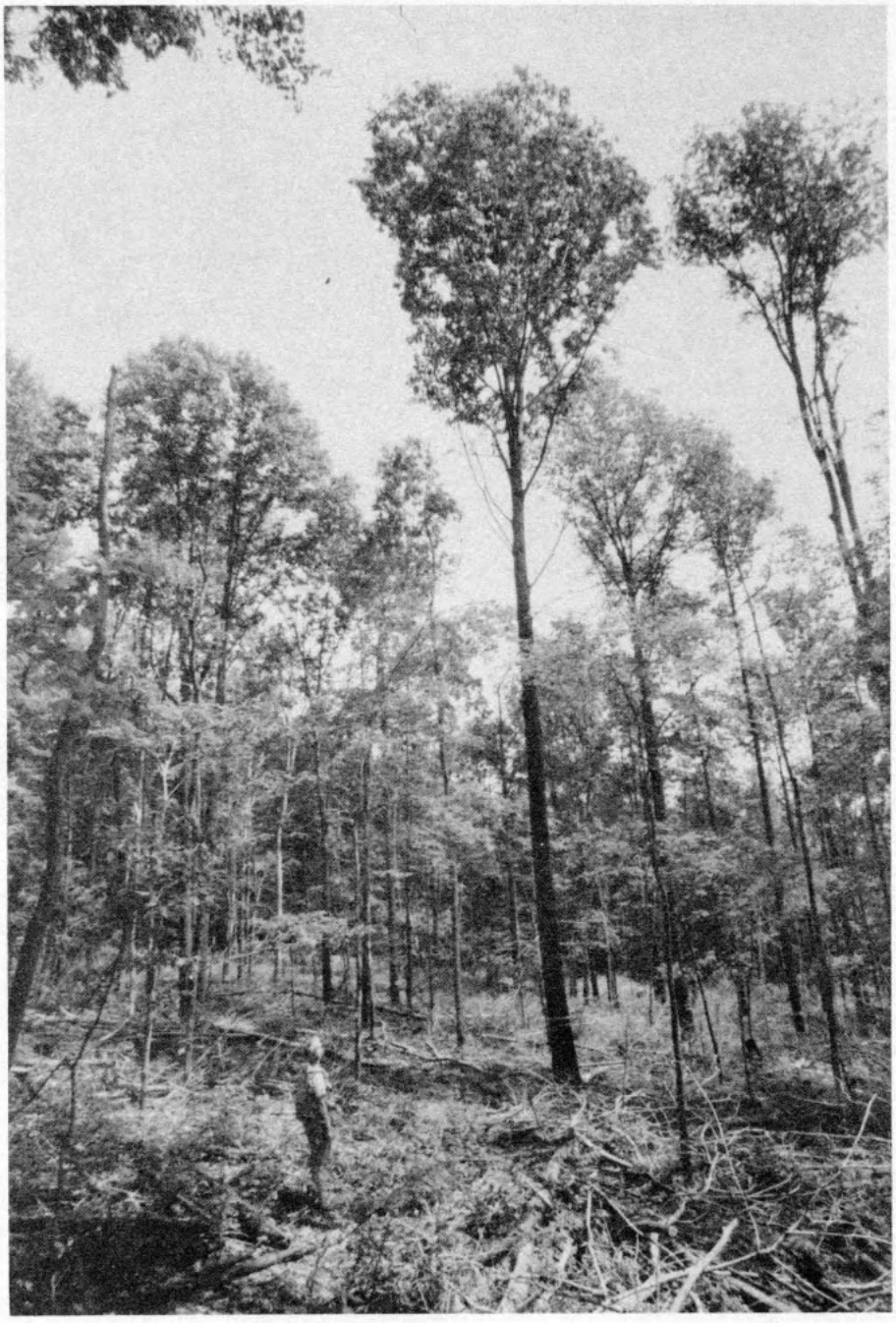

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Edited by

Larry H. McCormick and Kurt W. Gottschalk

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FOREWORD

This conference is the eighth in a series of biennial meetings that began in 1976 at Southern Illinois University. Other conferences have been hosted by Purdue University, University of Missouri, University of Kentucky, University of Illinois, and University of Tennessee. The purpose of these conferences has remained the same: to provide a forum for the exchange of information concerning the central hardwoods and to engender coordination among forest scientists in the central hardwood region. This purpose is evidently well-served: the last several conferences have each attracted some 45 to 65 program contributions, and the audiences have been correspondingly large.

Previous organizers have refrained from drawing precise boundaries around the "central hardwood region." We prefer to continue that policy on the grounds that to do otherwise might preclude some very worthwhile participation. Thus, while the principal focus has remained on the oak resource for reasons that are obvious, the ecological scope has broadened from oak-hickory (in the early meetings) to Appalachian oak (Knoxville and State College) and mesophytic forests. With a few exceptions, the commercially significant species are similar for all these forest types, and advancements in knowledge are of general interest.

But the central hardwood region is not merely a collection of similar forest types. It also has historical, demographic, political, and economic characteristics that tend to distinguish it from other forest regions of the United States. For example, the population is heavily rural and agricultural, primary wood markets tend to be diffuse and unorganized, wilderness values and endangered species have generally not been overriding issues, and a relatively minor proportion of the forest land is controlled by public agencies or corporate ownerships. These and related conditions play critical roles in the practice of forestry in this region, and in the aggregate they emphasize its distinction from other regions; but no single one is necessarily unique to the central hardwoods. For these reasons, the characteristics of nonindustrial private forest land owners in Massachusetts might be just as relevant to the central hardwood region as regeneration methods for white oak in Indiana.

Since these proceedings are being published in advance, we have no way of judging the ultimate success of the upcoming Eighth Conference. Of course, our earnest hope is that this meeting shall sustain the excellent reputation of the series. We believe this hope is encouraged by the quality of the papers in these proceedings.

REVIEW PROCEDURES

Each manuscript published in these proceedings was critically reviewed by at least two scientists with expertise in disciplines closely aligned to the subject of the manuscript. Reviews were returned to the senior author, who revised the manuscript appropriately and resubmitted it in a diskette format suitable for printing by the Northeastern Forest Experiment Station, USDA Forest Service where they were edited to a uniform format and type style. Manuscript authors are responsible for the accuracy and style of their papers.

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MANAGEMENT OF HARDWOOD FORESTS IN THE MID-ATLANTIC REGION: PAST, PRESENT, AND FUTURE

David A. Marquis[1]

Abstract: Hardwood forests of the Mid-Atlantic region have a multitude of values. They provide timber for furniture, paper, and other products, habitats for wildlife, water for homes and industry, and opportunities for outdoor recreation activities of many types. They dominate much of our landscape, serve as reservoirs of biological diversity, alter climate, and affect our lives in many ways that we are only beginning to understand.

As we consider the management challenges that lie ahead, we need to maintain some perspective -- both on the forests themselves and on our efforts to manage them. Present forests are largely second-growth, having originated from the period of intensive forest exploitation at the turn of the last century. Many of the trends occurring in these forests today are still the result of natural development processes in these relatively young forests. Our efforts to manage eastern hardwoods are less than 50 years old, and there have been several major shifts in management direction in that short time span. Much of our forest land has yet to receive any planned management at all.

In recent years, research has been providing increasingly sophisticated information on forest management, and much of this knowledge is being applied on those lands that are under planned management. Traditional emphasis on management primarily for timber production has been gradually shifting toward increasing recognition of other forest uses and values. Unfortunately, public perceptions of forest management and public objectives for their forests have changed much more rapidly than either forest management or research.

There are many challenges for both management and research in the years ahead. We need to incorporate a much broader range of forest values into management planning, and to devise effective ways to integrate management for that full range of uses. We need to dramatically increase the proportion of forest land under planned management. And we need to find ways to ensure that the best and most up-to-date procedures are available to practitioners and that they are used effectively. Research will need to provide much information on many and varied topics. Rather than many individual research efforts aimed at special uses and current high-visibility topics, we need to plan a long-term research program that will systematically improve our basic understanding of forest growth and regeneration processes, so that we can apply that knowledge in a wide variety of ways to meet specific resource needs.

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CENTRAL HARDWOOD FOREST RESOURCES: A SOCIAL SCIENCE PERSPECTIVE

John F. Dwyer, Herbert W. Schroeder, and Paul H. Gobster[1]

Abstract: People-forest interactions in the Central Hardwoods region are expanding in scope and importance and are generating increasing controversy. In order to manage Central Hardwoods in a manner that contributes most fully to the needs of people, it is important that we better understand the perceptions, goals, objectives, and values of forest users, owners, managers, and the concerned public.

INTRODUCTION

The Central Hardwoods are a significant forest resource, extending over some 100 million acres and providing an environment for more than one-fourth of the U.S. population. Within this broad area, geologic history, climate, and previous land use vary greatly. Many ecologically different associations of soils, water, plants and animals occur. Diverse ecosystems provide a wide range of benefits to many residents within the region and beyond. These benefits range from beautiful landscapes and opportunities to experience a wide range of distinctive natural environments, to fine wood for high quality furniture and chances to explore the past.

Our purpose in this paper is to provide an overview of the Central Hardwoods from a social science perspective, focusing on interactions between people and forest resources. We want to provide a people-oriented context for interpreting what you will hear in the Conference and to stimulate your thinking on how we can increase the contribution of Central Hardwood forests to the needs of forest users, owners, managers, and the concerned public.

HISTORY OF LAND USE

The character of the Central Hardwoods region has changed markedly over time and will change still more in the years ahead. Early settlers cleared the forest and established farms and towns. Wood was an important raw material and fuel; but land clearing often provided more than was needed, and substantial amounts were sometimes burned or left to rot. Uncontrolled fires spread across the landscape. Many woodland areas provided important forage for livestock, and overgrazing was common. By the end of the 1800's much of the

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region had been cleared for agriculture. Substantial areas were also disrupted by surface and subsurface mining.

With continued economic development in the region and beyond, many of the farms were no longer competitive and cultivation ceased on substantial portions of the land. Steep hilly areas with poor soils far from markets were often the first to leave crop production. Most of these "retired" areas subsequently returned to forest. In some instances trees were planted to accelerate the conversion to forest and reduce soil erosion. Areas that had been mined were often planted with trees as part of the restoration process. Efforts to control fire, trespass, and grazing contributed to forest growth and development.

CURRENT STATE OF THE FOREST

The current tree cover reflects past cutting practices and previous land uses. Tree sizes are increasing and the growth of wood volume has exceeded removal and other losses for some time. Many Central Hardwood forests are now reaching middle age and have regained nearly all of the tree species that were originally present. All but a few of the animals have returned -- the exception being the large mammals. This is, in itself, a remarkable success story in restoring forest resources to a region.

Forests have become a prominent component of landscapes throughout the region. Forest lands are intermingled with croplands, pasture, cities, and other land uses in an intricate patchwork that varies over the region. The portion of the landscape in forest and the size of individual forest tracts are largest in the southern and eastern portions of the region. In the central and western portions, forests are found in smaller scattered tracts on farms and in cities as well as in narrow corridors along rivers, streams, and city streets. Iverson (1988) presents an interesting analysis of the Illinois landscape, including forests.

The overall extent of the forest is relatively stable and is not expected to change much in the near future. Small amounts of land shift between forest and agricultural crop production as crop prices, agricultural technology, and environmental quality standards change.

Urbanization continues to transform important acreages each year. Urban forests are significant in the region and contain many of the same Central Hardwood tree species that are found in the surrounding areas. Remnant oaks and other species are prominent in many urban parks and residential areas. Many communities have active forest management programs to replace lost trees and preserve existing trees. These programs help to create a vigorous and sustainable urban forest that will contribute to a pleasing environment. Tree planting in the region's urban centers is on the increase as a result of a number of public and private initiatives. As residential development extends into cropland, tree planting extends the urban forest into previously open areas. New plantings often emphasize "bottomland hardwoods" such as ash, basswood (linden), hackberry, red maple, and honeylocust that can withstand the alternating floods and drought that are generated by extensive impervious surfaces in the urban environment.

RESIDENTS OF THE REGION

The Central Hardwoods region is culturally diverse and it is difficult to characterize its residents. The region does not conform to ordinary political boundaries and spans all of five states and parts of 16 more. Portions of the region are often referred to as part of the "Middle Atlantic States," "Southeast," "South," "Midwest," "Plains," "Lake States," or "Central States." It is difficult to find much commonality among the residents of these diverse areas, other than that the forests in which they live, work, and play can be characterized as "Central Hardwoods."

The region includes high levels of urbanization along a corridor from Milwaukee to Pittsburgh and in a few other locations, with low population densities in many other areas -- particularly on the region's periphery. Agriculture is an important component of the landscape in the central and western portions of the region. In other rural areas mining, timber, and tourism are important to the way of life. Some of the region's residents see the forest as essential to their employment and income, while others see it as an important determinant of environmental quality and the quality of their lives. Still others see the forest playing both of these roles simultaneously and perhaps others as well.

Parts of the region have not fared well over time in terms of employment and income. Often it is the heavily forested areas that have done poorly in these respects. Local residents, entrepreneurs, and others concerned with rural America are looking to forest resources for opportunities to increase income and employment. One of the challenges that they face is identifying sustainable developments that contribute to the overall quality of rural life.

Large cities are found throughout the region and Central Hardwood forests are in the "back yard" of substantial urban populations. In fact, nearly every acre of Central Hardwoods is within a half-day drive from a population center of one million or more. Second or vacation homes are increasingly popular in some portions of the region, and a significant number of individuals have moved to rural areas of the region in search of a higher quality of life. Some of these individuals are retired while others are engaged in "footloose" occupations that do not require working directly with others in a central location such as a town or a city. These developments sometimes bring changes in the social structure of some rural parts of the region.

USES OF THE FOREST

Recent trends toward short vacations or "long weekends" make outings in the Central Hardwoods especially attractive for residents of large urban centers, as does growing interest in the region's historic and cultural resources. Forest growth has yet to obscure many of the fences, roads, homesteads, towns, and factories from the past. In some instances these relics of a bygone area have become important attractions for tourists and students of history. These attractions also remind us that the forest is ever-changing as are the uses that people

make of it. In some localities traditional crafts and businesses have been revived to cater to tourists. Extensive re-creations of early environments and lifestyles such as in "Old World Wisconsin" are also popular and often featured in tourism promotions. Covered bridge festivals, maple syrup festivals, and other events that focus on the region's natural and cultural resources are major attractions.

A well-developed system of "country roads" facilitates travel throughout the region. Fall colors are a major attraction, and guides to the time and place for "peak colors" are often provided in the region's newspapers. Hunting and fishing have long been popular in the Central Hardwoods -- and are a key part of the fabric of rural life. Non-consumptive use of wildlife such as bird watching is on the increase as well. In some areas the amount of private land available for hunting is decreasing. This puts increased pressure on public lands and brings increased conflict between consumptive and non-consumptive uses of wildlife.

Overuse and conflict among users can be a significant problem with privately and publicly owned forests near urban areas, sometimes leading to the closing of those lands to particular uses. Significant issues concern how to disperse forest use, reduce conflict, and keep resources open to the public.

Past settlement and the fragmented pattern of forest lands throughout the region has limited the opportunities for wilderness experiences. However, these opportunities can be found on some of the larger tracts of public and private lands. There are designated wilderness areas on National Forests and proposals to designate additional areas.

The management of wilderness resources in the Central Hardwoods poses a number of challenges in addition to those usually associated with wilderness management. Some of these challenges are associated with the relatively small size of these areas in conjunction with adjacent or nearby developments, roads, and remnants of previous settlements, including cemeteries.

The Central Hardwoods provide some of the finest high-quality hardwood timber produced anywhere. Fine furniture, gunstocks, and other high-quality specialty items produced from Central Hardwoods timber are known throughout the world, and high-quality hardwood logs and lumber produced in the region are shipped great distances for additional processing. The scarcity of high-quality wood continues to be one of the industry's major concerns.

OWNERS OF THE FOREST

Ownership of the Central Hardwoods is highly fragmented, and three-fourths of the forest land is held by "small non-industrial private forest land owners" who have a wide range of complex goals and objectives. Alig (1990) points out the heterogeneity of non-industrial private forest owners that has been reflected in a significant amount of research:

1. The characteristics of their forest holdings vary widely.

2. Their forest management intentions and activities vary widely.

3. Many are absentee owners.

4. They are older, on the average, than the general population.

5. Their land changes hands frequently; even when it doesn't, the intentions of individual owners often change over the length of a timber rotation.

6. Many do not cite timber management as a primary land management goal.

Efforts to provide education and technical assistance to non-industrial private forest landowners have been complicated by the diversity of owners cited above, as well as lack of agreement on the most effective programs, messages, or systems of communication with those owners. These efforts are complicated by large numbers of non-industrial private forest owners who often have relatively small holdings, diverse and changing goals and objectives, and short ownership tenure. Future management and use of the Central Hardwood forests will be determined, in large part, by the large number of diverse private non-industrial landowners who will own a substantial portion of the resource. There will probably continue to be significant private and public efforts to influence the management and use of these lands by providing information, education, technical assistance, financial assistance, and other incentives aimed at producing particular goods and services. In order to plan for and change the management of these important forest lands in the years ahead, it will be necessary to predict how owners will respond to changing resources and opportunities for forest resource management and use.

Past research has identified the characteristics of private forest landowners, their goals, and their receptivity to government programs aimed at influencing the management and use of their holdings. What we do not yet understand is how landowners will actually manage and use their land in the years ahead -- how they will implement their goals and objectives and make use of public programs and incentives and the markets that become available to them. Will they follow up on tree planting with sound protection and forest improvement efforts over the long haul? When their forest stands contain large trees and when good markets are available, will they be interested in selling timber -- and if so under what conditions such as price and expected disruption of the forest environment? Under what circumstances will forest management programs initiated by one owner be carried out by subsequent owners? Will owners be willing to make their lands accessible to various types of users, and under what circumstances (i.e., what activities, restrictions, fees)? Will individual landowners be interested in cooperating with other landowners (public and private) to provide habitat for wildlife, attractive landscapes, or opportunities for recreation? How can esthetically or environmentally sensitive forests near urban areas be better protected from development pressures? What mechanisms will be most effective for implementing cooperation in managing the Central Hardwoods landscape? The fragmented nature of public forest

ownership in the region, particularly the National Forests, makes the key question one of cooperative approaches to management of public resources as well.

MANAGING THE FOREST

Management of the Central Hardwoods is complex and poses major challenges to managers and users. The diverse plant and animal communities found throughout the region make it difficult to predict how the forest will change over time with or without various forms of manipulation or other management strategies. While trees and other plants tend to regenerate well, obtaining vegetation of a particular species or species mix on a particular site at a specified time continues to be a problem that resists solution despite heroic efforts by managers and researchers. Control of fires in the forest and restrictions on the use of herbicides and timber cutting make it difficult to create many of the conditions that are thought to be desirable for regeneration, growth, and development of particular forest types.

The character of the forest and its uses and users varies across the region, often making it difficult to transfer management techniques and research results from one area to another. Oak management in the Missouri Ozarks has important linkages to the management of oaks in the Forest Preserves and residential landscapes around Chicago; but there are important differences as well. Some of these differences have their origins in the biology/ecology of the forests in these areas; others arise from the different values and expectations of those who own or live in and near these forests.

Landscape Ecology

The intricate patchwork of forests, cropland, cities, and other land uses complicates the production of timber and the management of wildlife habitats, esthetics, and environments for outdoor recreation. In managing Central Hardwoods there has recently been increased attention to "landscape ecology" which focuses on the distribution of and relationships between landscape elements over time and space. At the Seventh Central Hardwood Conference, Tom Crow (1989) pointed out that tract size has a "major control over the physical and biological characteristics of an individual ecosystem." He presented examples of the minimum size woodlot that has at least 50 percent chance of supporting a breeding population of each of 16 species of birds. The results ranged from 20 to 200 acres. This is important information for managing the highly fragmented Central Hardwood resource. Hopefully, we can extend the analysis to other species of animals, and include the role of connecting corridors and proximity to other tracts in maintaining a breeding population.

But what are we are learning about habitat requirements for the increasing numbers of people who use the forest environment? What is the minimum size tract for a squirrel hunter, a mushroom picker, a ginseng gatherer, a hiker, or an individual in search of solitude? We know that some of these activities can be enhanced by a mixture of dense tree cover, open areas, wetlands, etc.; but what exactly is the best configuration of land use and vegetative cover for each activity -- or even the minimum requirement? For example, driving for pleasure is a major use of forest lands in the region, but what mixture or pattern of forest and open areas is most preferred by users? What role does the opportunity to experience cultural resources play in the desirablity of drives through particular areas? What kinds of human artifacts or impacts of forest management do individuals who drive for pleasure find objectionable?

In many instances people have very specific requirements that are not provided for because we lack knowledge about habitats for people. The Central Hardwood Notes (U.S. Forest Service 1989) present 13 notes on wildlife habitat; but only 3 dealing with recreation and esthetics. Furthermore, those 3 contain only general guides for planning and do not cite any actual studies. Similarly the proceedings of the Seventh Central Hardwood Conference contains 54 papers; but only one of the titles mentions wildlife and only one mentions recreation.

Important characteristics of habitats for people go beyond the configuration of the landscape discussed above to the actual composition of the forest as well as the character of associated development. What species mix in the overstory and in the ground cover is preferred by hikers? What kinds of interpretation are appropriate to enhance various uses of the forest? What is the importance of being able to see deer while driving through a forested area? How important are den trees and other signs of wildlife to hikers? How important are large trees and an undisturbed understory for those seeking solitude? What kinds of roads and trails are preferred by various users? What efforts, if any, need to be undertaken to reduce the apparent impact of road building and timber harvesting in particular environments?

Preferred habitats in urban forests may differ markedly from those in rural parts of the region. Ouestions about the management of trees and forests also take on a decidedly different perspective when issues focus on the urban landscape: What densities and spatial arrangements of trees do people prefer in urban park settings? What role does vegetation play in people's perceptions of urban park safety? To what extent do trees contribute to the attractiveness of residential street corridors and home landscapes? What are the desirable and undesirable attributes of street tree species commonly planted in municipal forestry programs? What variations in urban forest preferences and needs exist among important subgroups of the urban population, for example, older adults and ethnic minorities? Some progress has been made in addressing these kinds of questions (see Schroeder 1989, for a review of this research), but we have much yet to learn.

A fundamental problem is that we do not have basic guides for the management of forest stands for use by people, including esthetics, recreation, cultural resources, etc. Considerable research has been directed towards the development of silvicultural systems for production of hardwood trees that have traditionally commanded high prices in the timber market. However, it is not all that clear that the users of the forest environment prefer stands composed of these same species or that they find the harvest and silvicultural systems that are used to generate them to be acceptable. What is needed is a silviculture for recreation, esthetics, and other forest uses. The alternative to the development of these systems is a forced choice between intensive timber production of "high value" species on one hand, and complete prohibition of vegetation management on the other.

We are pleased to see two presentations at this conference dealing with the scenic and recreational aspects of Central Hardwoods management. The paper by Ribe considers the esthetics of timber harvesting, while the paper by Hollenhorst et. al. focuses on the esthetic and recreational impacts of the gypsy moth. Additional work along these lines that helps us understand public perceptions of and response to forest management options will be most helpful.

Visual Quality

Esthetic values of the Central Hardwoods region rank high among forest management issues that concern local residents and visitors. Conflicts and controversy over forest harvesting activities often have their roots in esthetic judgments of what is seen on-the-ground. The scenic appeal of the region also enhances people's enjoyment of developed and dispersed outdoor recreation activities. Management of the appearance of forest sites and areas is an important component in providing a quality recreation experience.

Programs that address visual quality management recognize the need to look at the esthetics of forests from both regional and stand perspectives. The U.S. Forest Service's "Visual Management System" identifies several different landscape character types that define the variety of land, water, vegetation, and cultural patterns found in the region (U.S. Forest Service 1980). In the Central Hardwoods, topography ranges from broad, flat areas of glacial drift to highly dissected ridges and valleys; water features include many small streams as well as major rivers and large reservoirs; forest vegetation includes many species and community types from oak savannahs to extensive pine forests; and cultural patterns reflect not only a rich history, but current strong ties to the land. These broad scale characteristics help define the region's unique visual characteristics and "sense of place."

Forest managers have an important role to play in maintaining and enhancing the regional visual character of the Central Hardwoods. For example, National Forest visual management programs look at "variety" as an indicator of visual quality, and in many cases (e.g., road corridor planning) aim to increase variety through manipulation of forest vegetation (U.S. Forest Service 1974). This may not be the best policy, however, for forest management in the Central Hardwoods. The visual variety of the region is already very high, and National

Forests offer some of the few places where extensive blocks of forest land can be viewed. In many cases public groups desire to see a greater continuity in forest cover, which has led some Forests to make more extensive use of silvicultural systems that promote a continuous forest cover.

In cases where it may not be possible to assemble or manage extensive forest areas, corridor management programs can help integrate fragmented land ownership and interpret regional visual resources to the public. The Forest Service's "Scenic Byways" program is a successful example of a corridor approach to visual management, and several Byways have been designated on National Forests in the region since the program was initiated in 1988. National Forest Scenic Byways showcase exceptional scenic corridors within a Forest, and tie together areas or sites of recreational, historic, scientific, and cultural significance. Public perceptions of forest management often depend on information, and the Byways program provides forest managers an opportunity to interpret vegetation management and other multiple use management activities.

Much of the research on public perceptions of visual quality has taken place at the stand level, focusing on the attributes of forests that are viewed at close range and can be manipulated by managers. In contrast to the regional scale landscape dimensions such as landform and cultural patterns mentioned previously, indicators of near-view forest visual quality often relate directly to vegetation management practices. Ribe's (1991) research on the visual quality of Northern Hardwood stands shows the importance the public places on such factors as slash removal and maintaining large diameter trees to enhance visual quality or mitigate the visual impacts of timber harvesting. Multivariate statistical techniques used in studies such as this allow managers to estimate the relative importance the public places on different forest attributes, and to look at tradeoffs between alternative management objectives. This research can also help to model and estimate the changes in visual quality over time after harvesting or stand treatment activities have taken place (Ribe 1991, Palmer 1990).

Few forest visual preference studies have focused specifically on Central Hardwoods timber types or on the forest management issues that have gained momentum in the region. There is evidence that models developed in one region have some degree of generalizability when applied elsewhere (Ribe 1990); but there are unique characteristics of the Central Hardwoods forest and landscape for which more research is needed. At the stand level, we need better information on public perceptions of uneven-aged management techniques, as well as on even-aged silvicultural systems such as deferment cutting that have an intended esthetic goal. Site quality changes dramatically within the Central Hardwoods region, and managers need better information on the effects that post-harvest treatments may have on accelerating the "visual recovery" of sites after harvesting. We also need better information about regional visual quality issues in the Central Hardwoods, so that managers have a better idea of how public forest lands are perceived in the context of the surrounding landscape. The forests form an essential part in the visual character of the region, and a coordinated approach is needed in order to maintain and enhance the sense of place that exists there.

Public involvement in decisions about management and use of the region's National Forests has revealed very strong interest in the Central Hardwoods by groups at the local, regional, and national levels. Throughout the region there is a tradition of strong local ties to public and private forest lands. Regional and national interests are becoming increasingly significant. Reconciling the often conflicting perceptions, demands, and expectations found at these levels of interest has proved to be a major challenge. Increasing public concern over environmental quality and the management of public resources has added to the debate which shows clear signs of extending to other public lands and perhaps private holdings as well. The diversity of Central Hardwood forests, the multitude of uses/benefits provided, the difficulty of regenerating particular species, and debate over appropriate methods for regenerating stands on particular sites have fueled the controversy. The intense debate over the management and use of public forest lands in the region has been characterized by terms such as "polarized," "extreme," "urban-rural conflict," and "no middle ground." Many look to "new forestry," "new persepectives," and entirely new management approaches such as "landscape ecology" for solutions.

Part of the controversy has focused on clearcutting as a method of harvest/regeneration. Many people object to the seeming destruction of the forest environment that accompanies clearcutting, and are concerned over possible long-term degradation of the environment. Others see clearcutting as a viable option for removing timber and developing the kind of forest environment they think forest users are seeking. Still others are fearful of the outcome of no cutting and intensive fire control on the character of the forest. The complexity of the regeneration, growth, and development of Central Hardwood stands as well as uncertainty over the outcome of various harvest/regeneration systems adds to the debate. The controversy is intensified when individuals have a personal stake in the results, such as is the case with hunters, hikers, wilderness campers, loggers, and those who work in wood-using industries.

One of the factors that makes management of Central Hardwood forests difficult is that professional resource managers, special interest groups, and the general public have very different backgrounds and viewpoints with respect to forest management. Research carried out by Joanne Vining of the Institute for Environmental Studies at the University of Illinois, in cooperation with the North Central Forest Experiment Station, is investigating some of these differences. In this research, members of different groups were given written scenarios about a hypothetical Central Hardwood forest management conflict. The conflict involved a request by local timber interests to expand timber harvesting using clear-cutting. After reading the scenario, participants filled out rating scales to indicate the kind and intensity of emotions experienced while reading the scenario, and the perceived importance of 10 different management goals for Central Hardwood forests.

The participants represented three groups: members of a regional chapter of a major environmental organization, employees of the Mark Twain National Forest, and members of the general public in Champaign-Urbana, Illinois. One third of the people in each group were asked for their own responses to the emotion and goal scales. The rest were asked to predict

how they thought a member of one of the other two groups would respond to the items. In this way, the study addressed not only differences in the emotions and attitudes between the three groups, but also the accuracy with which members of any one group perceived the emotions and attitudes of members of the other groups.

With respect to both emotions and goal importance, the public responses were more similar to the environmental group's than to the forest managers'. The public and the environmental group expressed higher levels of anger, distress, and fear and lower levels of happiness than did the Forest Service employees. Forest Service employees placed greater importance on timber harvesting and local employment, and lower importance on roadless area management and wilderness preservation than did either the public or the environmental group.

Both Forest Service employees and the environmental group members underestimated the extent to which the public would feel distressed, nervous, angry, alert, and afraid while reading the scenario. Forest Service employees and environmental group members also seriously underestimated the importance that the public placed on wilderness and roadless areas.

These results suggest that differences in emotions and attitudes and inaccuracies in perceptions of how different groups respond to issues may hinder the resolution of resource management conflicts in the Central Hardwoods region. Managers are trained to approach resource issues in a dispassionate and analytical way, while the public and special interest groups are more likely to adopt an intuitive and emotional viewpoint. The vehemence with which many members of the public respond to forest resource issues reflects the importance that forest environments have for them. In the course of our research over the last decade it has become increasingly clear that many people feel powerful psychological ties to forests and trees (Dwyer, Schroeder, and Gobster 1990). The effect of natural environments on people can be measured physiologically in the form of a strong relaxation response (Ulrich 1984). In our research at the Morton Arboretum near Chicago, people have reported a variety of ways in which trees and forests add meaning and value to their lives. The emotions that people experience with trees and forests can be very profound, and sometimes take on a religious or spiritual quality. Trees and forests often appear in the myths and folklore by which diverse cultures have symbolically expressed their deepest values and their connections to the world around them. It is no wonder that issues involving the management (and particularly the cutting) of forests become emotionally charged!

These strong emotional and intuitive ties to forest environments must not be ignored or disdained, even when they clash with scientific training and judgment. The Forest Service's "New Perspectives" programs calls for expanding our concepts of forest values beyond the traditional economic values associated with commodities that are bought and sold in the marketplace. Much of the discussion of New Perspectives at present centers on biological values such as biodiversity and sustainability, but the deep psychological values of forests are equally crucial. Failure to consider these values will result in continued intense emotional clashes between professional resource managers and the publics they serve.

SUMMARY AND CONCLUSIONS

The Central Hardwoods will be increasingly important to residents of the region and beyond for an even wider range of goods and services than in the past. The extent and distribution of the resource is likely to remain relatively stable. Public interest in Central Hardwood forests will remain high and perhaps increase. "Commodity" uses such as timber and mining will continue, and the region will produce some very fine hardwoods. Use of the forest environment for recreation, a scenic backdrop, or a place to live will continue to increase in importance over time. People's psychological ties with trees and forests will increase. Urban forests will increase in significance as a component of the urban environment. Forest ownership is likely to remain fragmented, with "non-industrial private landowners" holding a large portion of the resource for a wide range of complex goals. Farm ownerships are likely to continue to decline as a portion of the forest land, and forest owners will live on the land, in nearby towns, and in more distant areas. Locations near major urban centers and in especially attractive areas will be increasingly popular for second and retirement homes as well as residences for "footloose" households that are not tied to particular locations. Recreation and tourism will increase in the region, with major concentrations of activity and development in especially attractive areas and near urban centers or major highways. Viewing wildlife and exploring historic and cultural resources will be increasingly important aspects of outdoor recreation.

Management of Central Hardwoods will continue to be a major challenge, given the diversity of sites, species, ownerships, uses, and interests involved. Public perceptions and values as well as the goals and objectives of landowners will increasingly guide forest resource management. There will continue to be conflicts among the various interests in these valuable resources, with resolutions coming only from better understanding of the perceptions, values, viewpoints, and beliefs of those involved. A rigorous research program will be needed to help managers understand how the forest is likely to respond to various changes, as well as what people expect from the forest environment and the goods and services that forests provide.

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AN ALTERNATE PROPERTY TAX PROGRAM REQUIRING A FOREST MANAGEMENT PLAN AND SCHEDULED HARVESTING

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Abstract: Vermont's Use Value Appraisal property tax program, designed to address problems such as tax inequity and forced development caused by taxing agricultural and forest land based on speculative values, requires a forest management plan and scheduled harvests. A probit analysis of enrollment provides evidence of the program's success in attracting large parcels of undeveloped land, in providing financial relief in areas where taxes are most burdensome, and in encouraging more affluent landowners, whom previous studies show to be less interested in timber production, to harvest timber.

INTRODUCTION

Private forests are expected to play an important role in meeting future timber needs. Nearly three-quarters of the Nation's timberland is privately owned, being particularly concentrated in the eastern hardwood region. Approximately 82 percent of the Nation's hardwood growing stock, nearly 249 billion cubic feet, is in private ownership (USDA Forest Service 1988).

Public policy makers and industrial planners are concerned that these lands may not meet their potential in fulfilling future needs for timber. Continued division of the forest into smaller parcels and increased development may make harvesting uneconomical over large areas. There is also concern that increasingly affluent landowners, who are more interested in the nontimber aspects of land ownership, may be unwilling to manage and harvest their forests. These concerns are supported by several empirical studies (Binkley 1981, Dennis 1989, 1990, Widmann and Birch 1988).

This study provides evidence that alternatives to property taxation based on fair market value can slow parcelling of the forest and entice otherwise uninterested landowners to manage and harvest timber. Vermont's Use Value Appraisal (UVA) property tax program was designed to address problems, such as tax inequity and development of rural land, caused by taxing agricultural and forest land based on speculative values. Private forests are particularly important in Vermont, where only 10 percent of the timberland is publicly owned. Vermont's program is unique in that it requires a forest management plan that includes scheduled harvesting, an annual conformance report, and periodic inspection by State foresters.

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Enrollment has been rapid and by 1989, 21 percent of the state's eligible forest land was enrolled. Since tax burdens are shifted, this program comes under frequent scrutiny.

A probit model was used to analyze the relationship between the probability of enrollment in the program and characteristics of the parcel, owner, and surrounding community. The results are useful in assessing potential future enrollment and provide insight into the program's effectiveness by identifying characteristics of enrolled lands. The results also provide insight in evaluating the merits and potential enrollment in similar programs in other states. The more important inferences are that the program is successful in attracting large parcels of undeveloped land, in providing financial relief in areas where the property tax is most burdensome, and in encouraging more affluent landowners, whom previous studies show to be less interested in timber production, to manage their woodland and harvest timber.

VERMONT'S USE VALUE APPRAISAL PROGRAM

In 1977, Vermont enacted a UVA property tax program that included three separate categories: farmland, agricultural land, and forest land. Although each provides important benefits, our analyses and discussion are confined to the forest land program.

The UVA program was established by the Vermont legislature to achieve more equitable taxation for undeveloped land, encourage productivity, and help preserve the scenic landscape. The scenic landscape was specifically stated to be a "working" landscape and the legislation was meant to help preserve the viability of the state's agricultural and forest industries.

Entry into the program is optional, but each parcel must consist of at least 25 acres and be managed under a forest plan approved by the Vermont Department of Forests, Parks and Recreation. Private consulting foresters generally prepare the plans, which must meet specified requirements that include scheduled harvests. In addition to annual conformance reports, State foresters inspect the property at least once every 5 years.

A penalty, equivalent to 10 percent of the fair market value at the time of a conversion, is assessed if enrolled land is converted to a non-qualifying use. Failure to comply with the management plan may be deemed conversion to a non-qualifying use and trigger the penalty. The penalty, called a land use change tax, is guaranteed by a lien placed on the property at the time of enrollment. The lien remains with the parcel through transfers of ownership.

Tax relief is provided by modifying the assessed value of the parcel to reflect its value for growing timber, instead of development potential. The modified or use values are determined annually by the Current Use Advisory Board, based on a capitalization of expected returns from timber growth. The 1989 use values for forest land were $65 per acre for productive land (USDA Forest Service Site Classes I to III) and $10 per acre for non-productive and open land. By contrast, Armstrong (1988) reported that in 1987 average per-acre market prices for Vermont forest land were $296 for parcels larger than 250 acres, $509 for parcels

between 100 and 249 acres, and $658 for parcels of 75 to 99 acres. Landowners saved approximately 75 percent of their tax liability by entering the program.

The State legislature appropriates funds annually to reimburse towns for lost revenue resulting from modified assessments. The reimbursement is the difference between fair market value and use value, multiplied by the town tax rate, with a maximum currently set at $24.50 per acre. Reimbursements for the total program (farm, agricultural, and forest) exceeded $7.3 million in 1988. Since the amount is significant for a small state like Vermont, the program comes under critical review each year. Failure of the State legislature to appropriate funds for the program in any year gives enrollees the option of leaving the program without penalty.

DATA

Forest characteristics were obtained for 338 sample plots measured by the USDA Forest Service during its periodic survey of Vermont (Frieswyk and Malley 1985). Each plot was located on a privately owned parcel of at least 25 acres, the minimum size eligible for enrollment in the UVA program. Species composition, timber volume, basal area, road access, elevation, and a variety of other physical characteristics were recorded. State forestry personnel identified whether the sample plots were located on parcels enrolled in the UVA program. The owner of each parcel was sent a questionnaire requesting the owner's age, education level, occupation, tenure of ownership, income, whether he or she was brought up in a rural or urban environment, and several other characteristics. Characteristics of the surrounding community, such as population density, town growth rate, and the town tax rate were obtained from State census and property valuation data.

METHODS

A binary choice (probit) model was used to analyze the relationship between a dichotomous dependent variable (Y_i), coded 1 if the ith parcel was enrolled in the UVA program or 0 if it was not, and characteristics of the forest, property owner, and surrounding community (X_i). Detailed discussions of the generalized use of probit models may be found in many econometrics textbooks (e.g. Judge et al. 1982). A brief explanation follows.

We assume that the probability of a parcel being enrolled in the UVA program is represented by an unobservable random index (Y_i^*), which can be defined as a function of observable characteristics ($X_i'B$) and a random disturbance (e_i). If the observed choice (Y_i) equals one when $Y_i^* > 0$ and zero when $Y_i^* < 0$, then:

$$P(Y_i=1)=P(Y_i^*>0)=P(e_i<X_i'B)=F(X_i'B)=\int_{-\infty}^{X'B} f(e)de \qquad (1)$$

F( ) is the cumulative distribution function and f( ) is the probability density function of e_i, which are specified to be normal in the probit model.

Because the specification is nonlinear, the estimated coefficients do not represent the change in probability of enrollment resulting from a unit change in an explanatory variable. The marginal change in probability depends on the original probability as determined by the values for all the variables and coefficients. The marginal change in probability is computed as:

$$\frac{\partial P_i}{\partial X_{ik}} = f(X_i'B)B_k \qquad (2)$$

where k indexes the explanatory variables. The sign of a coefficient shows the direction of change while the magnitude depends on the value for $f(X_i'B)$, which reflects the steepness of the cumulative distribution at $X_i'B$.

RESULTS

Table 1 lists and briefly describes each variable. The results provided in the upper portion of Table 2 are for the probit analysis of the entire sample (N = 338). So that the effects of individual owner characteristics, such as education, could be analyzed, a subsample was formed that excluded all parcels held by businesses or organizations. These results are reported in the lower portion of Table 2 (N = 252).

Table 1.--Variable Summary

Variable	Definition
ACRES	Natural logarithm of acreage of forest ownership
ROAD	Coded 1, if parcel is within 1/4-mile of a maintained road; 0 otherwise
IND	Coded 1, if parcel is owned by a forest industry; 0 otherwise
DEN	Population per square mile in town where plot is located
GRO	Population growth rate in town where plot is located
TR	Equalized town property tax rate
ED	Years of formal education

Table 2.--Probit results

Explanatory Variable	Coefficient	Standard error	Mean in UVA Program	Mean not in UVA Program
N = 338	All parcels			
Constant**	-2.6739	0.5766	1.00	1.00
ACRES**	0.2186	0.0618	6.48	5.76
ROAD	-0.1583	0.1732	0.55	0.66
IND**	-0.7725	0.3668	0.15	0.13
DEN	-0.0018	0.0018	37.38	41.06
GRO**	-0.0305	0.0143	6.85	8.84
TR*	0.6603	0.2036	1.71	1.57
Likelihood ratio statistic = 30.11				
N = 252	Individually owned parcels			
Constant**	-3.1657	0.8421	1.00	1.00
ACRES**	0.1626	0.0729	5.59	5.04
ROAD	-0.1878	0.2172	0.61	0.71
ED**	0.0935	0.0309	15.53	14.17
DEN	-0.0045	0.0032	34.36	42.94
GRO**	-0.0584	0.0192	6.42	8.98
TR*	0.4799	0.2515	1.75	1.65
Likelihood ratio statistic = 30.28				

*Significant at the 10-percent level.
**Significant at the 5-percent level.

There was some concern from both the public and lawmakers that large industrial owners might be the primary beneficiaries of the program and little public benefit would be obtained, since these owners were likely to retain and manage their land, regardless of tax liabilities. A positive relationship was estimated between the natural logarithm of ownership size and enrollment in the UVA program. Larger parcels more likely may be held for long-term timber production due to economies of scale in both harvesting and management and due to larger overall tax liabilities that offer greater incentive for enrollment. However, all else equal, industrial holdings appear less likely to be enrolled. There was a negative correlation between industrial ownership and enrollment. We estimate that approximately 10 percent of total benefits paid for the forest land portion of the UVA program accrue to forest industry.

Development potential and speculative values were expected to be higher in densely populated or rapidly growing areas and for parcels with close proximity to a maintained road. The estimated coefficients for all three variables were negative but only the coefficient for the town growth rate was significant at the 10-percent level.

Higher tax rates appeared to motivate landowners to seek tax relief. Program enrollment was positively correlated with the equalized town property tax rate.

More highly educated landowners were more likely to enroll their land in the UVA program, but other owner characteristics that we tested were not significantly correlated with enrollment. An owner's age, occupation, income, tenure of ownership, and whether he or she was brought up in a rural or urban environment did not appear to influence enrollment significantly. Also, an expressed concern that out-of-state residents were more likely to benefit from the program was not substantiated. The estimated correlation between enrollment and Vermont residency was positive, but not statistically significant.

Forest conditions did not appear to affect enrollment. No significant correlations were found between enrollment and per-acre timber volume, basal area, and variables that measured species composition. These results corroborate the results of another study that found little difference in statewide inventory statistics for enrolled and unenrolled lands (Sendak and Dennis 1989).

DISCUSSION

Probit analysis also can be used to estimate the probability of enrollment for parcels with selected characteristics. Since future enrollment was of interest, the probability of enrollment was calculated at the mean values of the explanatory variables for all parcels not currently enrolled in the UVA program. This estimate was 0.18, compared with an estimated probability of 0.25 when computed at the mean values for enrolled parcels.

The probit results indicate how changes in the characteristics of the parcel, owner, and community are expected to influence future enrollment. The results suggest that continued division of the forest and population growth will tend to slow enrollment. However, continued increases in the education levels of landowners and increased tax liabilities should have an opposite effect. An estimated elasticity of approximately 2 suggests that increases in education will have a relatively strong impact on enrollment. Elasticity measures the percentage change in the probability of enrollment expected to result from a 1-percent change in an explanatory variable.

The strong correlation between enrollment and education level suggests that the program is effective in enticing otherwise uninterested owners to manage and harvest timber. Previous empirical studies of timber supply from private forests yielded strong negative correlations between harvesting and education levels (Binkley 1981, Dennis 1989). Brighton (1988)

estimated that 40 percent of the participants had never worked with a forester before enrollment.

Overall, Vermont's UVA program appears successful. Rapid enrollment has brought 21 percent of the state's eligible forest land into the program by 1989. Total net growth of timber on UVA land could supply approximately half of the average annual statewide removals (Sendak and Dennis 1989). Improved silvicultural practices and supervision of logging by foresters should increase the long-run productivity and health of Vermont's forests. Improved productivity and the commitment of an increasing portion of the state's forest land to long-term timber production should enhance greatly the prospects for Vermont's wood using industries.

Landowners and the general public also benefit. Inequities, inherent in the unmodified ad valorem property tax, are reduced when taxes are based on the value for growing timber, as opposed to development potential. The tax savings relieve development pressures and to some extent compensate landowners for the externalities, like wildlife habitat, scenery, and improved water quality, that their lands provide. The strong positive correlation between enrollment and parcel size suggests that the program is effective in attracting large blocks of undeveloped land, which public sentiment has shown to be desirable. There has been considerable public concern over the recent sale of 985,000 acres in northern Vermont and New Hampshire by Diamond International. Suddenly, large blocks of land that were traditionally open to the public became available to developers.

The positive correlation between enrollment and tax rates suggests that the program is effective in relieving tax pressures in areas where it is needed most. Providing equitable taxation is a stated goal of the program.

Although, the overall success of the program is supported, one troubling, but minor, concern emerged. Since enrollment was negatively correlated with both population density and a town's growth rate, the program may be least effective in attracting participants in areas where it is needed most, from the perspective of maintaining open space. However, each undeveloped parcel is likely to provide significant aesthetic benefits to local residents in densely populated areas.

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EFFECTS OF GYPSY MOTH INFESTATION ON NEAR-VIEW AESTHETIC PREFERENCES AND RECREATION BEHAVIOR INTENTIONS

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Abstract: Using the Scenic Beauty Estimator (SBE) approach, near-view color photographs were taken of 25 forested sites exhibiting gypsy moth induced tree mortality from 6% - 97%. A quadratic function of tree mortality by preference rating best described the variability in ratings (R^2 = .60). The effect of flowering mountain laurel flowers was also significant with the covariate "presence of flowers" increasing the R^2 to .74. Scenic preferences and appeal for visitation increased initially as mortality approached 20-30%. Up to this point, increased sunlight, visual penetration, and understory regrowth may have mitigated the negative effects of mortality. As mortality exceeded 20-30%, ratings dropped sharply. Attitudes regarding proper forest management were not a factor in preference ratings. Awareness of the presence of insect damage did not significantly influence ratings, suggesting the limited usefulness of information or education efforts aimed at shaping public responses to gypsy moth damage. Scenic beauty preferences were closely linked to recreation behavior intentions, thus providing managers with a relatively simple and inexpensive surrogate measure of visitor behavioral responses to insect damage. We conclude that if near-view aesthetics or recreation visitation are the only consideration, except where tree mortality is expected to be unusually high, suppression is not justifiable.

INTRODUCTION

Legislative mandate and growing public concern for preserving beauty in natural landscapes necessitate formal consideration of aesthetic merit in the public resource allocation process. The "visual landscape" has, in fact, secured recognition as a basic resource warranting equal consideration among more established forest resource values. As a result, measurement methods have been developed that can produce valid and reliable indices of scenic beauty (Daniel and Boster 1976; Buhyoff and others 1981; Zube 1982; Anderson and Schroeder 1984; Ribe 1989). By determining the effects of different resource conditions or management alternatives on aesthetic qualities, these methods provide explicit quantitative values based on people's perceptions or judgments of stimuli (i.e. the visual quality of a

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forest stand). The application of these methods has generally focused on estimating changes in aesthetic quality resulting from alternative resource conditions that policy makers and managers can at least partially influence (Hull and Buhyoff 1986).

Since its introduction in the Boston area in 1869, the range of the gypsy moth *Lymantria dispar* L. has expanded from the Northeast to the Central Appalachian Plateau region and promises to continue moving south and west. Despite being arguably the most thoroughly studied forest insect and the target of the most intensive control and eradication effort (McManus 1987) the gypsy moth persists, periodically erupts, and continues to expand its range. Along with the more tangible forms of damage caused by the gypsy moth (e.g. loss of saw timber volume and change in forest composition), the continuing spread of the gypsy moth poses a serious threat to aesthetic values.

There is no published empirical work on the aesthetic impact of gypsy moth damage. Anecdotal evidence suggests that recreational participation during high defoliation periods may be curtailed by as much as 20% (Goebl 1987). More enduring visual impact may occur as a result of tree mortality and changes in forest composition. This may be particularly true at intensively used recreation areas, along scenic byways, or where private landowners place high value on the scenic qualities of their property. Resource policy and management responses to gypsy moth (e.g. aerial spraying, silvicultural treatments, "let-infest" policies, public education and information) may also have significant aesthetic impacts.

Study Objectives

The goal of this study was to provide resource policy makers, public land managers, tourism interests, and private landowners with useful information for making decisions regarding the gypsy moth. This was accomplished under three primary objectives. First, the study sought to determine whether gypsy moth-induced tree mortality results in aesthetic impacts. We chose to look at the long-term aesthetic impacts that may result from gypsy moth induced tree mortality and forest compositional change; as opposed to the more intermittent and transient effects of defoliation. It has been consistently proven that insect damage affects the scenic quality of within stand sites and scenic vistas. Buhyoff and Leuschner (1978) found that visual preferences decreased rapidly as forest damage from southern pine beetle *Dendroctonous frontalis* Z. approached 10%. Declines in preference ratings were slight thereafter. Of primary concern in this study was whether this relationship would prove true with gypsy moth damage.

Second, we were interested in determining the relationship between aesthetic assessments and recreation behavior intentions. Preferences such as perceived security and perceived enjoyment have been successfully measured using scenic beauty assessment methods (Schroeder and Anderson 1983, 1984; Schroeder 1983) These efforts demonstrated that amenity preferences other than aesthetic quality can be quantified. In this study, we examined the behavior intention "Likelihood of Visiting" (LOV) in relation to gypsy moth damage.

When knowledge of the presence of insect damage has been provided to the respondents, preference ratings have typically been more critical (Riesenman 1977, Buhyoff and others 1979, 1980, 1982; Schroeder and Daniel 1981). Conversely, information and education may also be a factor managers can use to moderate aesthetic or recreation impacts of the gypsy moth. Therefore, a third objective of this study was to examine the of effect knowledge of the presence of gypsy moth on preference ratings.

METHODS

Study Site Selection

The sites were located in Somerset county of southwestern Pennsylvania and are representative of the Central Appalachian Plateau region. Forest measurement data available on the sites back to 1985 allowed us to select sites with a broad spectrum of tree mortality (Fosbroke and Hicks 1989). Twenty-five sites were selected from a population of 181 sites. The sample sites depict a range of gypsy moth related tree mortality from 6.1% to 97.9%. The mean and median dead basal area of the population sites were 27.9% and 19.97% respectively. Topography of the sites ranges from very steep to relatively flat. The mean basal area was 103 ft^2/acre and ranged from 57-149 ft^2/acre. The average percentage of oak on the sites prior to mortality was 93.5%. The mean stand age was 83.9 years with a standard deviation of 21.3 years.

Photo Sampling

During the month of June, 1989, three 35mm color near-view photos were taken of the sites in random directions. The camera was held vertically and the angle of view was maintained at consistent levels. It should be pointed out that the photos were all taken in June and 42% of the slides contained a noticeable amount of flowering mountain laurel *Kalmia latifolia* L. and thus do not represent seasonal differences. The effects of the flowers are adjusted for in a covariate analysis but the appearance of the sites is delimited to May through July when mountain laurel is flowering.

Subjects

The slides were randomly sorted into a slide carousel and presented to 400 individuals. Comparison of differing user groups is common in aesthetic preference research. Past studies have typically shown a lack of intergroup differences in preference ratings (Ribe 1989; McCool 1986). In this research effort, we attempted to represent a wide spectrum of resource management interests. The groups chosen for this study were members of the Izaak Walton

League (n=16), representing moderate preservationist interests, and professional foresters (n=31) representing utilitarian interests. The remaining three groups were drawn from students at West Virginia University and were composed of recreation students (n=61), forestry students (n=91), and a pool of general students (n=201). These three groups theoretically fall between the Izaak Walton league and the foresters on the preservation/utilization spectrum.

Scenic Beauty and Likelihood of Visiting Estimates

Tree mortality and scenic assessments may not be related in a linear fashion (Buhyoff and Leuschner 1978). Gypsy moth-related tree mortality also varies widely from site to site (Fosbroke and Hicks 1989a). It therefore was necessary to adopt a methodology whereby changes in aesthetic quality could be assessed across incremental changes in forest composition and tree mortality. An adaptation of the Scenic Beauty Estimation (SBE) method developed by Daniel and Boster (1976) was used to examine this relationship. The SBE method has emerged as the most sophisticated and commonly used visual assessment techniques (Ribe 1989). A derivative of signal detection theory, widely used in the field of psychophysics, the procedure yields standardized difference scores indicating the perceived scenic beauty of each site for each observer. The SBE method has been proven repeatedly to be a highly reliable and valid means of obtaining preference judgments (Daniel and Boster 1986; Brown and Daniel 1984; Schroeder and Anderson 1984).

We used the method to generate viewers' ratings for both the scenic quality and their likelihood of visiting the study sites. Within each subject group, half of the respondents rated the slides in regard to scenic beauty (SBE) and the other half rated the slides by the likelihood they would visit (LOV) the area represented by the slide. Additionally, half of the respondents were informed of the presence of Gypsy Moth through written instructions. The other half remained unaware while rating the slides.

Ratings were converted to Scenic Beauty and Likelihood of Visiting Estimates (SBE's and LOV's) using the "by slide" method developed by Daniel and Boster (1976). The method converts ratings of each slide to standard normal deviates which place all respondents on a common scale. The distance of each rating was then measured from a common baseline. A site which had been sprayed to prevent gypsy moth infestation served as this baseline. This site was assigned a scale value of '0' and all other sites were measured relative to this origin. The scores were multiplied by 100 to remove the decimal point, and the scores for each site were averaged for each group. Thus, the resulting score was not an individual preference, but a combination of preferences of several people for a variety of slides representing a site.

RESULTS

Intergroup Preferences

Similar to past research, the preference ratings of the five subject groups were quite similar. Correlations ranged from .94 between recreation students and foresters, to .99 between forestry students and general students ($p < .001$ in all cases). Analysis of variance between groups showed no significant differences between the means ($f = .0012$; $df = 4$; $p = .999$). The groups were pooled for further analysis.

Analysis of Treatment Effects

Pearson's sample correlation coefficients and t-tests were used to compare the ratings for scenic beauty and the likelihood of visitation and to compare the ratings of those who were aware and unaware of gypsy moth presence. Scenic beauty and likelihood of visiting ratings correlated at .99 ($p < .0001$) and had essentially equal means (prob > |t| = .99). The ratings of the aware and unaware respondents correlated at .97 ($p < .0001$) and also had similar means (prob > |t| = .98). Results of a 2x2 factorial analysis of variance indicated that neither variable had a significant effect on ratings, and no interactive effect was present (Table 1).

Table 1.--Factorial analysis of variance showing no effect of LOV vs. SBE., aware vs. naive, or their interactions. Gypsy Moth Aesthetics Study, Morgantown, West Virginia, 1989-90.

Source	DF	SS	F Ratio	Prob > F	R^2
SBE vs. LOV	1	4.188	0.0012	0.97	.000243
Aware vs. Naive	1	1.246	0.0004	0.98	
SBE vs. LOV x Aware vs. Naive	1	3.471	0.0010	0.97	

Effects of Gypsy Moth Caused Tree Mortality

With the lack of treatment effect by respondent group, knowledge, or whether respondents rated the slides for scenic beauty or likelihood of visitation, we felt justified in combining respondents for the purpose developing of a single predictive model. Percent tree mortality served as the experimentally manipulated variable. Other potential predictor variables included: mean DBH, mean height, stand age, plot tree volume, plot basal area, site index, and the percentage of each plot comprised of oak.

Visual examination of the scatter plots suggested a quadratic function might best explain the relationship between preference ratings and the percent tree mortality present on each site (Figure 1). Indeed, by fitting a quadratic polynomial to percent mortality, the R^2 of the model was increased from .50 to .60. This quadratic function produced the following model for predicting preference rating by the amount of tree mortality (t-values of coefficients are in brackets):

$$RATING = -30.41 + 1.50(\%DEAD) - .029(\%DEAD)^2 \quad (1)$$
$$[-.82] \quad [1.08] \quad [-2.19]$$
$$R^2 = .60 \quad Adjusted\ R^2 = .56$$

where: RATING = rating for either scenic beauty (SBE) or likelihood of visiting (LOV); %DEAD = percent dead basal area per site. Only the quadratic term made significant contributions to the R^2. Contrary to past investigations of aesthetic damage from insects, the scenic preference and appeal for visitation may increase slightly as gypsy moth induced tree mortality reaches 20-30% (Figure 1). When mortality exceeds these levels, however, ratings sharply decrease. The relatively high R^2 (.60) suggests that mortality serves as a good predictor of scenic preference and likelihood of visitation. None of the other previously mentioned site measurements contributed significantly to the model.

Mitigating Effects of Understory

Throughout implementation of this study, we were concerned about how the presence of flowering mountain laurel in 42% of the slides affected preference ratings. Two tactics were used to address this concern. First, through the use of available data, it was possible to calculate the percentage of mountain laurel understory in each site. An initial regression analysis suggested no linear relationship between ratings and the percent of mountain laurel understory.

Second, a cursory look at the slides suggested a relationship existed between mountain laurel flowers and percent tree mortality. By comparing sites with and without noticeable flowers, it was possible to develop a covariate model in which the presence of flowers (present or not present) were the categories and percent tree mortality was the regressor. Adjustment for the covariate "flowers" increased the R^2 of our model to .74 ($F = 13.61$; $df = 4,19$; $p < .0001$). The final model is as follows (t-values are in brackets):

$$RATING = -57.13 + 1.75(\%DEAD) - .025(\%DEAD)^2 - 20.69(FLOWERS) \quad (2)$$
$$[-1.51] \quad [1.23] \quad [-1.96] \quad [-1.86]$$
$$R^2 = .74 \quad Adjusted\ R^2 = .69$$

where: RATING = rating for either scenic beauty (SBE) or likelihood of visiting (LOV); %DEAD = percent dead basal area per site; FLOWERS = presence of visible mountain laurel flowers (present or not present).

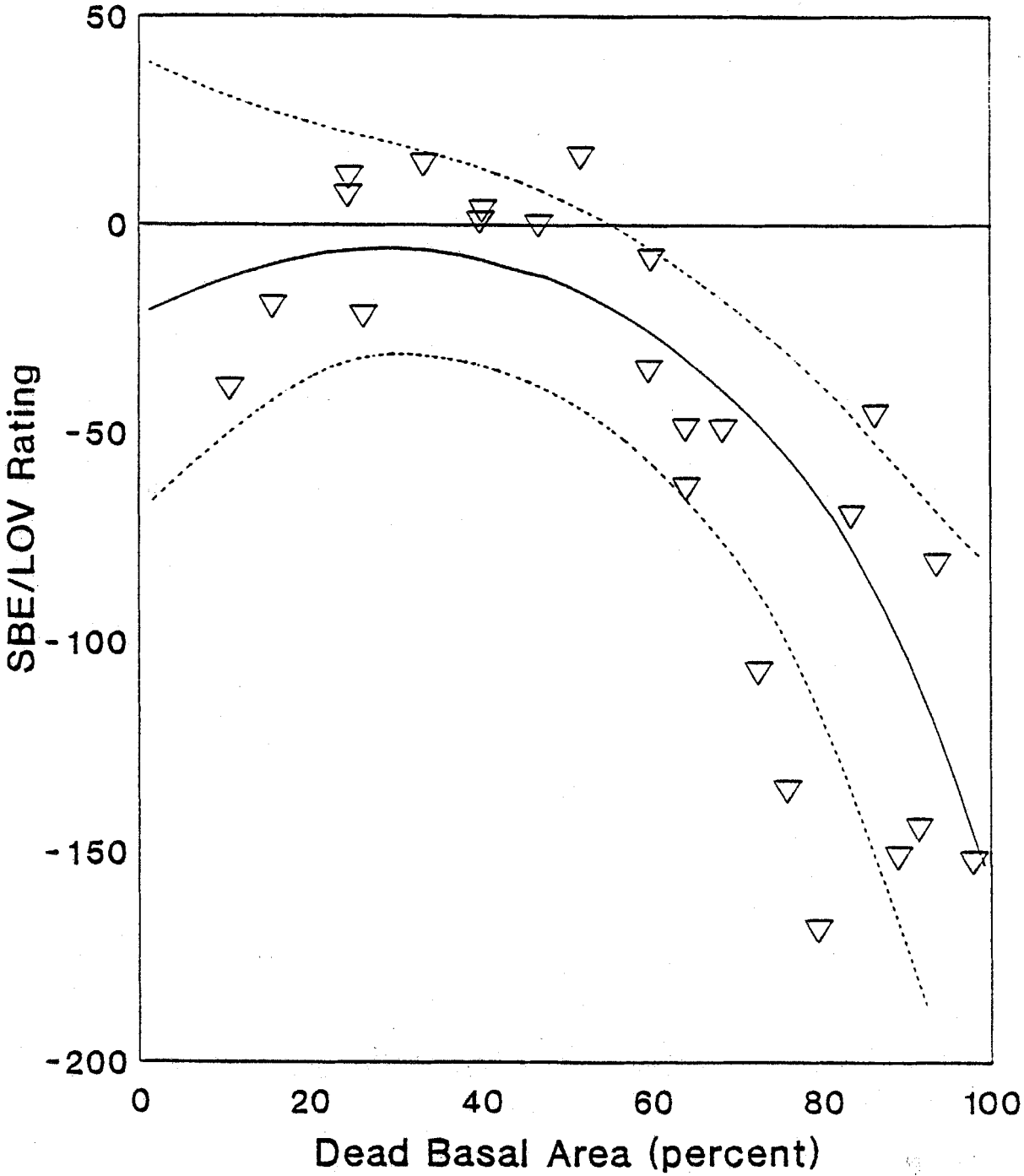

Figure 1. The effect of tree mortality caused by Gypsy Moth infestation on scenic beauty (SBE) and likelihood of visiting (LOV) preference ratings. Gypsy Moth Aesthetics Study, Morgantown, West Virginia, 1989-90. Dotted lines represent approximate 95% confidence intervals.

A comparison of the least square means (mean preference ratings adjusted for the presence of flowers) with the unadjusted means illustrate the mitigating influence of mountain laurel flowers (Table 2). The unadjusted means represent most closely the ratings of sites when

mountain laurel is not in bloom while the least squares means represent the ratings when the flowers are in bloom. It can be seen that sites with flowers were viewed much less critically. The covariate model also suggests that the sites without flowers were viewed more critically than the original regression model suggests, while the intercept is also closer to being significant.

Table 2.--Effects of covariate "flowers" on mean SBE/LOV ratings. Least square means reflect ratings when flowers are in bloom. Gypsy Moth Aesthetics Study, Morgantown, West Virginia, 1989-90.

Presence of flowers	# of Sites	Average Mortality	Mean Rating	Least Sq Mean	Standard Error
Not Present	14	42.5%	-18.88	-36.43	11.92
Present	10	80.4%	-102.38	-77.80	14.98

SUMMARY AND DISCUSSION

The percent of dead trees in a hardwood forest site is an outstanding predictor of the appeal a site will have regarding near-view scenic beauty or likelihood of visitation. A quadratic equation fit to the percentage of gypsy moth-caused tree mortality is the single best predictor of aesthetic damage (R^2 .60). Contrary to past studies in which preference ratings decreased rapidly as damage reached 10% and then leveled, we found that both scenic beauty and likelihood of visitation ratings may actually increase slightly until mortality reaches 20-30%. Up to this point, increased sunlight, a reduction in stand density, and changes in understory may mitigate the negative effects of mortality. Beyond 30% mortality, preference ratings drop drastically. It should also be pointed out that since our slides represented "near-view" interactions with the forest as opposed to distant vistas, the mitigating effects of understory regrowth and other subtle changes in forest composition may be more pronounced than was found in previous studies.

With the exception of the control sites (5% of the population and 12% of the sample), gypsy moth had not been suppressed on the study sites during the years of 1985-1988. Of the 181 sites in the population, the mean gypsy moth-caused tree mortality was 27.9%. The distribution of mortality, however, was not normal. With the large portion of sites (67%) with less than 34% mortality, the median of 19.97% is a more accurate statistic. In either case, this is well under the critical threshold of 30% regarding aesthetic quality and visitor displacement ratings.

If these mortality rates are in keeping with the entire Central Appalachian Plateau region, as is suggested by several studies (Fosbroke and Hicks 1989a, 1989b), suppression does not seem warranted from the standpoint of long-term near-view aesthetic qualities or recreation visitation. Recreation areas at risk of high mortality (greater than 30-40%), however, might be considered for suppression efforts. When considered in concert with the lack of difference

in the preferences ratings of the various user types, homogeneous management approaches would be appropriate for most near-view forested sites, regardless of the type of recreation users.

It also seems apparent that changes in forest composition must be considered when predicting aesthetic changes to an area in the path of gypsy moth. In this study, the presence of flowering mountain laurel was significantly correlated with gypsy moth- induced tree mortality. This relationship mitigated some of the negative effect on preference ratings, and led to a model explaining 74% of the variance in preference ratings.

The extent to which the general public should be informed about specific management policies is an important concern of forest managers. The results of past research suggest that respondents who were aware of the presence of forest insect damage were more critical of the scenery. Although that may be the case during defoliation periods, the results of this study indicate that there is no negative effect of knowledge regarding the long term effects of Gypsy Moth infestation to near-view sites. It is not likely that managers will be able to positively influence visitor perceptions by informing them (i.e. signs and brochures) of the presence of gypsy moth. The effectiveness of more intensive information and education efforts is a question for further research.

The high correlation between scenic beauty ratings and likelihood of visitation ratings suggest that the scenic beauty estimation method can be used to predict visitor behavior intentions. This finding is supported further by the results of an additional question asked of respondents: how much gypsy moth-induced tree mortality would cause you to choose another outdoor recreation area? In close agreement with the predictive model, 79% of the respondents replied that 30% or more tree mortality in a forest stand would cause them to seek an alternative area for outdoor recreation. We suggest that future research tests this finding on actual visitation rates.

The tree mortality and changes in forest composition that result from gypsy moth infestation have important influences on both scenic beauty and the recreation behavior intentions of potential visitors. However, it appears that most viewers will be tolerant, possibly even positively disposed towards, the level of long-term gypsy moth damage expected on most sites. Forest managers and resource policy managers must still use professional judgment in developing strategies for dealing with the gypsy moth. Aesthetic and recreation qualities are but two factors that must be considered. Estimates of scenic beauty and recreation behavior intentions should, however, provide useful information for making these decisions.

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THE SCENIC IMPACT OF KEY FOREST ATTRIBUTES AND LONG-TERM MANAGEMENT ALTERNATIVES FOR HARDWOOD FORESTS[1]

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Abstract: The problem of identifying the scenic value of forest attributes and management plans is empirically explored. A sample of hardwood forests in Wisconsin, representing a diversity of management histories, is analyzed through photographs and field inventories. Scenic beauty judgements of the photographs by a diversity of respondents yield general scenic beauty estimates for the sampled forests. A general model is reported for predicting these estimates from forests' structural attributes. This model is then used to isolate and identify the marginal scenic impacts of single critical forest attributes with the effects of other attributes discounted. These are interpreted for their relative scenic value. In addition, rough estimations of scenic beauty flows for each of several basic long-term hardwood management alternatives are identified. These scenic flows are compared for their average scenic beauty "output". The results provide guidance to hardwood forest managers in selecting overall management plans and management prescriptions for forests where scenic beauty is an important goal.

INTRODUCTION

Scenic values are an important factor in management decisions for many public hardwood forests. Where these are popular for recreation or highly visible examples of public land management, foresters must often consider the scenic merit of their decisions to meet the needs of visitors and retain the confidence of the constituents who must support those decisions. For example, the U.S. Forest Service now classifies portions of forest landscapes according to the visual quality objectives that must be sought there (USDA 1974), including those for scenic corridors along highways and trails. That agency often also identifies recreation opportunity spectrum classes for areas according to the nature of the settings to be provided in each with attendant visual quality objectives (USDA 1986).

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To work toward providing scenically satisfying forest landscapes, managers can rely to some extent on their intuitive sensibilities about the relative beauty of alternative forest conditions, or upon landscape designers to suggest preferable spatial arrangements and vegetation structures for forests. To make decisions, especially among alternatives with intuitively similar scenic merit, with more confidence and administrative defensibility, foresters must turn to empirical research investigating the scenic preferences of the public for forest landscapes. In response to this need a considerable body of research has been reported about public perceptions of scenic beauty within forests (Ribe 1989).

Information Problems

The information yielded to hardwood forest managers by empirical scenic preference studies is of limited value for practical decision making. Most studies either report a few odd findings or report a forest-structure-based model for predicting the scenic beauty of one particular forest type. In the first case, the findings are often limited to answering a few questions and the answers may be specific to particular scenic comparisons or contexts such that they can vary from one study to another either in direction or magnitude. In the second case, particular relationships that may inform decisions can be buried within a scenic beauty prediction model or have been selected against in model development in favor of a related but more powerful variable. As a result, these models do not readily answer questions for foresters who do not wish to fully study and interpret such research reports. In addition, the hardwood forest manager will find that only one such study investigated hardwood forests and then only included basal area and slash volume as scenic beauty predictors (Vodak and others 1985). Many reported findings between forests' structures and their perceived scenic beauty tend mainly to confirm the obvious. Where more subtle relationships are reported, or obvious relationships are studied as to their magnitude, the different studies' results tend to diverge. This yields little clear support for decisions about subtly different managements or the complex trade-offs among forest attributes and their scenic and other resource consequences. Indeed, research methods and results to date yield little to compare the magnitude of scenic results among alternative forest management decisions.

There are two types of things that foresters most need to know to determine the near-view, within-stand scenic beauty of alternative future hardwood forest conditions. The first is the relative scenic worth of changing incrementally any single important forest attribute independent of the many possible overall states of the forest in question. (This is called the "marginal value" of that attribute.) For example, foresters often ask just how much is it worth to the passing recreator to retain the extra two big trees per acre in a forest compared to cleaning up down wood or thinning, irrespective of exactly how many other big trees are already there or whether the forest contains many saplings or has an open floor. The second kind of information most often needed is the relative scenic merit of alternative general forest management programs that might be pursued in areas with different scenic requirements. These choices are not always obvious, as several alternatives may yield intuitively, equally-meritorious scenic values. For example, foresters may ask whether an even-aged rotation might actually yield more total scenic beauty over time than an uneven-aged one.

This could be true in spite of the initial scenic impact of harvesting if the even-aged rotation yielded much higher scenic beauty during its period of forest maturity. More empirical and valid information must be sought to answer such questions.

Research Design

The research reported here sought to provide hardwood forest managers with the two kinds of practical information needs described above. It began in the same manner as have the many reported scenic beauty modeling studies, and then added further analysis aimed at answering the two key kinds of questions. A sample of such forests was inventoried and photographed and then judged for scenic beauty by a sample of public respondents. A model was then developed to predict average scenic beauty values for forests using many of their structural attributes. This model was then used to account for the observed scenic beauty of forests as much as possible by the scenic effects of all but one variable at a time. This allowed the identification of marginal relationships between each of several critical forest attributes and their singular effect on scenic beauty, all other scenic factors being accounted for. In each case, the marginal variable analyzed was chosen for its practical value in informing forestry decisions. (Consequently, the variables analyzed for their marginal scenic values were sometimes slightly different from those optimally included in the more general scenic beauty model.) This permitted the identification of simple and informative relationships between manageable attributes of hardwood forests and their scenic effects. And, those relative effects are all measured on the same ratio scale of scenic beauty for ready comparison in selecting future forest conditions to maximize scenic beauty goals.

To answer the second kind of question regarding the scenic merit of alternative general hardwood forest managements, a simpler research design was employed. A few forests representing different stages of forest development under several management alternatives were sampled. A curve was then fitted through the observed scenic beauty of these forests plotted against time to indicate the general flow of scenic beauty that might be expected from each management alternative. The resulting general scenic flow patterns could then be compared in roughly estimating the relative scenic merit of general management alternatives.

METHODS

The development of the scenic beauty prediction model is explained in greater detail in Ribe (1990). The process involved field-sampling a diverse set of predominantly hardwood forests, having a variety of respondents judge scenes from the forests for scenic beauty, standardizing and then averaging the respondents judgements by forest, and then finding a linear regression model that used forest structure attributes to predict these average scenic beauty values across the forests.

Stand Sample

A sample of 31 dominantly hardwood forests were selected to include a variety of ages, dominant species, management histories- including experimental stands, structures, site qualities and slash treatments. The average site index was 50 for Sugar Maple (*Acer saccharum*), base age 50. They ranged from 10 to 180 acres, and their interior floors were flat and free of artifacts.

The stands were sampled during mid-day in July 1987- mid way through the seasonal decline in perceived scenic beauty due to progressive dulling of foliage color (Buhyoff and Wellman 1980, Rudis and others 1988). Each stand was sampled around two randomly selected points. At each, three photographs were taken in different directions away from the sun with a 35 mm lens. The stands structure was then measured within a 1/10 acre plot surrounding each sample point in a manner like that of Brown and Daniel (1986). The diameter distribution was counted for trees exceeding 2 inches dbh in 5 inch categories, and a count of all saplings at least 5 feet tall but less than 2 inches dbh was made. Transects were measured for percent canopy in shrubs and seedlings less than 5 feet tall (Canfield 1941), and cubic feet of sound slash per acre (Brown 1974). Rectangular plots served to measure percent canopy coverage in live ground vegetation (Daubenmire 1959). The two sample point values for these structural attributes were averaged to yield single values for each stand. These attributes exhibited a broad range of values and a variety of value combinations due to the diversity of the stand sample.

Scenic Beauty Measurement

Three slides were selected from each stand's sample for photographic quality and range of scenery represented. The slides from all the stands were then shown in random orders to 139 judges. These were from 12 diverse but dominantly white public groups from Wisconsin. Only one group, consisting of Wisconsin Department of Natural Resources staff members, included a significant representation of people familiar with forest management. The judges rated every slide for scenic beauty on a scale from -5 to +5, corresponding to a range from ugly to beautiful perceptions. These ratings were then standardized and averaged for each stand across all judges using the ratio scenic beauty estimate (RSBE) method (Ribe 1988), modified from the scenic beauty estimation method (Daniel and Boster 1976). Scenic beauty estimates on a ratio scale take on positive and negative values that correspondingly indicate the relative beauty or ugliness of landscapes, as opposed to those on an interval scale that take on relative values around an arbitrary zero value.

Model Development

An optimal linear regression model was sought using measures of forest structure derived from the stands' inventory data as independent variables to predict the RSBE's of the stands. Independent variables were selected to be intuitively reasonable as scenic beauty predictors, by reference to past research (Ribe 1989) and by replication of other models with the new hardwood data set (Ribe 1990). A large number of independent variables were included in the model to capture many of the important scenic attributes of forests and to minimize bias in all variables' estimated coefficients. To be included in the model, a variable had to have the expected direction of effect upon scenic beauty, a statistically significant coefficient at the P=.05 level, and pass further statistical tests described in Ribe (1990). In selecting from among alternative models including variables that met these criteria, a final model was chosen that maximized the F statistic and the model's explanation of variance in RSBE's.

Data Analysis

The marginal impact of each critical forest attribute upon perceived scenic beauty was analyzed through its own separate analysis, albeit one very similar to that for the other attributes. Each such analysis began by discounting each forest's observed scenic beauty for the scenic-beauty-producing effects of all forest attributes in the regression model other than the one being analyzed. This was achieved simply by performing algebra upon the regression equation with the observed rather than predicted RSBE value for each forest included as the dependent variable value. Each forest's observed values for all independent variables being discounted from scenic beauty were multiplied by their regression coefficient and then subtracted from the forest's observed RSBE. The result was a residual RSBE value for each forest that can only be explained by the remaining undiscounted forest attribute being analyzed for its scenic impact, as well as all other scenically affective attributes not included in the regression model.

The relationship between each critical forest attribute and the residual scenic beauty it might serve to explain was then analyzed. This was done by plotting the two variables across all 31 forests on a graph and fitting a least squares function through the points. The resulting relationship was then analyzed by an F test for statistical significance and an R^2 test for explanation of variance in residual RSBE's across all forests. The forest attribute measurement variable plotted against residual RSBE's at this point needed not be exactly the same as that included in the regression model. Instead, a more informative measure of the forest attribute in question was often plotted against the residual RSBE's largely attributable to that aspect of hardwood forests' structure.

The nature of perceived scenic beauty flows from alternative long-term forest managements was plotted through a rough application of the Scenic Beauty Temporal Distribution method (Hull and Buhyoff 1986). This involved a separate and much simpler analysis than that described above for the critical forest attributes. It involved taking forests from the sample

which represented different conditions over time within a management program and plotting their observed RSBE's against forest age. A curve was then plotted through each program's plot of points to roughly approximate the flow of scenic beauty from that program. This was done by eye. Where a long time gap occurred between two sample forests within a management program it was done with educated guessing about the development of forests under different managements. This simple method served as a first approximation of scenic flows using the relatively few forests that could be sampled to represent different management programs.

RESULTS

The sample of hardwood forests exhibited a wide range of RSBE values, making possible some informative analysis of the contribution of forest attributes to scenic beauty and the flow of beauty from alternative management programs. Fortuitously, the range of observed RSBE values took on a property that aids the interpretation of their numeric intervals. Namely, the old-growth forest received an RSBE of close to +100 and the recent clear-cut forest a value of just over -100. Consequently, this range of RSBE values can be viewed as the range of scenic beauty possible from hardwood forests. The zero RSBE value halfway in-between corresponds to forests of "neutral" or aesthetically indifferent scenic value just between those which respondents liked and disliked.

General Scenic Beauty Model

The best linear regression model for predicting RSBE's from hardwood forest's structural attributes is reported in Table 1. The importance of the variables in this model in predicting RSBE's, by virtue of their stepwise contribution to R^2, corresponds to their order from top to bottom in that table. All intercorrelations among the independent variables were less than 0.50 indicating an absence of multicollinearity. The unusually high R^2 and F statistic values for this model indicate that it can serve well the marginal scenic impact analyses of the research. This is because any residual variance in discounted RSBE's will be largely explained by a remaining undiscounted scenic factor. The ability to isolate the scenic impact of one variable at a time is further enhanced by the inclusion of many forest attributes as variables in the model that can all be clearly discounted from RSBE's. And, such discounting is also more accurate because all the regression coefficient estimates are minimally biased by including all relevant and evidently valid variables in the model.

All the independent variables in the model are statistically significant in their relations to scenic beauty at the P=.05 level. They are intuitively reasonable, although some take on nonlinear functional forms through special functional specifications and interaction terms: Aspen and birch trees are together positively related to RSBE's but with a nonlinear asymptotic relation expressed by the negative coefficient for the reciprocal of this variable. The number of trees per acre greater than 2 inches dbh appears in two variables as a

Table 1.--Hardwood Forests Scenic Beauty Model

Dependent Variable: Ratio Scenic Beauty Estimate (RSBE)

Independent Variables:

	Estim. Coeff.	Beta	Stand. Error	t Value
Slash >3" (cu.ft./acre)	-.034	-.701	.003	10.958*
Number of trees >2"/acre	.093	.162	.040	2.353*
[Trees & saplings/acre]^2	$-9x10^{-8}$	-.187	$3x10^{-8}$	-3.053*
Number of trees >15"/acre	.670	.207	.198	3.382*
Ground vegetation (% cover)	.437	.209	.130	3.364*
1/[% trees aspen/birch]	-63.465	-.124	27.854	-2.278*
[Standing slash >18" tall/ acre rescaled to 0-100] X [Percent trees dead] X [Bare ground (% cover)]	-.0002	-.159	.0001	-2.422*
Constant	14.433			

Regression Statistics:

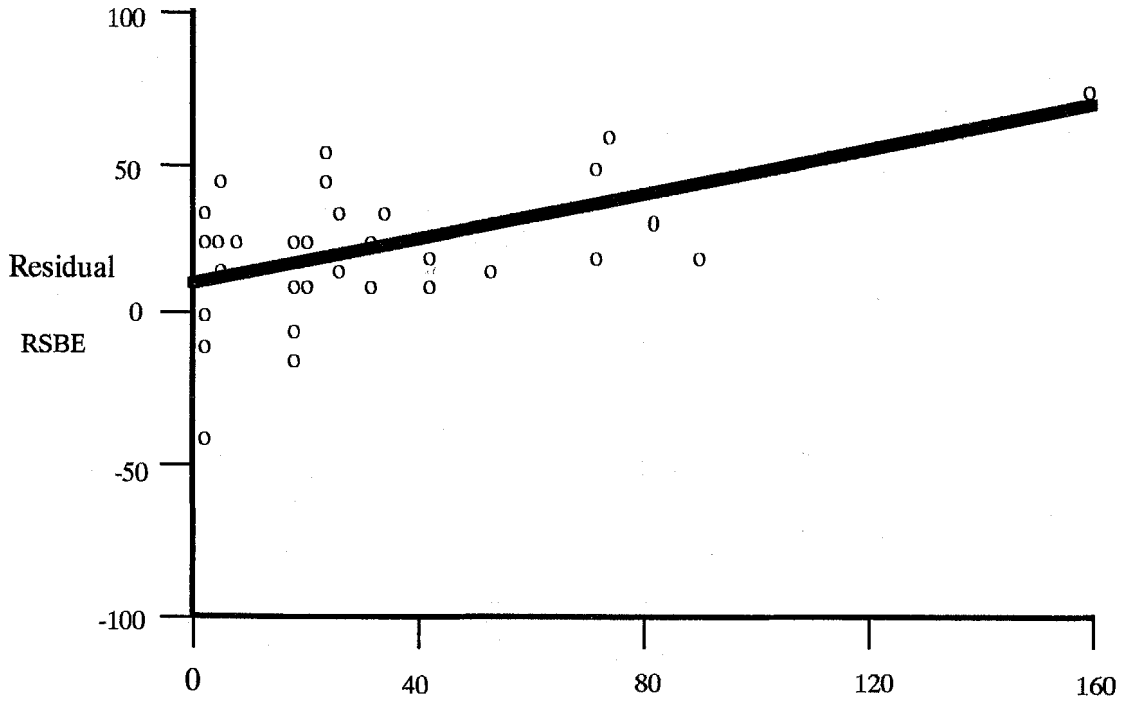
R^2 = .967 Adjusted R^2 = .934 F= 46.829

* Indicates statistical significance at alpha =.05 level.

quadratic specification defining a curve like that in Figure 3. Finally, the last variable multiplies three similarly scaled factors which together produce the appearance of death or sterility in the forest. The other variables are self explanatory.

Big Trees

The marginal impact of big trees upon perceived scenic beauty was isolated by discounting each forest's observed RSBE's by the scenic effects of all variables in the model except for the number of trees bigger than 15 inches dbh per acre. The resulting residual RSBE's are plotted in Figure 1 against the basal area per acre of such trees. This is a more interesting



Residual RSBE = 12.66 + .36(Basal Area in Big Trees)

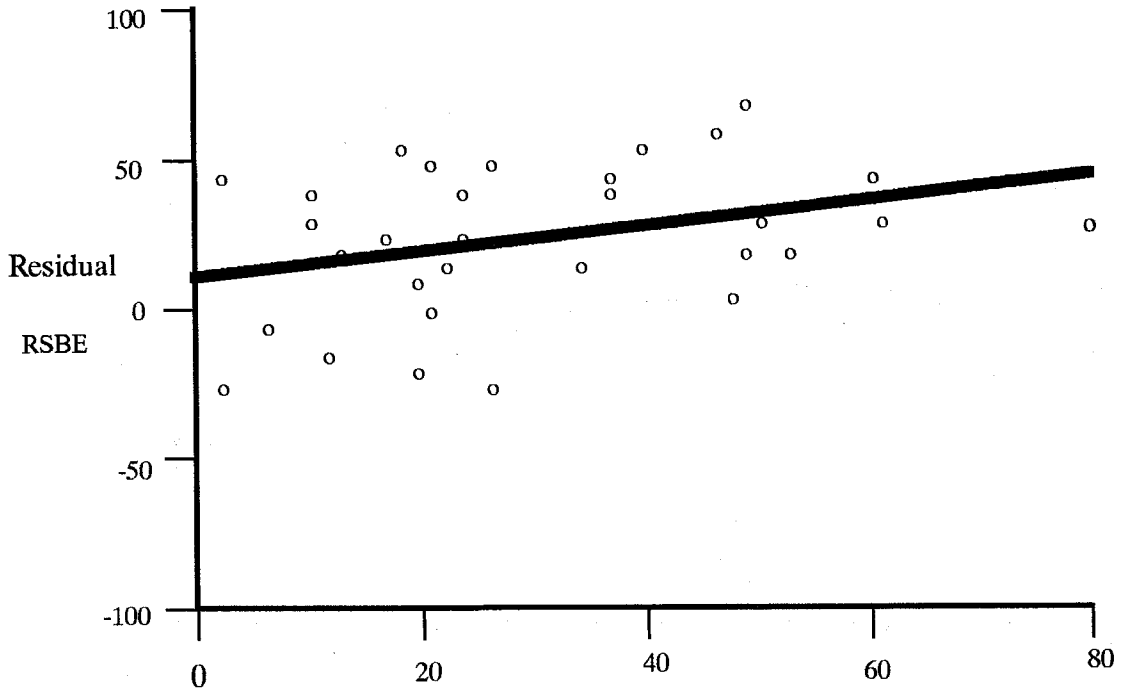
$P = .0002 \quad R^2 = .62$

Figure 1. Relation between big trees and scenic beauty.

variable for detailed analysis because it indicates more about how scenically valuable it is to retain the largest trees in a stand rather than simply maximizing the number greater than 15 inches dbh. These results indicate that the basal area of large trees more than their numbers (a less beautiful forest could have many 15 inch dbh trees and none larger) is strongly related to forests' scenic beauty. Each 15 square feet of basal area in trees exceeding 15 inches dbh adds to scenic beauty by about 10 percent of the possible range of positive beauty from an aesthetically neutral landscape to an old-growth forest, all other factors being equal. This relationship is strongly supported by its statistical significance and the strong explanation of variance in residual RSBE's by basal area in big trees (Figure 1).

Pole Sized Trees

The result reported above for big trees might apply equally to pole sized trees if observers simply judged the beauty of forests by the presence of any and all full-grown trees. This possibility was tested by isolating the marginal impact of trees between 5 and 15 inches dbh upon perceived scenic beauty. This was done by discounting each forest's observed RSBE by all variables in the model except for the number of trees per acre exceeding 2 inches dbh and



Residual RSBE = 13.22 + .42(Basal Area in Poles)

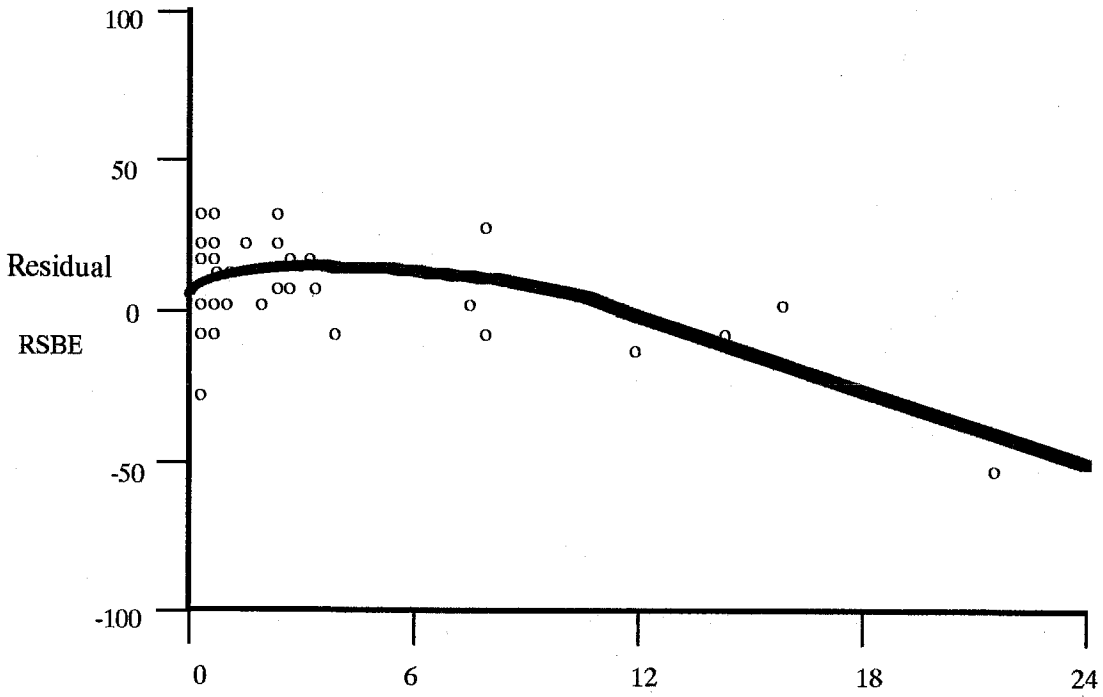
$P = .0042 \quad R^2 = .50$

Figure 2. Relation between pole sized trees and scenic beauty.

plotting these residual RSBE's against basal area in pole sized trees. The results appear in Figure 2. They indicate that basal area in pole sized trees is positively related to scenic beauty, but not as strongly as that for big trees. The scatter plot is less clearly linear and the explanation of variance and statistical significance are lower. Most importantly, the contribution of basal area in pole sized trees to scenic beauty is half that for big trees. Each 30 square feet of basal area in trees between 5 and 15 inches dbh adds to scenic beauty only about 10 percent of the possible range of positive beauty, all other factors being equal. This is twice the basal area requirement to achieve a 10 RSBE point increase than that needed in trees greater than 15 inches dbh to achieve the same scenic beauty result. This confirms the relative importance of big versus pole sized trees in producing forests that the public finds attractive.

Small Trees

The marginal impact of small trees upon perceived scenic beauty was isolated by discounting each forest's observed RSBE's by the scenic effects of all variables in the model except for the number of trees and saplings per acre squared. The resulting residual RSBE's are plotted

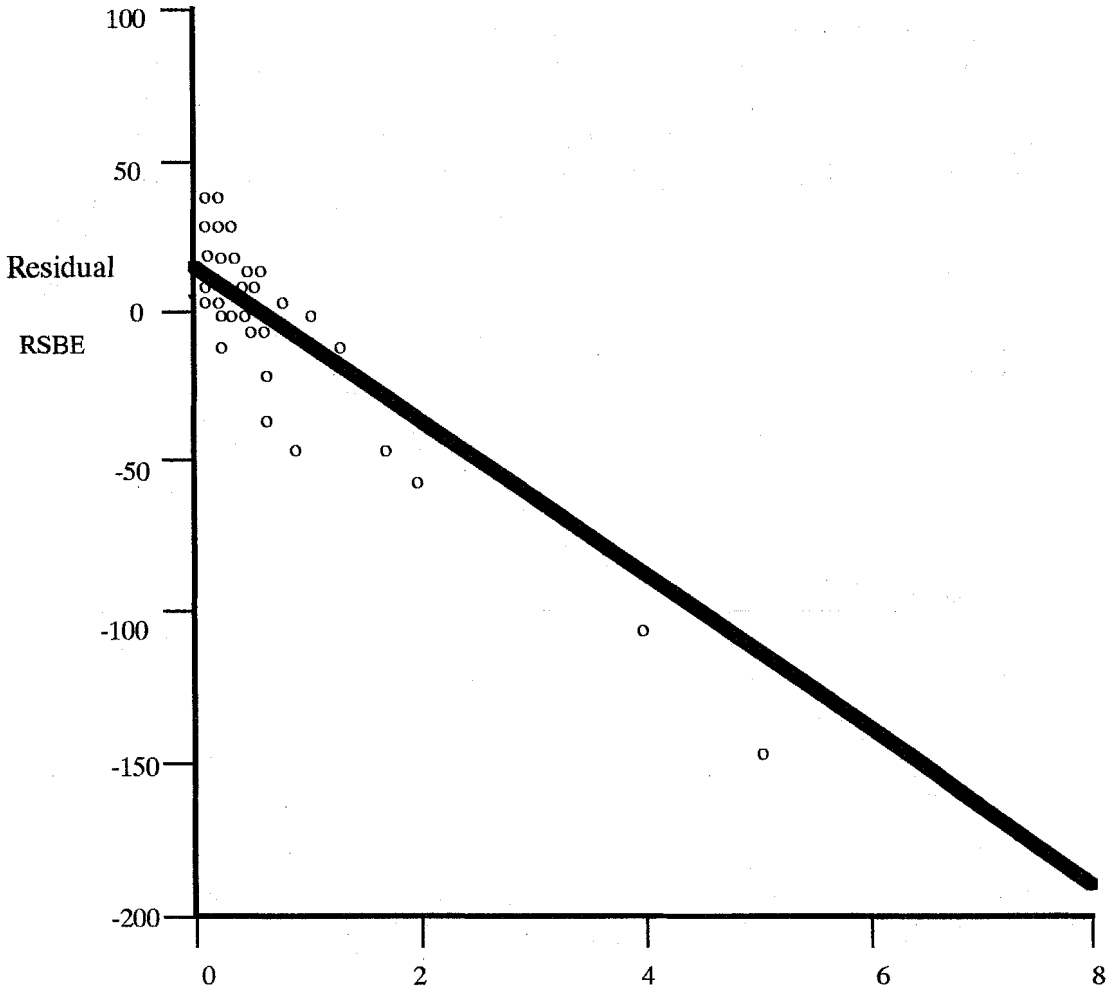


Residual RSBE = 11.44 + .0009(Number Saplings) - .0000001(Number Saplings)

$P = .0009 \quad R^2 = .63$

Figure 3. Relation between saplings and scenic beauty.

in Figure 3 against the number of trees per acre at least 5 feet tall and less than 5 inches dbh. The best least squares functional fit through this scatter plot proved to be a quadratic specification, which is consistent with that found in the general regression model for tree numbers. This curve indicates that up to 4 thousand small trees per acre have a negligible marginal impact upon perceived scenic beauty. With more small trees than that, their marginal negative impact upon scenic beauty becomes increasingly pronounced. For example, beyond 10 thousand small trees per acre, each thousand small trees reduces scenic beauty by about 10 percent of the possible negative range of scenic beauty from an aesthetically neutral landscape to a fresh clear-cut, all other factors equal. This relationship is strongly supported by its statistical significance and explanation of variance in residual RSBE's.



Residual RSBE = 14.86 - .02(Cubic Feet Down Wood)

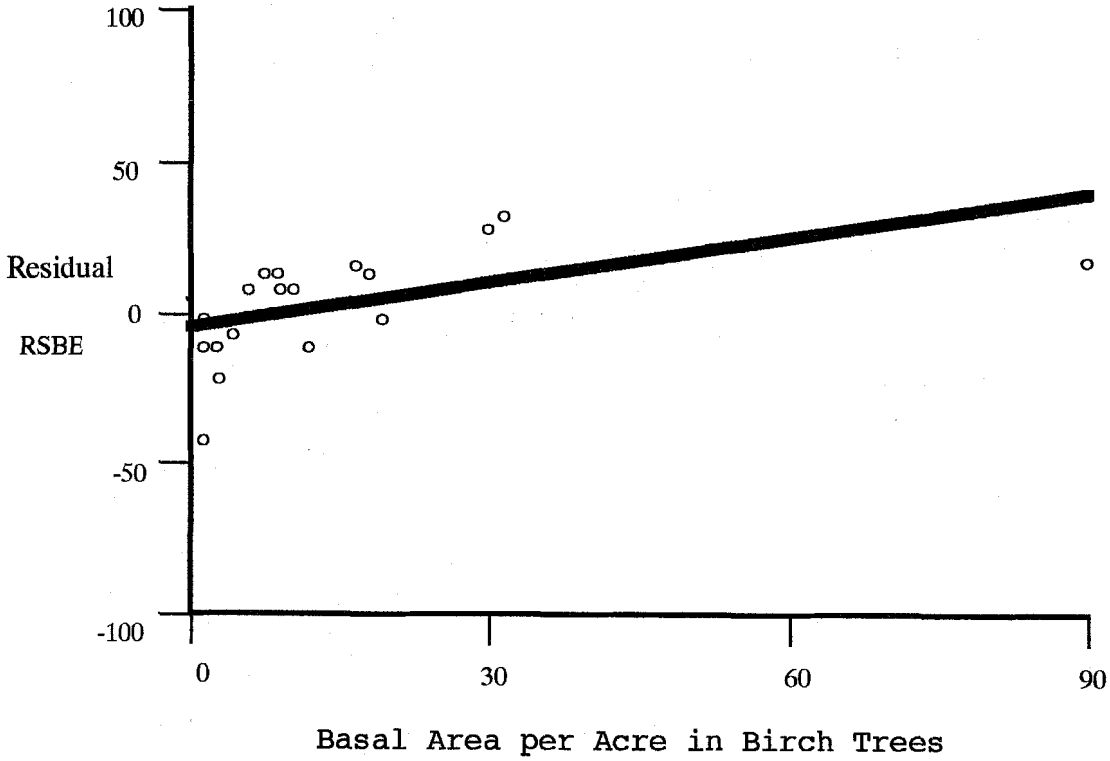
$P = .00001$ $R^2 = .93$

Figure 4. Relation between down wood and scenic beauty.

Down Wood

The negative scenic effect of down wood proved to be the most powerful single predictor of variance in RSBE's in the general regression model. To single out the marginal impact of down wood on scenic beauty each forest's observed RSBE was discounted by the scenic effects of all variables in the model except for cubic feet per acre of "slash" greater than 3 inches in diameter. This variable includes all down wood whether from natural or harvesting

sources. The resulting residual RSBE's are plotted in Figure 4 against a slightly different more inclusive measure of down wood- namely cubic feet per acre greater than 1 inch in diameter. As the general model suggests, the resulting relationship is strongly negative, linear, and of very strong statistical significance and capacity to explain variance in residual RSBE's. Each thousand cubic feet per acre of down wood reduces perceived scenic beauty by about 10 percent of the possible range of negative scenic beauty, all other factors being equal.



Residual RSBE = -2.35 + .44(Basal Area Birches)

$P = ..012 \quad R^2 = .58$

Figure 5. Relation between birch trees and scenic beauty.

Birch Trees

To investigate the marginal scenic impact of contrasting tree types, such impacts were investigated for both birch (Betula alleghaniensis or papyrifera) and evergreen trees, which are most frequently of interest to managers of hardwood forests. The general regression model worked best by combining both birch and aspen trees in one variable because a number of aspen stands were sampled to enable an investigation of scenic flows from clear-cut even aged rotations dominated by aspens. To investigate the marginal impact of only birch trees, which more frequently occur in dominantly hardwood forests in northern

zones, the observed RSBE's were discounted by all independent variables in the model except for the reciprocal of the percent of trees aspen or birch variable. The resulting residual RSBE's were plotted against the basal area per acre in birch trees, ignoring stands that had no basal area in such trees. It was assumed that the scenic affect of contrasting trees would only play upon perceptions when such trees are at least minimally evident. The results appear in Figure 5. Each 20 square feet of basal area per acre in birches increases scenic beauty by about 10 percent of the possible range of positive scenic beauty. This relationship is supported by its statistical significance at the P = .02 level and by an explanation of 58 percent of the variance in residual RSBE's.

Residual RSBE = 10.58 + .15(Basal Area Evergreens)

$P = ..19 \quad R^2 = .35$

Figure 6. Relation between evergreen trees and scenic beauty.

Evergreen Trees

The other contrasting tree type that can occur in hardwood forests are evergreens. These did not succeed in contributing to RSBE prediction for inclusion in the general regression model. This may be because most of the hardwood forests sampled had no or very few evergreen trees and only one had a basal area in such trees exceeding 20 square feet per acre, and perhaps also because the forests were sampled in the summer when evergreen trees may have less scenic impact. For the sake of exploration, a marginal scenic impact analysis for

evergreen trees was still performed. Because such trees do not appear as a variable in the general model, the forests' observed RSBE's were discounted by the scenic effects of all the independent variables in the model. The resulting residual RSBE's not explained by the model were then plotted against the basal area per acre in evergreen trees. The results appear in Figure 6. As in the analysis for birch trees, forests with no evergreen trees were left out of the analysis. The least squares function through the points is positive, suggesting evergreen trees do have a positive marginal impact upon scenic beauty. But, consistent with the results of the general model, this relationship is not supported by statistical significance or a high R^2. It suggests that each 10 square feet of basal area in evergreen trees may contribute to scenic beauty by about 2 percent of its possible positive range, but an analysis of forests with more such trees would be more conclusive.

Even-aged Managements

Shelterwood harvest rotations are the even-aged management of choice among the hardwood forests sampled in this study To estimate the flow of scenic beauty from such rotations, forests were sampled from several points in time along this management program. Naturally, these forests varied a bit in site quality, species composition and exact historical development. The intent was to obtain a sample of the general appearance of forests throughout such rotations for the respondents to judge for scenic beauty. The resulting RSBE's are plotted against forest age in Figure 7 either as small circles or with the "S" symbol. A 110 year rotation is illustrated because that is the average time to culmination of mean annual increment among the forests sampled in this study. A solid-line curve is fitted through the sample points along this rotation to roughly estimate the scenic flow from it. While the methods employed here do not permit a calculation of average or total scenic beauty flow from this rotation, the results do indicate the degree to which a shelterwood harvest impacts scenic beauty, the rate at which perceived attractiveness recovers, and the portion of the forest's life with relatively high (RSBE > 70) scenic beauty.

Two forests were also sampled from an even-aged shelterwood rotation that had been pre-commercially thinned at around age 50. These are also plotted in Figure 7 with the symbol "T" and the scenic beauty flow from them estimated with the broken line. Based upon this limited evidence, as well as that regarding numbers of small and big trees in the general scenic beauty model, these thinnings increase the scenic beauty flow from such forests slightly after they are made until harvest.

The other even-aged management option commonly pursued on the hardwood sites sampled in this study is clear-cutting with the resulting establishment of aspen (*Populus tremuloides* or *grandidentata*) species. Six forests from this management program were sampled and these are plotted with an estimated scenic flow in Figure 8 for a 40 year rotation. The form of the solid-line curve for this rotation is similar to that in Figure 7 for an even-aged hardwood rotation. However, the frequency of harvests and their scenic impact are both greater, the recovery of scenic beauty after harvests may be slower, and the highest scenic beauty achieved is a lower. While the methods used to plot this flow also do not permit quantitative

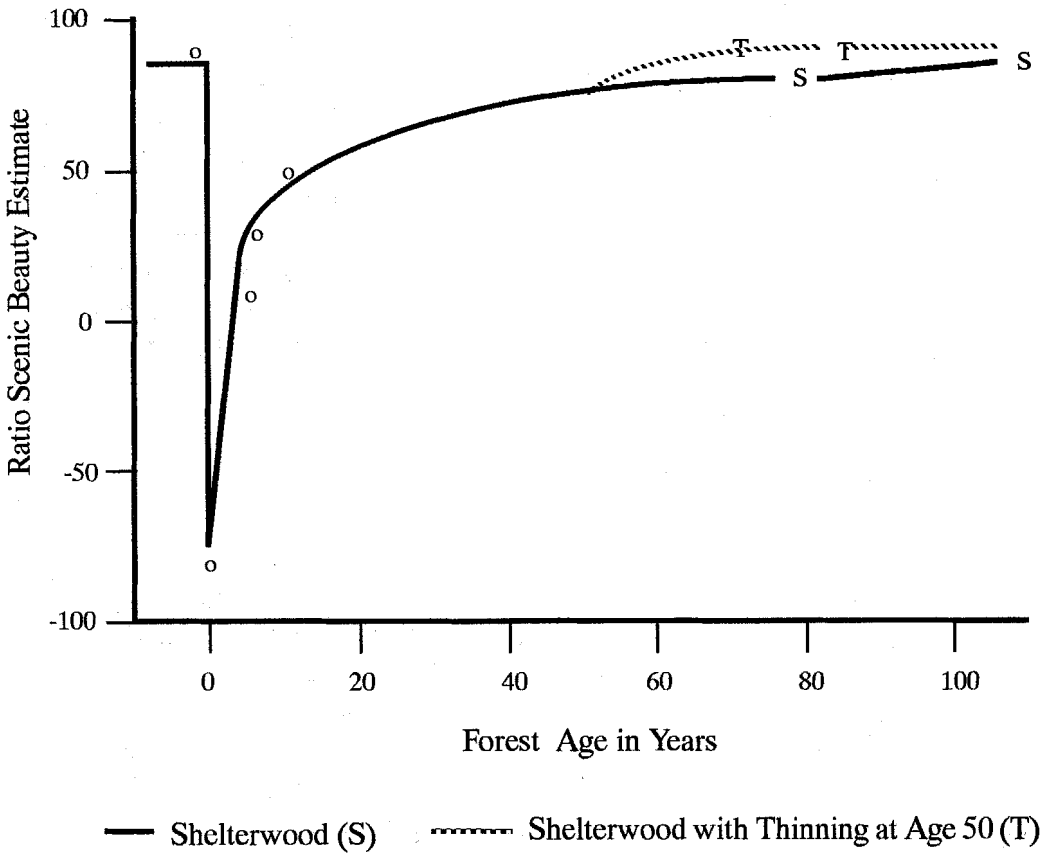


Figure 7. Scenic flows from even-aged hardwood rotations.

estimates of relative scenic flows from this management program, it seems safe to assert that it yields less scenic beauty over time than the shelterwood hardwood rotation.

There is a forest management option that might mitigate the low scenic flow from even-aged clear-cut aspen dominated rotations. This would be to allow shade tolerant fir trees to grow within the aspen forest to replace the aspen trees as they die or are selectively harvested. Forests which represented the deliberate execution of this management option were not found. However, two forests were sampled that had developed as aspen stands from clear-cuts- and in one case with some birch trees- which had been allowed to mature to the point that they were dominated by young to middle aged fir trees. The RSBE's for these are also plotted in Figure 8 with the "F" symbols and an estimated scenic flow from this management option plotted with the broken line. These rough results suggest that the conversion of aspen stands to fir dominated forests will yield greater scenic beauty flow over time than if such stands are clear-cut to begin a new aspen rotation. The results account for the perceived scenic beauty of forests containing a mix of mature aspen and young fir trees. They do not incorporate the effects of selectively harvesting the aspen trees while leaving the firs. They also do not reflect the long-term scenic flow from allowing the fir dominated forest to mature because this research did not explore the scenic beauty of non-hardwood fir or pine dominated forests.

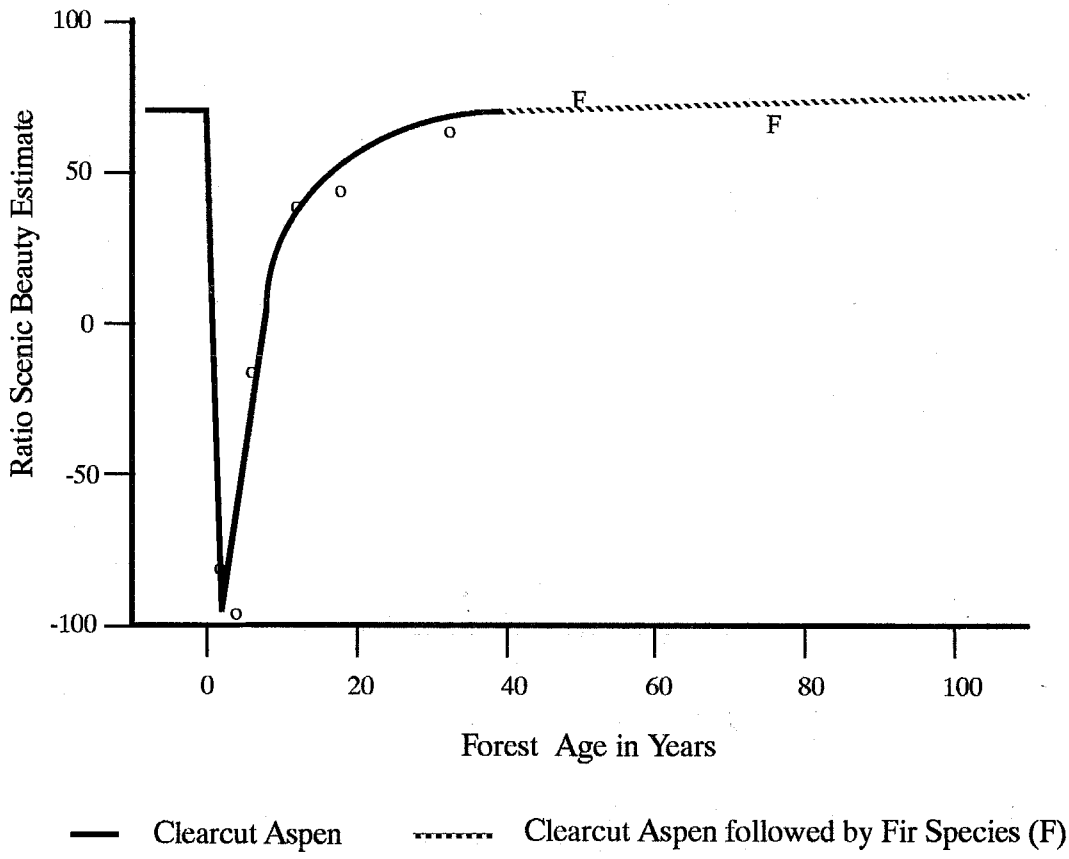


Figure 8. Scenic flows from even-aged softwood rotations.

Uneven-aged Managements

Uneven-aged forest managements are generally believed to be preferable in their scenic beauty yields due to the elimination of major harvests and the maintenance of a forest that more nearly simulates natural conditions. Old-growth forests are similarly viewed as aesthetically preferable and are often left or allowed to develop in areas where recreation is the dominant use. Consequently, forests were included in the sample to allow rough estimations of the scenic beauty flows from these management options. A beginning point forest was chosen to represent a 40 year old even-aged stand of average site index and species composition for northern Wisconsin hardwood forests.

Three experimental forests were then sampled to represent stages of successful conversion to an optimal growth-rate uneven-aged condition (Erdmann 1986). A 40 year old forest was chosen as the starting point for this analysis because that was the age when these sampled experimental forests began this conversion. One forest was also sampled that represented an established optimal uneven-aged forest that was assumed to be in a long-term stable appearing condition under selective harvesting (Arbogast 1957, Crow and others 1981). These forests RSBE's are plotted in Figure 9 with the "M" symbols, and an estimated scenic beauty flow

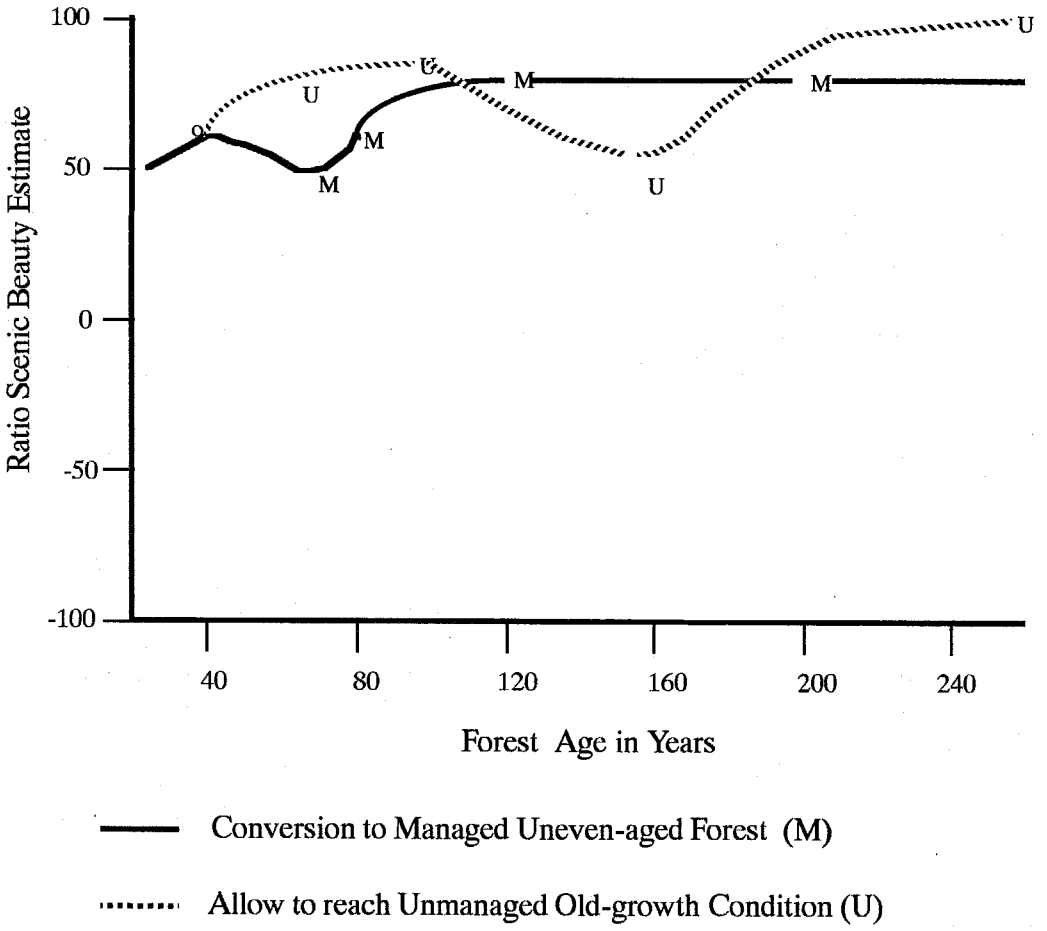


Figure 9. Scenic flows from uneven-aged hardwood forests.

from them is plotted as the solid line. The resulting flow pattern indicates a period of about 20 years after thinnings to 75 square feet of residual basal area per acre when scenic beauty declines due to increased sapling and reduced pole sized tree numbers. After that time the forest grows in beauty to reach a long-term scenic beauty level comparable to that of a mature even-aged hardwood forest.

The same kind of analysis was done to roughly estimate the scenic flow from allowing a forest to attain an uneven aged condition through aging to an old-growth condition. The results appear in Figure 9 as "U" symbols for the sampled forests and the broken line for the flow of scenic beauty from this management option. The general pattern is the same as for a managed conversion to an uneven-aged condition. The differences are as might be expected. The final long-term level of scenic beauty achieved is considerably higher due to more large trees and fewer small ones. The time it takes for conversion to uneven ages through natural mortality is much longer and also produces a temporary decline in perceived scenic beauty. And, there is an early increase in scenic beauty with the maturation of the even-aged forest before natural conversion to uneven ages begins.

DISCUSSION

Critical Forest Attributes

The key finding in the analysis of critical forest attributes' relation to scenic beauty lies in the interpretation of the functional slopes found in Figures 1 through 6. All these slopes relate the value of their respective forest attributes to the same ratio scale of scenic beauty. Consequently, a decision maker can readily compare the scenic returns from changes in sets of forest conditions to be created or promoted through management. These relationships have each been carefully isolated as marginal relationships that apply after the effects of other forest attributes upon scenic beauty have been discounted. As a result, they can be applied with confidence that they are not likely to change from one forest context to another because the effect of each factor has not been commingled and confused with that of other forest attributes. Above all, by knowing the independent, stable, and commensurable magnitude of each forest attributes relation to perceived scenic beauty, managers can have a grasp of the subtleties of how forests take on scenic beauty rather than relying upon their general intuitive sensibilities that these relationships do exist in some rough and complex way.
The interpretation of these marginal impacts of forest attributes upon scenic beauty is dependent upon the set of choices for modifying forest conditions available to the forester in each situation. Consequently, it is difficult to make any generalizations about the scenic value of different attributes, particularly without accounting for the relative financial and resource costs that might be incurred in producing them in different forests. What can be summarized from these findings is that the following changes in the state of a forest all produce about the same marginal impact upon scenic beauty equal to 10 RSBE points, or 5 percent of the total possible range of hardwood forest beauty: 15 square feet basal area per acre in big trees, 30 square feet basal area in pole sized trees, 20 square feet basal area in birch trees, 50 square feet basal area in evergreen trees, a reduction of down wood by 1,000 cubic feet per acre, and a reduction of 1000 saplings per acre. To the extent that these variables' stepwise explanation of variance in the general regression model indicates their relative importance in producing summer scenic beauty, the removal of down wood is the most valuable scenic management, followed by the avoidance of many saplings, and then the retention of big trees. For managers seeking to maximize the scenic beauty of important recreational forests, all these variables (with the possible exception of more evergreen trees) should be maximized within silvicultural constraints.

Management Programs

The results found in Figures 7 through 9 showing flows of scenic beauty from alternative long-term management programs are of critical interest to hardwood forest managers. They are useful in the same way that other informed long-term expectation for forest products are, such as those for expected wildlife habitat values. They show estimated flows that can be generally anticipated, and as such are only approximate. This is because they are based upon

only a few representative forests from a management program over time and upon only a rough fitting of curves through these few points. Further research can yield more accurate estimates of scenic beauty flows from hardwood forest management programs by simulating the development of forests with computer programs such as STEMS (Belcher 1981) and applying the general scenic beauty model shown in Table 1 to the resulting simulated forest conditions to identify flows of scenic beauty over time.

Within the limitations of the accuracy of these scenic beauty flow estimates, several expected findings can be summarized. Uneven-aged managements do yield higher long-term average scenic beauty values, and, among these, old-growth hardwood forests evidently yield the most beauty beyond the age of 200 years. Among even-aged managements, those that involve longer rotations yield the highest long-term average scenic beauty values, including successional management programs such as allowing fir trees to replace aspens. The evidence also suggests, and is corroborated by the general model, that management programs that reduce numbers of small trees and increase basal area in large trees over some of the forest's life yield greater long-term flows of scenic beauty. Because the flow curves in Figures 7 through 9 were fitted in places by eye with these kind of expectations in mind, these results should be interpreted with some caution. Only further research simulating forests' growth or with more sample forests for each program can assure the validity of these and more specific findings.

CONCLUSIONS

Foresters have come to rely on scientific information to aid them in gaining the production of a variety of resource values from the forests they manage. The results of this study should aid those working with hardwood forests to do so also for the production of scenic beauty. They provide the kind of simple relationships and general expectations of future forest production rates that can be most useful in making decisions to enhance the scenic beauty of hardwood forests. Two kinds of information have been produced for the first time. First, the relative marginal scenic effects of key forest attributes have been isolated by discounting for the effects of other attributes across a sample of forests. These key positive scenic attributes are the basal area of large trees, a reduced quantity of down wood, the number of pole sized or birch trees, and a reduced number of small trees. Second, the scenic flow of alternative general forest management programs have been roughly estimated for comparison of even-aged, uneven-aged and alternative managements for hardwood sites. These rough estimates suggest that the greatest long-term scenic beauty flow may be obtained from allowing forests to reach an old-growth condition, followed by an uneven-aged management program, a shelterwood management with thinning, and then the same without thinning. Lower scenic beauty flows might be expected from a clear-cut aspen rotation allowed to progress into a successional fir forest or a much lower flow from a simple clear-cut aspen rotation. With this information, and that produced by further research improving the scenic flow results, the scenic impact of management choices in multiple-use hardwood forests need not be left to guess-work. Decisions can be better substantiated and documented to assure the continuous provision of enjoyable landscape experiences in hardwood forests.

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SHIPPING COAL TO NEW CASTLE: ARE SRIC *POPULUS* PLANTATIONS A VIABLE FIBER PRODUCTION OPTION FOR THE CENTRAL HARDWOODS REGION?

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Abstract: Production costs for short rotation, intensive culture (SRIC) *Populus* biomass were developed from commercial-sized plantations under investigation throughout the eastern U.S. *Populus* hybrid planted on good quality agricultural sites at a density of 850 cuttings/acre was projected to yield an average of 7 ovendry (OD) tons/acre/year. Discounted cash-flow analysis of multiple rotations showed pre-harvest production costs of $15/ton (OD). Harvesting and transportation expenses would increase the delivered cost to $36/ton (OD). Although this total cost compared favorably with the regional market price for aspen (*Populus tremuloides*), future investments in SRIC systems will require the development of markets specific to this biomass output.

INTRODUCTION

Foreign restrictions of oil imports to the U.S. during the 1970s resulted in a review of energy-use policies and an allied search for alternate energy sources. The perceived energy crisis brought about an accelerated exploration for domestic sources of fossil fuels and an investigation into the use of solar energy and allied forms of renewable energy (OTA 1980).

Woody biomass was evaluated as a supplemental fuel source, both in terms of expanded supplies from domestic forests and from short rotation, intensive culture (SRIC) energy plantations. During the 1970s wood provided a small portion of U.S. energy supplies, amounting to 2% of annual energy needs (OTA 1980). Most of this biomass was used for residential heating. In terms of the future, an expanded use of forest growth, mortality, and urban wood waste, above current forest industry usage, could provide about 8% of U.S. energy needs (Peterson 1983). An additional 6% of our energy needs could be developed by converting one-tenth of the nation's private forest, range, and pasture lands to SRIC plantations (OTA 1980). However, one of the unresolved questions is whether woody biomass could compete, cost-wise, with other fuel sources.

Most of the early proposals regarding the expanded use of wood energy were tied to the direct combustion of biomass for electric generation (Skelton et al. 1982). However, under current and near-future world prices for coal and petroleum, biomass-dedicated conversion

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systems cannot compete with large scale, coal- and oil-fired systems (Strauss et al. 1988). Woody biomass would have a better option as a feedstock for ethanol production. Liquid fuels are in strategic short supply within the U.S., making this country vulnerable to supply and/or price disruptions (Wright 1988). The production of ethanol from woody biomass has been proposed under several processes, with the final product considered to be cost competitive under open-market situations (Wright and d'Agincourt 1984, Bergeron et al. 1988). Biomass from SRIC *Populus* plantations would be particularly well suited to these conversion processes on the basis of material characteristics and supply capabilities (Ranney et al. 1987, Strauss et al. 1988).

SRIC production is designed to promote high biomass yields at a young stand age. The most cost-effective cultural approaches have included the use of improved clonal material, intensive site preparation and weed control, planting densities of 600 to 1600 trees/acre, fertilization, coppice regeneration, and two to three harvest cycles of five to eight years each (Ranney et al. 1987). In order to facilitate these cultural designs and secure a maximum output, most of the SRIC plantations have been placed on good agricultural lands. Hardwoods have been preferred due to their rapid early growth, good stress tolerance, and strong coppicing ability. Major attention has been directed to the poplars (*Populus* spp. and hybrids), eucalypts (*Eucalyptus* spp.), silver maple (*Acer saccharinum*), sweetgum (*Liquidambar styraciflua*), sycamore (*Platanus occidentalis*) and black locust (*Robinia pseudoacacia*). Willows (*Salix* spp.) have been investigated in Canada and northern U.S., involving "wood grass" strategies with over 10,000 stems/acre and ultra-short rotations of one to three years (Wright et al. 1988).

Research on SRIC technology in the U.S. was initiated in the mid-1960s, with major improvements secured through numerous experimental trials. Much of this work was funded or co-funded by the U.S. Department of Energy and coordinated through its Short Rotation Woody Crops Program (SRWCP) (Wright et al. 1989).

In order to encourage the commercialization of SRIC programs, the economics of plantation systems are being evaluated under two general stages of research. These include feasibility studies of proposed commercial-sized systems (Perlack et al. 1986, Strauss et al. 1988) and, more recently, the scale-up analysis of actual commercial plantations (Wright, in press). This latter effort includes economic and viability trials of 50-acre or larger monoculture plantations established by several research institutions and private companies through cost-sharing programs. Much of the work in both stages was completed in the northcentral and northeastern regions of the U.S. and has focused on various *Populus* hybrids (Wright, in press).

This paper develops a general production model from these combined research efforts; focusing on the establishment and maintenance of commercial-sized *Populus* plantations. Unit costs for biomass are developed and compared to the current market price of similar wood supplies from domestic forests.

PROCEDURES

Research sponsored by SRWCP over the past decade provided a nation-wide appraisal of various silvicultural designs for SRIC biomass plantations. In an effort to summarize the central findings of these investigations, a woody biomass production model was developed and evaluated under a discounted cash-flow design.

Plantation Design and Operations

The design for the SRIC system uses *Populus* hybrid planted on good agricultural sites at a density of 850 trees/acre. Rotation length was expected to fall in the range of five to eight years, with two to three rotations anticipated from the initial planting. Selection of the optimum-length rotation was dependent on a discounted cash-flow analysis of production costs.

The establishment of SRIC plantations is similar to the procedures used for agricultural row crops, involving a fall preparation of the site and spring planting of the poplar cuttings (Perlack et al. 1986, Grado et al. 1988). During the fall period, the site receives a total- kill herbicide and mowing operation to remove old field vegetation, followed by offset disking to prepare the soil for planting. Lime may be added at this time, depending on soil acidity. In the spring, the soil is disk harrowed, with a pre-emergent herbicide applied to counter residual weed sources. In order to insure an adequate nutrient base for tree growth, a complete nitrogen-phosphorus-potassium fertilizer prescription is applied prior to planting, with additional nitrogen supplemented throughout the rotation (Table 1). Machine planting was assumed within the cost structure of the model, with the poplar cuttings produced at a self-owned nursery (Grado et al. 1988).

Additional herbicide applications were scheduled at the beginning of the first and second summer periods to limit weed growth. Protection from insect and canker attack was provided through a biennial insecticide/fungicide spray program. This represented an insurance cost in reducing the susceptibility of monoculture systems to infestations, such as cottonwood leaf beetle (*Chrysomela scripta*) and *Septoria* canker (Ostry et al. 1988).

Annual charges were also assessed for land rent, property taxes, and the managerial supervision of the entire production effort. In this manner, land and management were identified as specific inputs to the production system.

Table 1.--Establishment and maintenance costs for SRIC plantations, 1987-88.

Operations	Cost Components	$ /acre
FALL ESTABLISHMENT:		
Total kill herbicide	machine and labor	2.
	materials (1.3 lb/a)*	30.
Mowing/brushing	machine and labor	8.
Plowing	machine and labor	14.
Liming	machine and labor	3.
	materials (1 ton/a)	28.
Total		85.
SPRING ESTABLISHMENT:		
Disking	machine and labor	5.
Pre-emerg. herbicide	machine and labor	2.
	materials (1.6 lb/a)*	36.
Fertilization	machine and labor	6.
	materials (50 lb/a each N,P,K)	18.
Planting	planter and labor	9.
	materials (850 cuttings/a)	42.
Total		118.
SUMMER ESTABLISHMENT:		
Herbicide-year 1	machine and labor	2.
	materials (1.0 lb/a)*	22.
Herbicide-year 2	machine and labor	2.
	materials (1.0 lb/a)*	22.
Total		48.
MAINTENANCE:		
Insecticide/fung.	machine and labor	1.
(years 2,4,6)	materials (1.4 lb/a/appl.)**	9.
Fertilization	machine and labor	3.
(years 3,5,7)	materials (110 lb/a/appl. of N)	11.
Land rent	(5.0% of $690/a)	35.
Land taxes	(0.75% of $690/a)	5.
Managerial	labor and facilities	14.
	av. annual	66.

* combination of linuron/glyphosate.
** combination of Sevin/Dylox.

Plantation Yields

Growth and yield functions were developed from SRWCP data sets. These included yield information from partial and first rotations of several *Populus* systems planted at 700-1400 trees/acre and one double rotation system planted at 8500 trees/acre.

An estimated growth curve was developed for an 850 trees/acre plantation, having, as a targeted yield, 7 ovendry (OD) tons/acre/year. This production level was consistent with current research results and was considered a conservative estimate of future SRIC yields (Ranney et al. 1987). Recent summaries of record SRIC small-plot yields for *Populus* hybrid have shown production levels in the range of 6-9 tons (OD)/acre/year (Hansen 1988).

Biomass Costs

The unit cost of biomass was developed from a least-cost model for SRIC plantations (Strauss et al. 1990):

$$C = \frac{\left(\frac{R}{i} + \frac{T}{i}\right) + \left(\frac{E(1+i)^n}{(1+i)^n - 1}\right)}{\frac{Y_t}{(1+i)^t - 1}} \qquad (1)$$

where,

C = biomass cost, per unit of yield
R = annual land rent and taxes, per unit area
T = annual maintenance costs, per unit area
E = establishment costs, per unit area
Y_t = yield, per unit area
t = rotation age in years
n = plantation life expectancy in years
and i = real interest rate.

Under this formula, unit costs are a function of the discounted cash flows originating from the establishment and annual operations of the SRIC system and the discounted yields of the plantation. Annual costs, including land rent, taxes, and maintenance, were discounted as annual perpetual series. Established costs were compounded to end of the plantation's life expectancy and then discounted as periodic perpetual series. It was assumed that the requirements and costs of reestablishing a new plantation would approximate those followed in the original establishment phase. Yields were discounted as perpetual periodic series specific to their individual rotation lengths. The plantation's life expectancy was based on the number and length of rotations in any given analysis.

A 5% real rate of return was used throughout the analysis. This represented a compromise between the 6% historic real rate identified for corporate capital (Klemperer 1979) and the 4% real rate expected on new long-term investments (Row et al. 1981).

Establishment and Annual Operating Costs

Estimated costs for the individual operations were developed from the SRWCP data base and are reported in U.S. dollars for the 1987-1988 period (Table 1). Contract charges for the establishment and annual operations of commercial-sized plantations compared well to previous models of SRIC systems (Lothner et al. 1985, Perlack et al. 1986, Grado et al. 1988). Variations in costs were largely attributed to the differences in equipment and prescribed materials used on alternate sites. The final budget reflected the establishment and annual operations of a site having good aspect and soil quality.

Establishment costs totaled $250/acre, including the discounted cost of the second-year herbicide operation (Table 1). Herbicide operations were 47% of establishment costs, with materials constituting over 90% of this expense. Land preparation and planting were 31% of establishment costs, with 54% of this expense tied to the poplar cuttings (Grado et al. 1988). First-year liming and fertilization constituted the final 21% of establishment costs.

Annual maintenance included additional fertilization on an alternate year basis ($14/acre/application) and the application of insecticides/fungicides on an alternate year schedule ($10/acre/application). In addition, an annual managerial cost of $14/acre was assessed for administrative and personnel requirements (Strauss et al. 1988).

Annual rent was assessed at 5% of the land value, with annual property taxes estimated at 0.75% of land value. Land was valued at $690/acre, representing the capitalized net return of a good corn production site (110 bu corn/acre/year). This was representative of the land values from several SRIC projects and was 20% above the 1988 U.S. average for farm real estate (USDA ERS 1988).

Growth and Yield

The projected growth of *Populus* hybrid represented an average function for first and second rotations (Table 2). Typically, the above-ground growth secured during the initial portion of the first rotation will be 20-40% lower than for comparable points in the second rotation due to the concurrent development of root systems in the first rotation.

Current annual increment (CAI) was projected to accelerate during the first five years, reaching a maximum of 10.5 tons (OD)/acre in the 5th growing season. As expected, mean annual increment (MAI) increased at a more gradual rate, attaining the targeted maximum of

7.0 tons (OD)/acre/year after the 6th growing season. The narrow range of MAI values in the 5th to 8th years reflected the high CAIs in the 3rd to 6th growing seasons.

Table 2.--Yields and cost of biomass for SRIC plantations.

Year	Yields (ton(OD)/acre)	Cost* - 2 Rotations ($/ton(OD))	Cost* - 3 Rotations ($/ton(OD))
3	13.4	27.11	23.80
4	23.4	19.28	17.35
5	33.9	16.03	14.68
6	42.4	15.11	14.02
7	48.9	15.19	14.23
8	53.3	15.95	15.07

* Discounted cash flow analysis at 5%.

RESULTS

Unit Costs of Biomass

The discounted cash-flow analysis of pre-harvest production costs under a two rotation system placed the least-cost solution in the 6th year at $15.11/ton (Table 2). Optimum rotation coincided with maximum MAI due to the compression of the plantation's growth function into a relatively short period. During this period, annual growth changes were more volatile than the respective increases in cost, with the short time span also reducing the effects of discounting. Of further interest, extending the plantations into the 7th growing season increased the output cost by less than 1%. This reflected the modest decline of CAI in the 7th year.

The principal cost in the SRIC model was land rent and taxes, amounting to 42% of the total. Managerial costs, fertilizer and lime, and herbicides each represented about 14-15% of the total. The composite of land preparation, planting, and insecticide/fungicides was the final 15% of expenses.

If the plantations could support a third rotation under the same yield pattern, the least-cost solution would also occur in the 6th year, with the unit cost reduced to $14.02/ton (Table 2). The 7% cost reduction resulted from the extended prorate of the establishment costs over the additional rotation.

Harvesting costs were based on a feller/buncher unit designed for closely-spaced, small-diameter trees (Stokes et al. 1986, Woodfin et al. 1988, Strauss et al. 1988). The harvested

material would be chipped in the field, and transported 25 miles with tractor-trailer units. Under this design, harvesting and transportation costs were estimated at $18/ton (OD). A final delivered cost of $36/ton (OD) was established for the two rotation system on the basis of an 85% net delivery of plantation yields.

DISCUSSION

Marketing and Pricing Considerations

Given the financial profile for SRIC wood production, some question remains as to whether this venture represents a viable option for northeastern U.S. In terms of fiber production, our hardwood forests are typically overstocked with respect to available markets. Softwoods are the principle force in pulpwood markets, with the short-fibered hardwoods representing a certain drudge on the market. On the basis of stumpage prices, softwoods typically carry two to three times the value of hardwoods (Peterson 1990).

An exception to this hardwood situation is provided by aspen (Populus tremuloides) in the Lake States. This lighter weight and faster growing species has generated a major roundwood market among the particleboard and paper industries. Current prices for delivered, unpeeled aspen in the Lake States are $38-40/ton (OD) (Peterson 1990). Of interest, aspen shares many of the mechanical and chemical properties of the hybrid poplars, with both species groups adaptable to the production of ethanol. Several ethanol-conversion studies have established feedstock prices in the range of $38-42/ton (OD) (Wright 1989, Bergeron et al. 1989). As such, SRIC biomass at $36/ton (OD), delivered, would be competitive with domestic aspen and also meet the expected feedstock prices for ethanol production.

In many respects, *Populus* biomass is a unique product. It is homogeneous in terms of either physical or chemical properties and can be genetically engineered for sensitive chemical processes (Blankenhorn et al. 1984). Furthermore, SRIC designs would permit a constant and sustained rate of production. Probably the best example of commercial SRIC *Populus* production in the U.S. is the 7000 acres of plantations developed by the James River Corporation along the Columbia River in Oregon. These plantations were initiated in 1984 in response to hardwood shortages among Pacific Northwest paper mills (Stanton 1987). Their general design and estimated output levels parallel the SRIC model presented in this paper.

Plantation and Allied Production Costs

Sensitivity analysis was used to evaluate the parameters having the greatest impact on pre-harvest and delivered costs. The pre-harvest cost was most sensitive to land costs and biomass yields, with harvesting and transportation having the greatest effect on total delivered cost. A further address of these factors was considered.

The general SRIC model included land rent and taxes as specific cost requirements. These charges, representing 42% of pre-harvest costs, were a direct reflection of land's value in other agricultural pursuits. In order for the SRIC proposal to compete for this resource, comparable or higher net returns will be required from the biomass enterprise. The option of using lower priced, marginal lands for SRIC plantations would reduce this cost impact but, in all probability, would also lower yield potentials. Further investigations of the economic niche of SRIC production within the various gradients of land may be required.

Plantation yields had the greatest impact on pre-harvest unit costs. If, for example, yields were reduced by 25%, plantation costs would increase by 32%. In contrast, a 25% increase in output would decrease pre-harvest costs by over 20%. A comparison of record experimental yields to actual field yields among agricultural crops and for SRIC Populus plantations (Hansen 1988) suggested that the immediate field potential for commercial SRIC plantations may only be within the range of 4.5 - 5.5 ton/acre/year. Further increases were considered possible, with the realization of future gains dependent on cultural and breeding research. More recent estimates of growth in commercial-sized *Populus* plantations by Wright (in press) point to the 7 - 9 ton/acre/year range as an attainable objective. This range has also been verified by results from commercial-sized field trials in northcentral U.S.

The particular design of a SRIC plantation is paramount in determining production success. This involves a careful matching of clonal hybrids to the particular growing site and a successful implementation of the prescribed cultural strategy. Attention to these design prerequisites will, in large measure, enhance the degree of success in SRIC ventures.

In order to move SRIC biomass to the market, major harvesting and transportation costs have to be met. These costs, plus those associated with material loss, more than doubled the final delivered cost of biomass in the SRIC model. Currently, most SRIC harvesting systems represent either developing technologies or adaptations of existing systems used in native forests. Cost reductions can be anticipated, as harvesting equipment is better designed for the needs of biomass plantations (Stokes et al. 1986, Woodfin et al. 1988). However, a current stalemate exists in the development process owing to the lack of investments in SRIC plantations and allied conversion technologies. In all likelihood, the feasibility of energy and fiber technologies need to be first resolved before further attention is placed on SRIC harvesting equipment.

SUMMARY AND CONCLUSIONS

A general model of a commercial-sized SRIC biomass plantation was developed from a series of research programs coordinated by the U.S. Department of Energy's Short Rotation Woody Crops Program. The model centered on the use of *Populus* hybrid, planted on good quality agricultural sites at a density of 850 cuttings/acre. Establishment costs amounted to $250/acre, with weed control and planting representing 47% and 21%, respectively, of this total expense. Average annual maintenance, including the prorated cost of land, amounted to $66/acre/year.

Plantation yields were projected to reach a maximum MAI of 7 tons (OD)/acre/year by the sixth year. Discounted cash-flow analysis of cost and growth parameters indicated that two 6-year rotations would achieve a pre-harvest unit cost of $15/ton. Land was the dominant cost factor, representing 42% of the unit cost. Managerial costs, fertilizer and lime, and herbicides each contributed about 15% to the unit cost. Additional harvest and transportation requirements placed the delivered cost of *Populus* biomass at $36/ton.

In its proposed operational form, SRIC biomass would be competitive with aspen from domestic forests and also fulfill the cost requirements of a feedstock for ethanol production. The major cost of land within the financial model suggests the need for evaluating less expensive and lower quality land resources. However, the linkage between site quality and yields represents a critical balance in the cost equation. Although improvements in harvesting and transportation technologies could provide major cost reductions, further developments will probably depend on some form of industrial commitment to biomass production.

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HARVESTING IMPACTS ON STEEP SLOPES IN VIRGINIA

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Abstract: Ten tracts in the mountains of western Virginia were intensively sampled to determine the type and extent of soil disturbance from ground-based logging and the attendant erosion risk. Average slopes for the tracts ranged from 21 to 43 percent. Logged slopes exceeded 50 percent. All tracts surveyed were logged prior to the push for voluntary Best Management Practices and had been completed at least three months before the survey was conducted. Two logging methods were observed: skidding overland directly from stump to roadside, and the use of bladed skid trails. Overland skidding, when topography permits, was found to cause less disturbance and soil compaction. High risk of soil movement and erosion was associated with a relatively few, high-risk, spots left after harvesting, rather than the general application of the system.

INTRODUCTION

The increasing demand for Appalachian forest products, both lumber and pulpwood, coupled with increased environmental awareness, has renewed interest in the impacts of ground-based logging systems on steep slopes. Alternative systems such as helicopter, balloon and cable ways may find limited application on sites were the combination of volume, value, and ecological sensitivity can justify the additional expense required. Rubber-tired skidders with their advantages of cost, flexibility, modest skill requirements, and reduced weather sensitivity are the most economical means of removing timber from moderately steep (30-40% slopes) sites and will likely remain the method of choice from an operational standpoint.

The harvesting impacts of ground systems on these sites fall into three broad categories: those which increase erosion risk, those which reduce site productivity, and those which alter the aesthetics of the tract. Erosion risk increases as a result of removing the forest cover (a largely unavoidable consequence of timber harvesting), removing the litter layer, opening of drainage channels up and down the slope, and altering soil structure to the extent that infiltration rate is reduced. Soil compaction is perhaps the greatest threat to site productivity, especially if root penetration is inhibited and soil porosity is lost. Logging alters the canopy profile, but the most objectionable impacts are the exposure of mineral soil, imposing straight lines of haul roads and skid trails on the natural topography and leaving broken stems and piles of debris.

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The literature is replete with articles describing the impacts of harvesting on various soil types (Dickerson 1968, Dryness 1965, Froelich et al. 1981, Krag and Webb 1987, Mace 1970, Reinhart et al. 1963, Reisinger et al. 1988, Willis 1971). The diverse nature of forests, forest soils, past land management practices, and research objectives make it nearly impossible to draw broad generalizations from this research base. Harvesting technology has changed rapidly over the period of this research as well. Direct-drive machines of the early 70's have been supplanted by power-shift transmissions. Hydrostatic drive machines are becoming more common. Each advancement in drive trains alters the manner of soil machine interaction.

Major changes have occurred in tire and track design as well. Tire widths have increased, carcass construction has improved, and tread designs have been adapted to specific applications. Undercarriage design, balance, and drives for crawler tractors have improved over the same period. Soil effects have often driven these design changes. Lumping a new power-shift machine mounted on wide tires into the same category as a pre-1970's, direct-drive machine on modified agricultural tires negates much of this effort.

The change in technology has expanded the range of harvesting options. Wood form may range from log length to full tree. The ability to skid along the contour on steep slopes has increased, landing size and location can be better adapted to the terrain, and forest road designs altered to take advantage of more powerful and maneuverable trucks.

The fundamental divisions of the forestry profession often insulate those concerned with the effects of operations on the forests from those concerned with reducing those effects. The silviculturist is measuring the impacts of a technology that is at best current, more likely already superseded, on stand development. The harvesting specialist--whether forester, engineer or other professional--is concerned with the impacts of current and future technology and practices. The two can normally exist in blissful isolation until an external disturbance focus an interaction.

The recent move to Best Management Practices has been such a destabilizing influence. The various states have been involved in developing guidelines for forestry operations either voluntarily or at the direction of their legislatures. The basis for these guidelines has been a mix of published research findings, experience, and what the state next door is doing. The fit with the current activities and local conditions is seldom tested except by empirical methods based on improvement in the environmental variable of interest.

This study was structured to assess the harvesting impacts from current ground-based operations on slopes greater than 30 percent in the mountains of central Virginia. The objectives of the study were:

a. to document the form and extent of soil disturbance and compaction associated with conventional operations.

b. to identify this disturbance with specific forms of causality in planning, operation and closure, and;

c. to make recommendations for reducing these impacts in future operations.

METHODS AND PROCEDURES

The cooperators in the project--Georgia Pacific, Nekoosa Packaging, the U.S. Forest Service, and Westvaco--were asked to submit a list of tracts from the central Virginia region which had been or would be clearcut between September 1988 and September 1989 by ground-based systems, and which had average slopes in excess of 30 percent. The tracts were to be "forwarded" without consideration of the apparent "quality" of the logging job. Twenty-nine tracts were identified, of which 10 were selected for detailed study. The final selection attempted to assure a diversity of ownership, soil type, season of harvest, equipment, harvesting strategy, and skidding practices (Tables 1 and 2). None of the tracts was visited prior to selection. The contractors performing the harvest did not know the tracts were to be included in a study of this type. Virginia was updating its Best Management Practices activity at the time the tracts were cut, but compliance was still voluntary and inspections had not begun. Consequently, there was no indication that "special" precautions were taken by the contractor or crew during the harvest.

Designated skid trails are commonly recommended for steep terrain (Froelich et al., 1981). The research basis for much of this has come from the Pacific Northwest or Scandinavia (Wasterland 1987). The alternatives had not been fully tested on Appalachian forests. The 29 tracts provided were roughly evenly split between those harvested using designated bladed trails and those skidded overland. The split was maintained as an important variable in the study.

Tract orientation relative to the contour appears to be a major factor in determining which method will be used. Two of the tracts were harvested by the same contractor, using different skidding methods. Tracts laid out with the long axis running perpendicular to the contour were skidded using overland methods; tracts with the long axis parallel to the contours required bladed skid trails.

The cooperators provided maps and description of each tract. Additional information pertaining to soils, weather conditions during and following the harvest and other descriptive material was collected. A two-person study team visited each tract during the summer of 1989. The general characteristics of the tract were documented: the location of roads, landings, skid trails, rock outcrops, streams, and drainages, along with other gross tract features. This was supplemented by circular plots, 20 feet in diameter installed at 50-foot intervals along contours. The area encompassed by these plots ranged between 5 and 8 percent of the tract surface area, depending upon the amount of land area reserved for wildlife plots, streamside management zones, or deemed unloggable because of rock outcrops, bluffs, or low timber quality.

Table 1.--Summary of physical study-tract characteristics.

Tract	Soil Type	Ownership	Rainfall During Harvest	Average % Slope	Size (acres)	Aspect
A	silt loam and stoney loam[1]	industry	13.59 in. 3 months	43	11.0	west
B	shaly silt loam[2]	industry	11.53 in. 4 months	33	15.7	north
C	sandy loam to loamy sand[3]	public	14.12 in. 4 months	35	16.1	northwest
D	stoney, fine sandy loam[4]	private	12.02 in. 3 months	21	*20.8	northwest
E	sandy loam to loamy sand [3]	public	13.45 in. 4 months	27	40.4	southwest
F	sandy clay loam silt loam [5]	public	6.84 in. 3 months	29	18.0	southeast
G	shaly silt loam[2]	industry	22.65 in. 4 months	37	19.8	east
H	stoney, fine sandy loam[6]	public	17.12 in. 3 months	25	23.5	northwest
I	stoney, fine sandy loam[4]	private	22.70 in. 4 months	28	39.0	northwest
J	shaly silt loam[7]	public	13.46 in. 3 months	31	19.9	east

[1]Sequoia and Dekalb.
[2]Berks-Weikert.
[3]Leetonia.
[4]Edneytown.
[5]Landig-Berks.
[6]Edneytown-Peaks-Thurmond.
[7]Berks-Weikert-Rushtown.

Table 2.--Summary of study-tract harvest characteristics.

Tract	Season of Harvest	Skid Trail Type	Equip. (make/ model/tire size)	Skid Direction	Cubic Feet Harvested (per acre)
A	summer	overland	Timberjack 240E 23.1x26	15% uphill 85% down	2332
B	fall	overland	Timberjack 240E 23.1x26	96% uphill 4% down	3421
C	winter	overland	CAT 518 23.1x26	1% uphill 99% down	1509
D	spring	overland	Timberjack 230D 23.1x26	80% uphill 20% down	1734
E	summer	overland	John Deere 640 23.1x26	65% uphill 35% down	602
F	winter	bladed/ overland	CAT 518 18.4x34	35% uphill 65% down	1702
G	summer	bladed	Timberjack 450 23.1x26	95% uphill 5% down	2266
H	spring	bladed/ overland	Timberjack 230/ 450 18.4x34	94% uphill 6% down	2293
I	summer	bladed	Cat 518 23.1x26	2% uphill 98% down	2301
J	spring	bladed	John Deere 18.4x34	92% uphill 8% down	1072

The soil surface characteristics within each plot were mapped and classified using a descriptive system adapted from Miller and Sirois (1986):

1. Undisturbed: Litter in place and undisturbed; no evidence of machine traffic or compaction.
   Subclasses: Non-soil (rock outcrops, stumps, etc.)
   Debris piles (slash over 30 cm deep)

2. Slightly disturbed -- any of the following three conditions:

    a. Litter removed and mineral soil exposed
    b. Mineral soil and litter mixed
    c. Mineral soil deposited on top of litter to a depth of 5 cm
        Subclasses: Compacted -- obvious depression caused by passage of log or machine
        Debris piles

3. Severely disturbed: Surface soil removed and the subsoil exposed.

    a. Cut or rutted soil remaining in its original location
    b. Pushed or filled soil from harvesting or earthwork activities
        Subclasses: Compaction -- obvious depression caused by passage of log or machine
        Debris piles

4. Depression deposits: Sedimentation of soil in holes, troughs, or behind debris dams.

In addition, a cone penetrometer was used to measure differences in soil mechanical strength between the above categories and subcategories measured in each plot. If the entire plot was disturbed, an unimpacted measurement was taken from the nearest undisturbed area. (Penetrometer readings were not recorded for depression deposits because of the small area and major shift in soil structure with depth.) Slope was recorded at each plot center, and skid direction (uphill/downhill or along contour) was noted. Measurements of the depth of organic layer, soil texture, and other characteristics for each disturbance class were taken. Live brush density and the parameters required for the universal soil loss equation adapted to forested sites were recorded. Plots were installed in skid trails, landings and roads as well as the forest floor to assure all disturbance classes were documented.

A total of 1120 plots was established on the 10 tracts. These were further supplemented by measuring and documenting engineered earthworks, such as roads and landings, and non-engineered earthworks such as skidder blade work on skid trails or water bar construction. These on-the-ground measurements were supplemented by scaled measurements from aerial photographs taken of each tract.

RESULTS AND DISCUSSION

The Universal Soil Loss Equation was used to estimate potential soil movement, in terms of tons per acre per year, from each plot. Soil movement, estimated in this manner, means the soil is moved from its place of origin and should not be equated with potential stream sedimentation. The forest floors after harvest on most of the plots, had sufficient litter layer and micro topography to slow runoff and force deposition of much of the soil near the place of origin.

Figure 1 from Tract A shows the common pattern. No soil movement was expected for a majority of the plots and moderate movement for most of the others. Each tract contained a few plots with a very high risk. Five hundred fifty of the 1120 plots had an estimated zero risk of soil movement. Soil movements of less than 1 ton per acre per year were estimated for an additional 173 plots. Each tract contained a few "hot spots" with very high erosion risks. Maximum individual plot measurements for the 10 tracts ranged from a low of 6 tons per acre per year to a high of 158. These "hot spots," without exception, occurred on a road, landing, or skid trail. The values also reflect the risk during the first year after harvest and would decline rapidly as the tract revegetates, and exposed soil on roads, tracts, and landings are covered with grass.

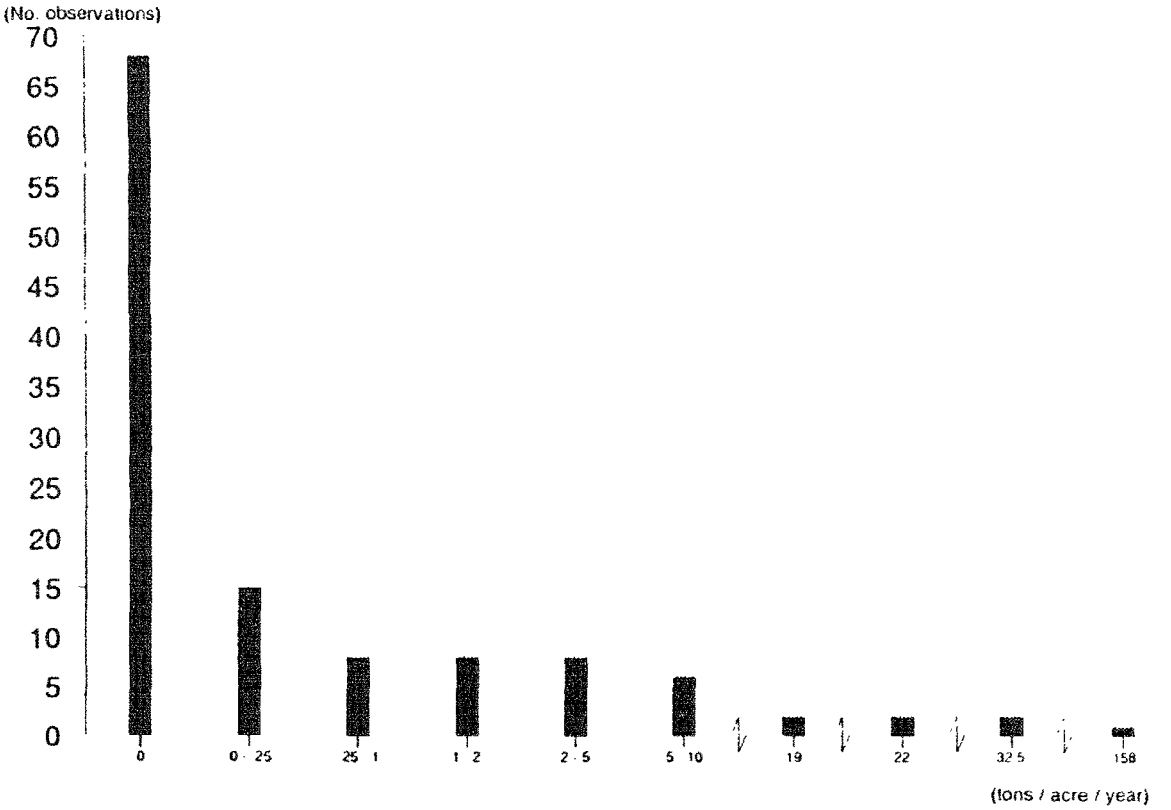

Figure 1. Frequency of potential soil movement estimates from the Universal Soil Loss Equation, based on estimates from 121 plots on Tract A.

Potential net soil loss (off-site sedimentation) was estimated for the entire tract using average values from plot data and a total tract parameter to estimate on-site storage. The results, shown in Figure 2, indicate that half of the tracts would lose less than 0.25 tons per acre during the first year after harvest. Only one of the tracts had an estimated loss of greater than 1 ton per acre per year. Tracts A through E were harvested using overland skidding methods, while F through J had systems of designated and bladed skid trail.

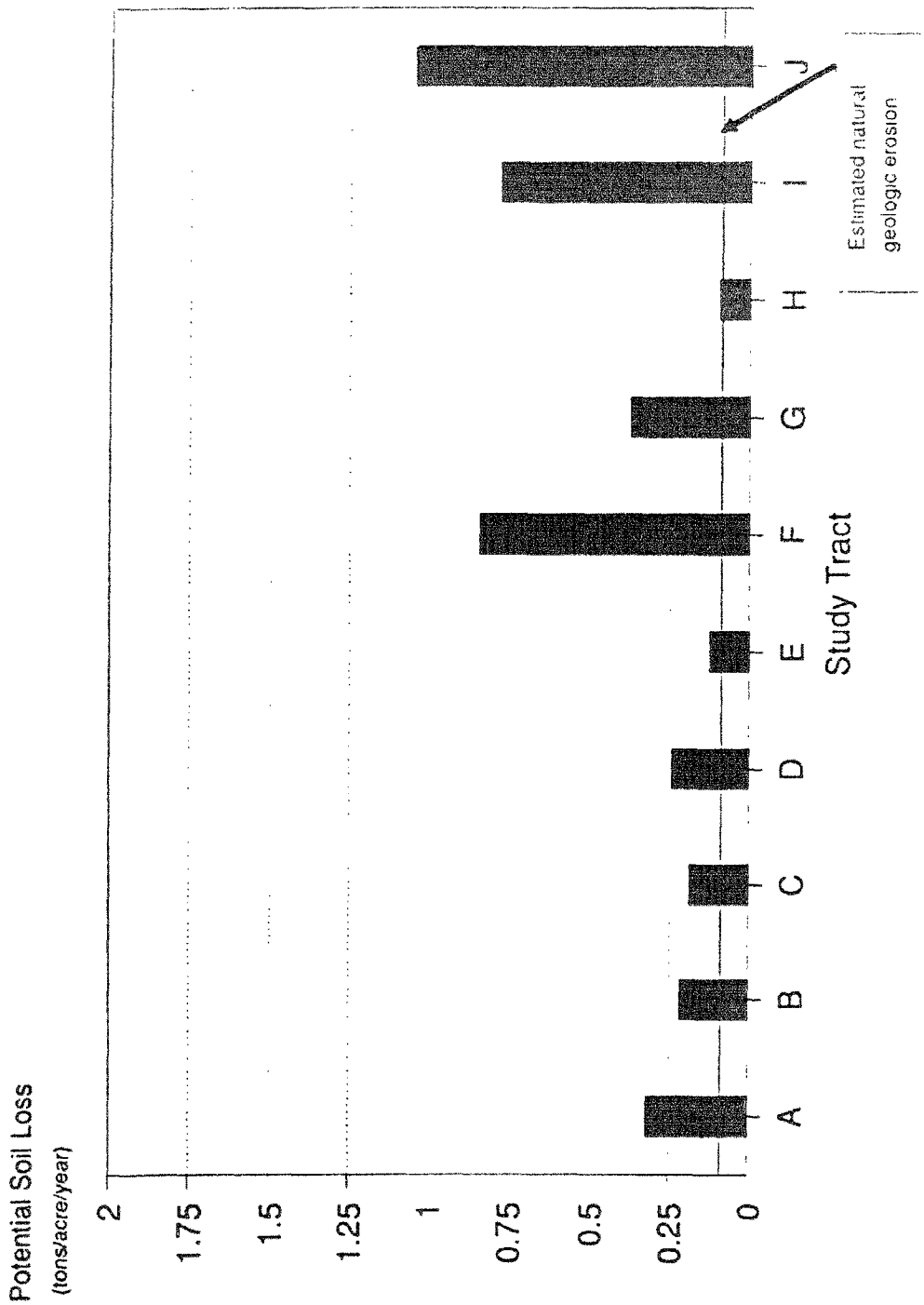

Figure 2. Potential soil loss estimates using the Universal Soil Loss Equation modifies for forested land.

Table 3 was developed by averaging the soil loss estimates for each of the sample plots to develop a tract average rate of soil movement. To demonstrate the importance of tract closure, the average was recalculated assuming the two and five highest risk plots were treated, reducing the movement risk to another zero. In most cases, treating the two highest risk sites reduced the average by 30 to 50 percent. Treating the five worst sites results in virtual elimination of soil movement on many of the tracts.

Table 3.--Potential soil movement estimates in terms of median, arithmetic average, and treated averages using field plot data.

Tract	Median	Arithmetic Average	*Added Closure Average	**Intensive Closure Average
A	0	3.37	2.10	1.49
B	0.04	2.86	2.21	1.90
C	0	0.41	0.27	0.14
D	0	0.37	0.27	0.12
E	0	0.21	0.12	0.05
F	O	1.08	0.83	0.58
G	O	2.94	2.01	1.06
H	O.01	1.17	0.60	0.42
I	O	1.01	0.66	0.45
J	O	1.17	0.26	0.04

* Arithmetic average assuming the two highest soil movement estimates equal zero.
** Arithmetic average assuming the five highest soil movement estimates equal zero.

SUBSOIL DISTURBANCE

Harvesting activities disturbed less than 30 percent of the tract area on all of the 10 tracts (Table 4). No differences could be found when overland skidding was compared with designated trails.

Table 4.--Comparison of undisturbed area (%) on tracts with overland skid trails and bladed skid trails using a rank sum test.

Tract	Percent Undisturbed Area Using Overland Skid Trails	Tract	Percent Undisturbed Area Using Bladed Skid Trails	Rank
D	71			1.0
		G	74	2.5
		H	74	2.5
		F	75	4.5
		J	75	4.5
B	79			6.5
C	79			6.5
		I	81	9.0
A	81			9.0
E	81			9.0
Total Ranks:	32		23	

Areas characterized by slight disturbance ranged from 11 to 15 percent on nine of the tracts (Table 5). One tract had a low of zero percent resulting from an extensive bladed trail system which reduced machine travel over the site. These values correspond with the findings of Miller and Sirois (1986), who estimated that 13% of the area of tracts they studied were left in this condition.

Six to 14 percent of the tracts' areas were left in a severely disturbed condition. Severe disturbance was most commonly associated with the construction of skid trails rather than skidder damage. Water-bars, haul roads, and landings were major contributors as well. A significant difference (alpha < 0.008) between skidding methods was found using the Wilcoxon Rank Sum Test (Table 6). Overland skidding resulted in less severe disturbance. The values shown for overload skidding include the disturbance associated with water bar construction. Excessive use of waterbars on overland trails (following BMP formulas) often resulted in greater risk of soil movement than if they had been omitted.

No significant differences were found in the percentage of the areas in the non-soil category, under debris piles or covered with depression deposit between skidding methods.

The percent of the tract area in skid trails did vary between skidding methods (Table 7). Overland skidding resulted in less skid trail area then using bladed trails (alpha = 0.075).

Table 5.--Comparison of slightly disturbed area (%) on tracts with overland skid trails and bladed skid trails using a rank sum test.

Tract	Percent Slightly Disturbed Area Using Overland Skid Trails	Tract	Percent Slightly Disturbed Area Using Bladed Skid Trails	Rank
		I	6	1.0
E	11			3.0
		F	11	3.0
		H	11	3.0
A	12			5.0
B	14			6.5
		G	14	6.5
C	15			9.0
D	15			9.0
		J	15	9.0
Total Ranks:	32.5		22.5	

Table 6.--Comparison of severely disturbed area (%) on tracts with overland skid trails and bladed skid trails using a rank sum test.

Tract	Percent severely disturbed area using overland skid trails	Tract	Percent severely disturbed area using bladed skid trails	Rank
B	6			1.5
C	6			1.5
A	7			3.0
E	8			4.0
D	10			5.5
		J	10	5.5
		G	12	7.0
		I	13	8.0
		F	14	9.5
		H	14	9.5
Total Ranks:	15.5		39.5	

Table 7.--Percent of total study tract surface area in noticeable skid trails.

Tract	Tract Percent in Overland Trails	Rank
A	4	2.5
B	3	1.0
C	9	8.5
D	6	5.5
E	4	2.5
		Total 20

Tract	Tract Percent in Bladed Trails	Rank
F	6	5.5
G	9	8.5
H	7	7.0
I	5	4.0
J	10	10.0
		Total 35

Compaction

The slightly disturbed/compacted class included from 1 to 5 percent of the tract areas. The resulting small sample size made it difficult to assign significances to these data. Values in italics in Table 8 are based on a sample size of less than 10. While no tests of significance were attempted, the absolute values indicate that the field crew's ability to identify compaction was good.

SUMMARY

Using conventional ground skidding systems left between 70 and 80 percent of the surface soil on the 10 tracts in an undisturbed condition. Six to 15 percent of the area had been slightly disturbed, a condition which would increase the risk of soil movement on the tract but not impact tree growth. Some compaction did occur within the slightly disturbed classification, but the amount (1 to 3 percent of the tract area) was too small to develop inferences concerning tree growth or water infiltration. Six to 14 percent of the tracts were left in a severely disturbed condition, usually as the result of construction skid trails, haul roads and landings.

Table 8.--Average change in mechanical strength (psi) between paired data samples of the undisturbed class and listed class.

Slightly disturbed class (Tract)	A	B	C	D	E	F	H	I	J
% of tract occupied by this class:	12	14	15	15	11	11	11	6	15
(Depth inches):									
1	-4	0	5	*13	-2	0	*30	*20*	6
2	11	1	1	*29	-2	-3	*33	*34*	7
3	14	4	-7	*39	4	2	*50	*39*	9
4	*24	11	-26	*40	12	-11	3	*67*	-5
5	*40	5	-28	*27	6	-11	25	*76*	-25
6	*59	2	-31	*26	-8	-7	28	*71*	-24

Slightly disturbed/compacted class (Tract)	A	B	C	D	E	F	H	I	J
% of tract occupied by this class:	2	2	2	5	2	1	1	1	3
(Depth inches):									
1	*35*	*13*	*104*	*63	15	*25*	*33*	*139*	*106*
2	*90*	*26*	*132*	*70	28	*48*	*54*	*146*	*131*
3	*138*	*47*	*145*	*84	18	*110*	*56*	*191*	*119*
4	*137*	*57*	*98*	*79	42	*52*	*15*	*173*	*99*
5	*135*	*63*	*89*	37	23	*68*	*3*	*169*	*71*
6	*140*	*70*	*68*	*57	16	*63*	*14*	*169*	*91*

* represents values significantly different at the 95% confidence level.
(00) had less than ten observations within the sample.

Skidding method had an effect on both the extent of severe disturbance and the potential off-site sedimentation. Overland skidding resulted in significantly less severe disturbance and generally less risk of off-site sedimentation.

Most of the risk of soil movements was associated with a relatively few, very vulnerable spots on each tract. Additional closure effort to reduce this vulnerability would have cut the average soil movement risk nearly in half.

CONCLUSIONS AND RECOMMENDATIONS

Conventional, ground-based harvesting systems can be used on slopes greater than 30 percent in the central Virginia highlands without significant risk to water quality or subsequent stand development. A reasonable degree of care and management is assumed.

High-risk areas -- those with fine-textured soils, poor drainage, and low rock content should be avoided during wet weather. Harvesting contractors should be allowed some flexibility in scheduling or contract life to reduce the urgency of cutting these tracts when the risk of damage to both the site and the equipment is greatest.

Tract boundaries should be laid out to favor overland skidding on slopes of less than 45 percent. On slopes greater than 45 percent, safety and common sense dictate the use of blade skid trails.

Tract closure is an especially important means of reducing erosion and sedimentation risk. A few very vulnerable spots accounted for a large share of the estimated soil movement and soil loss. Waterbars, if properly installed can be quite effective in reducing these risks; overuse can increase soil loss. Other techniques of slowing water flow rates on roads and trails which require less soil disturbance should be investigated. Alternatives include using logging debris, siltation barriers, paper machine felts, or other products entering the market.

Vegetation is the ultimate protector of the site. Leaving the site in a condition such that trees, grasses, shrubs and forbs can quickly reoccupy the tract is the best solution to minimizing runoff and sedimentation.

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IMPACT OF TIMBER HARVESTING ON RESIDUAL TREES IN A CENTRAL HARDWOOD FOREST IN INDIANA

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Abstract: Residual stand damage resulting from conventional ground-based logging operations was assessed on six oak-hickory, upland hardwood timber sales in south central Indiana. Two areas were harvested each year--1984, 1986 and 1988--using a combination of individual-tree and group selection methods. An average of 2.6 trees per acre was damaged, and 70% of the exposed sapwood wounds were larger than 100 in.^{2} in size. Skidding caused 71% and felling 29% of these injuries. Study results indicate that the size of the wounds and the percent damage to the larger diameter classes and to higher value species is greater than reported in previous studies. The data suggest that much of the skidding damage was caused by carelessness, and could have been avoided. Damage to residual stands can be kept to a minimum by closer supervision during logging, greater operator care when skidding, and better pre-harvest planning.

INTRODUCTION

Damage to residual trees continues to be a concern of forest managers responsible for implementing individual-tree selection harvests or other types of partial cuts in hardwood forests. Damage may be limited to skinned bark and exposed sapwood, root damage, or broken branches in the crown, any of which can result in decreased vigor and quality. Or the damage may be severe enough to kill the tree. When a tree is wounded, certain physiological changes and cell differentiation occurs in the area surrounding the wound, and the wound usually becomes sealed off from the rest of the tree (Shigo 1966). Most decay and defect problems in trees originate in and spread from some kind of wound, and the impact of these wounds is likely to increase with time (Shigo 1966, Shigo and Larson 1969, Shigo 1984, Carvell 1984). The type and severity of bole damage; the susceptibility of the tree species present; and the rate of wound healing (which may be indirectly related to discoloration or linked to sources of decay) are also important considerations.

Residual tree damage is an inherent aspect of partial cutting, but the level of damage should be minimized to assure future product quality. Recent emphasis on "quality" in the

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manufacturing sector demands that foresters examine the impact of current hardwood logging practices on the production of quality hardwood products. This paper reports on skidding and felling damage to residual trees for six timber sale areas where individual-tree selection and group selection harvesting was conducted over a six-year period. The objectives of the study were to obtain post-harvest data on the impact of harvesting operations on the residual stand; to assess the impact of damage on log quality; and to determine specific guidelines for minimizing stand damage when logging a central hardwood forest (Hammond 1988).

METHODS

Data were collected from six timber sale areas on the Morgan-Monroe State Forest located in the Brown County Hills section of the Highland Rim Natural Region of Indiana (Homoya et al. 1984). This section of Indiana is characterized by deeply dissected, well-drained, uplands underlain by siltstone, shale, and sandstone soils. The topography consists of ridges with moderate to steep slopes ranging from 10 to 70%. The forest type is predominantly oak-hickory with a mixture of other hardwoods such as yellow poplar, white ash, sugar maple, beech, sassafras, and cherry.

General site information for the six study areas is provided in Table 1. Each of the six harvest areas was similar in size, volume of timber that was removed, soil type and terrain. The same type of 4-wheel-drive rubber-tired skidding equipment was used in each. All timber sales were logged during the fall with two areas each harvested during 1984, 1986 and 1988. Sampling design was not replicated; but two similar areas were evaluated every two years over a 6-year period. The areas ranged from 57 to 108 acres in size with the average being 78 acres, and the volume removed averaged 1.41 MBF per acre (1000 board feet). Data on residual basal area prior to harvesting were not available.

Harvest trees on each sale area were marked by Indiana Division of Natural Resources (IDNR) foresters using a combination of individual-tree selection and group selection methods. The group selection method resulted in openings of various sizes; as shown in Table 1, the average number of openings was 2.3 and average size was 5.3 acres. All areas were logged by independent contractors using chainsaws for felling, and cable skidders for moving tree lengths to the landing area. Trees were topped at a merchantable diameter of approximately 8.0 inches and skidded full length (i.e., 18-40 feet). Landing or deck areas were designated by IDNR foresters, but skid trail locations were determined by individual contractors. In all cases, the logging contractors had no prior knowledge that these tracts would be evaluated for residual stand damage.

Residual stand damage data were obtained from 179 permanently marked 0.2 acre plots centered on transect lines uniformly distributed throughout each study area. Transect lines were spaced 5 chains (330 feet) apart and perpendicular to the topography; plot centers were placed 4 chains (264 feet) apart along the transect lines. This sampling design approximated a 20% sampling intensity.

Table 1.--General information for the six study sites located on Morgan-Monroe State Forest, Indiana.

Study Site	Year of Harvest	Tract Size (acres)	Volume Removed (MBF/acre)	Number & Acreage of Openings[1]	Residual Basal Area[2]
A	1988	71	1.43	-- (0.0)	36.9
B	1988	70	2.19	2 (5.0)	58.8
C	1986	57	1.70	2 (6.6)	45.7
D	1986	108	1.37	4 (9.7)	72.7
E	1984	84	2.49	2 (6.0)	48.6
F	1984	76	1.77	8 (15.0)	58.4
Mean		78	1.41	2.3 (5.3)	56.4

[1]Per tract.
[2]Basal area (square feet) per acre with openings.

Damage to residual stems was determined by examining all trees located within the sample plot boundaries (53-foot radius). A harvest-inflicted wound was defined as bark removed accompanied by exposure of cambium or sapwood on stems 6 inches dbh or larger, damage to branches or crown, and/or root damage. Destroyed, bent, or leaning trees less than 6 inch dbh were not recorded. Wound characteristics were recorded by species and dbh; data collected included:

1. Number of wounds per tree;
2. Position of each wound above groundline (to the nearest 1.0 foot);
3. Size of exposed sapwood wound (to nearest square inch);
4. Maximum depth of wound (to nearest 0.1 inch);
5. Percent crown damage (was determined ocularly); and
6. Root damage (was noted, but not measured).

Skid trail patterns and landing locations were mapped for each timber sale area. A hand-held compass and 150-foot steel tape were used to record bearings and distances for mapping primary and secondary skid trails throughout each tract. This information was digitized into a geographic information system (GIS), and the location of skid trails and landing areas were plotted along with study area transect lines, plot centers, contour lines, and haul roads.

RESULTS AND DISCUSSION

Number of Trees Damaged

Bark removals accompanied by sapwood exposure on stems 6 inches dbh or larger were the primary type of logging injury recorded. As indicated in Table 2, the average number of trees with exposed sapwood for all areas was 2.6 per acre, or 198.6 per tract. Area A had the fewest (1.9) injured trees per acre, one of the lowest volumes of timber removed (1.43 MBF/acre), and a low residual basal area (BA) of 36.9 ft.^{2}. In contrast, Area B had the highest number (4.0) of damaged trees per acre with one of the larger volume removals (2.19 MBF/acre) and residual BA (58.8 ft.^{2}). This pattern was not apparent in the results for the remaining study areas. The average BA of all residual stands was 56.4 ft.^{2} per acre (Table 1). These values include group selection openings which lowered the overall BA; when openings were not included, the average BA was 65.1 ft.^{2} per acre. Of the injured trees observed, 16 percent received multiple wounds with no particular pattern observed for any individual study area. Nyland and Gabriel (1971) also found that logging damage is often distributed irregularly throughout the stand, and the occurrence of logging wounds seemed independent of the density of the original or residual stand or the intensity of cut.

Size of Exposed Sapwood

The effect of exposed sapwood wounds on future stem quality is well documented, and depends on the severity of the injury. Previous research indicates that individual wounds greater than 100 in.^{2} are likely to cause decay (Nyland and Gabriel 1971). Exposed cambium wounds will callous and produce some decay in the butt log, but the damaged trees will rarely die because of these wounds. For this study, 70% of the wound sizes were greater than 100 in.^{2}, and the overall average size of tree wounds for all areas was 342.5 in.^{2} (Table 2). Area A had the smallest average wound size (179 in.^{2}) while D had the largest average wound size (535 in.^{2}). In a study in West Virginia on 50-70% slopes, Lamson et al. (1985) reported that less than 1% of the residual trees (4 trees per acre) had any wounds exceeding 100 in.^{2} in size. Their study found exposed sapwood wounds averaged 17, 39 and 26 in.^{2} for sapling, pole-size and sawtimber-size trees, respectively. In contrast to the West Virginia study, over half the wounds in this study were in the 150 in.^{2} or larger class (Figure 1).

Wound Depth and Position

A deep wound or gouge is of greater concern than bark abrasion or exposed sapwood. Wounds less than 4 inches wide tend to heal in as little as 2 to 4 years; but the longer the wound remains open the more discoloration and rot will result (Carvell 1984). For this study, the average depth of the tree wounds was 1.16 inches (Table 2). Trees on Areas E and F had

Table 2.--Number of trees injured and size, depth, and position of wounds for the six study sites.

Study Area	Injured Trees mean (per acre)	Injured Trees total (per tract)	Wound Size mean (sq. in.)	Wound Depth mean (inches)	Wound Position[1] mean (feet)
A	1.9	136	178.9	0.78	2.71
B	4.0	280	248.0	0.71	3.53
C	2.3	132	438.5	0.81	0.76
D	2.0	216	535.2	0.96	1.90
E	2.2	181	297.0	2.01	0.47
F	3.2	245	244.3	1.39	0.50
Mean	2.6	198.6	342.5	1.16	1.76

[1]Position above groundline.

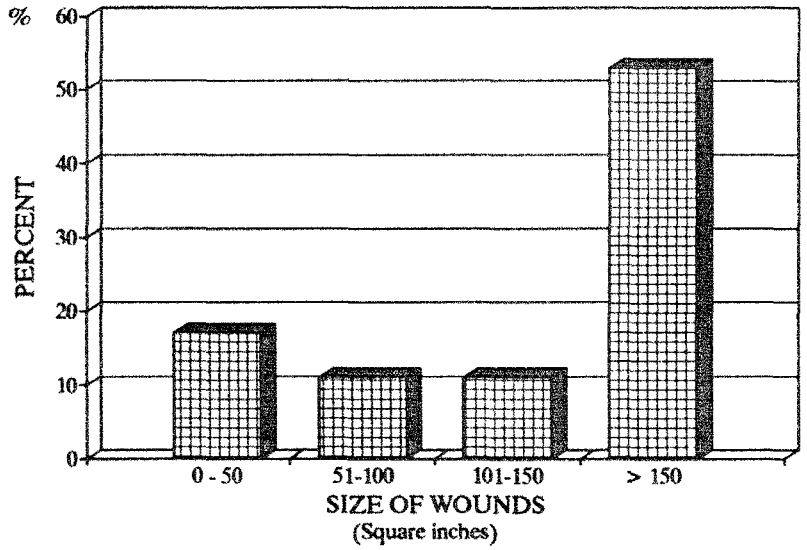

Figure 1. Percent of wounds by 50 in.^{2} size classes for the six study areas.

the deepest wounds at 2.01 and 1.39 inches, respectively. The mean depths for wounds on trees in the other areas were shallower, ranging from 0.71 to 0.96 inches. Residual trees found on the two tracts (Areas E and F) harvested four years ago have developed deep season checks from drying which accounts for the increase in depth. The most common location for

wounds on the tree stem was 2.0 feet above groundline (Table 2, Figure 2). For areas A and B, the average wound was higher than 2.0 feet; and the average was below 2 feet for the other four areas. Because the wounds on Areas A and B were fresh, they were more easily detected higher up on the stem than on the areas harvested 2 and 4 years ago. Overall, 73% of the wounds were below 2 feet and 78% were below 4 feet, which agrees with the results reported by Nyland and Gabriel (1971).

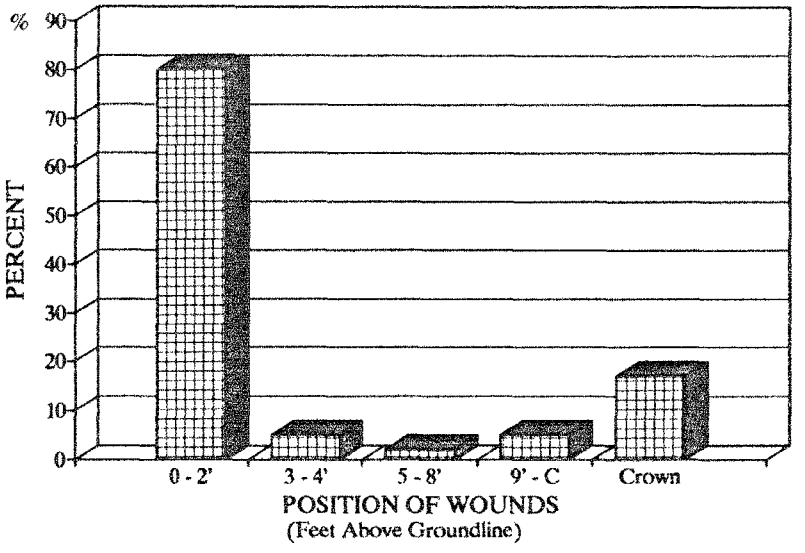

Figure 2. Percent of wounds by position class (above groundline) for the six study sites.

The percentage of wounds over 100 in.^{2} is greater than results found in previous studies (Lamson et al. 1985; Wendel and Kochenderfer 1978; and Biltonen et al. 1978). Such wounds, if they fail to heal quickly, could seriously affect the future quality of those trees injured. The low stem location of the wounds, however, could negate most of the detrimental effects to stem quality. Wounds near the ground are not as detrimental to the tree as wounds higher up on the stem (Shigo 1984). The wounds that cause the most concern are the large wounds located up on the main bole 4-10 feet above ground, and a low percentage of this type of wound was noted (Figure 2). However, a large volume of wood is lost in future harvests if the lower two feet of the butt log is of poor quality.

Tree Diameters and Species Damaged

Injury to stems was most common for trees in the 11- to 14-inch dbh class (Figure 3); 37 trees (34%) in this category and 34 (31%) in the 6-10 inch class were injured. For the 15- to 18-inch and 19- to 22-inch classes, tree damage occurred more frequently than the frequency of that diameter class in the residual stand. The 6- to 10-inch and 11- to 14-inch diameter classes had a lower frequency of damage than their frequency of occurrence in the stand. In

contrast to these findings, previous studies have reported that residual stand damage is usually concentrated in the lower diameter classes (Deitschman and Herrick 1957; Nyland and Gabriel 1971; Lamson et al. 1985). The results of this study suggest that the most likely cause of this damage is carelessness -- the skidder operators disregarded or failed to maneuver around the larger residual stems.

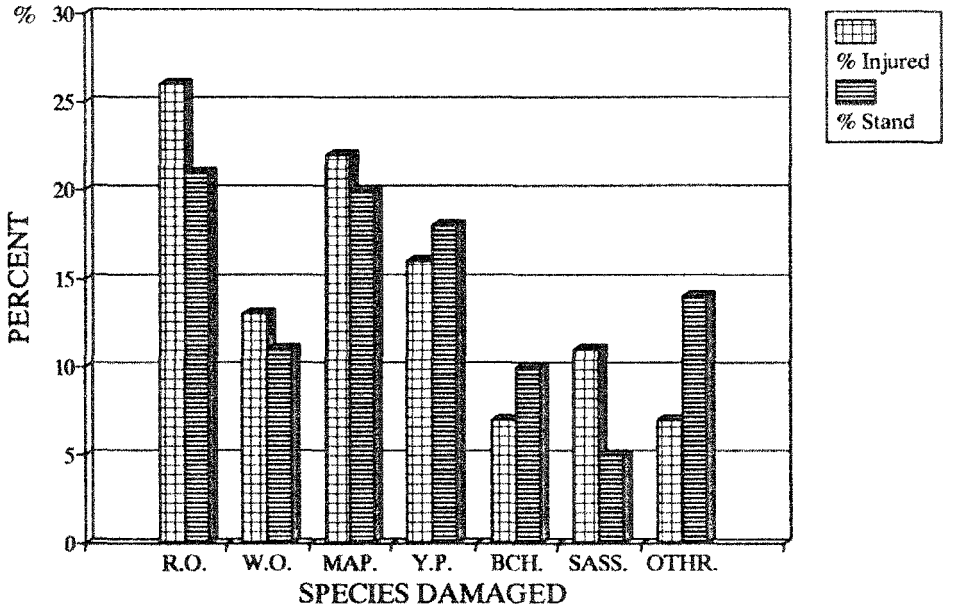

Figure 3. Percent of tree species injured for the six study sites.

Red and white oak, sugar maple, and yellow poplar were injured more often than other species found in these stands. As shown in Figure 4, the percentages of red oak, white oak, and sugar maple stems damaged were higher than their overall percentages in the residual stand. All other species had a lower injury percent than the frequency of occurrence in the stand. Red and white oaks combined accounted for 39% of the injured species while the percent of the oaks found in the residual stand was only 32%. One explanation for this could be the skidder operators' failure to recognize the value of future commercially important crop trees. Regardless of the reason, bark scraped from these stems is likely to reduce the future quality and value of these trees.

Operational Considerations

Slope and traffic intensity on the study sites had an effect on the number of trees injured. The highest number of injured trees (per acre) occurred on the flattest sites (Areas F and B), while the smallest number of injured trees occurred on the tract with the steepest terrain (Area A). On steeper slopes, the primary skid trails were located on the ridge tops and secondary

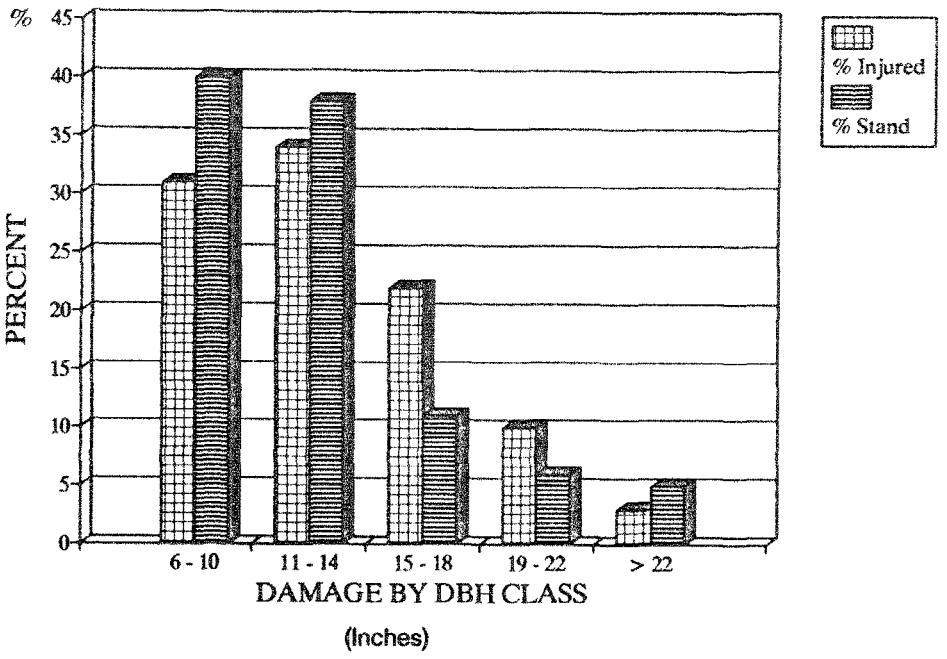

Figure 4. Percent of tree species injured for the six study sites.

skid trails were oriented directly up and down the slopes. Gentle terrain allowed the skidder operators to travel at higher speeds and cover a larger percentage of the total area which, in turn, damaged more residual trees.

As expected, higher rates of stand damage appear to be a function of traffic intensity or number of machine passes. The majority of residual stand damage occurred adjacent to the primary skid trails where the number of machine passes was the highest even though secondary skid trails disturbed 34% more surface area. The average number of trees injured by machine traffic on primary skid trails was 5.8 trees per acre, almost double the number of trees located on secondary skid trails (3.1 trees). Skidding caused 70% of the residual stand damage, felling caused 29%, and 1% of the wounds were caused by landing operations. Ten percent of the wounds were associated with root damage during skidding, and generally were confined to one side of the tree (i.e., adjacent to the skid trail). Other studies involving ground-based skidding report similar results (Nyland and Gabriel 1971; Johnson et al. 1979; Biltonen et al. 1978; and Olsen and Seifert 1984). Nyland and Gabriel (1971) suggest that over half of the skidding injuries might have been avoided by "slightly altering the skid path or using greater caution during skidding."

SUMMARY

The results of this study are similar to those of other studies that have evaluated residual stand damage after conventional ground skidding operations. Past research indicates that it is

inevitable that some trees will be injured during partial cutting, but the amount of damage can not be predicted in advance based on stand density or cutting intensity. The average number of trees (> 6" dbh) injured in this study (i.e., 2.6 trees per acre) is fairly typical for partial cuts in hardwood stands. However, the size of the wounds was larger than expected based on previous studies of logging damage, and a majority of these wounds are larger than 100 $in.^2$ size. Wounds this large have a greater potential to cause decay and discoloration, these wounds may not cause defect problems due to their low position on the main bole. The percentage of red and white oaks damaged was also higher than expected. Injury to these and other commercially important species is a concern because it poses a threat to the future merchantability of these hardwood stands. Slower travel speeds and additional care should be exercised by the skidder operators in order to protect future crop trees in the larger diameter classes and those species that have commercial value if product quality is to be maintained in successive harvests.

The majority of the residual stand damage (71%) is caused by skidding along primary skid trails with twice the number of trees damaged on the primary skid trails as on the secondary trails. Terrain seems to influence the position and number of skid trails used, and in turn affect the number of stems injured. Normal levels of residual stand damage associated with individual-tree/group selection cuts can be tolerated and should not cause serious quality problems (Lamson et al. 1985). Because partial cuts require frequent entry to the stand, continued efforts to minimize residual stand damage of each harvest must be encouraged particularly for high quality hardwood stands. The results of this research suggest that greater emphasis be given to the following recommendations.

1. **Operator training.** This research as well as past studies indicate that skidding damage (more than felling injuries) depends upon human factors and can often be avoided. New employees should be trained and experienced machine operators must be made aware of the value of residual crop trees and the importance of minimizing stand damage if uneven-aged stand management practices are to be successful.

2. **Closer supervision.** Many times the machine operators' paycheck is based on production rather than the quality of, or care taken in, carrying out that job. Close supervision of the skidding and felling operations by the logging foreman, management foresters, and/or the landowner is essential if machine operators are to be convinced that care should be exercised to avoid damage to potential crop trees. If that does not work, financial incentives for doing a quality job or penalties for excessive logging damage may need to be specified in the harvesting contract.

3. **Pre-harvest planning.** Preliminary planning done prior to beginning the harvest should consider ways to minimize residual stand damage. The use of pre-planned or designated skid trails offers a solution because pre-planning confines most of the machine traffic within a smaller area, thus reducing the amount of residual stand damage. The practice of leaving designated "rub" trees along main skid trails, where the majority of the trees are damaged, can also greatly decrease the number and severity of damage to residual trees. The "rub" trees receive a larger share of the skidding damage, and are then removed at the end of the harvest.

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A COMPARISON OF SMALL TRACTORS FOR THINNING CENTRAL HARDWOODS

Neil Huyler and Chris B. LeDoux[1]

Abstract: Young-growth hardwood forests in the central hardwood region will require intensive management if they are to help meet the Nation's increasing demand for wood. Such management generally will require entries into the stands when the trees are small. Many small-scale machines are available for harvesting small wood. Time and motion studies were conducted on small-scale logging operations in the Northeast. The small tractors were studied in a wide range of forest and operating conditions. The machines include the Pasquali 933, a Holder A60F, a Forest Ant Forwarder (Skogsmyran), a Same Minitaurus, and a Massey-Ferguson. The use of small tractors in low-volume, small-diameter hardwood stands is feasible. The Forest Ant should be used only as a forwarding machine while the skidding tractors--Holder, Pasquali, Same and Massey-Ferguson--should be used in stands of medium to large stems and with short skid distances.

INTRODUCTION

As the Nation's demand for wood fiber increases for both wood products and as a source of renewable energy, more youth-growth hardwood forests in the central hardwood region will be required to meet this growing demand.

The intensive forest management required to maintain a sustained yield and attain the production potential of the forest land will require the harvesting of small-diameter, low-quality trees that are characteristic of the central hardwood region. Time of entries and suitable harvesting equipment must be evaluated to ensure a profitable operation.

Several small-scale harvesting machines with suitable economic and physical features are an attractive alternative to conventional ground-based machines that have raised profit ability and environmental concerns (Huyler et al. 1984, Turner et al. 1988).[2]

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[2]Huyler, Neil K. and Chris B. LeDoux. Cycle time equations for five small tractors operating in low volume small diameter hardwood stands. USDA For. Serv. Res. Pap. NE-__ (in preparation).

On the basis of time and motion studies, cost comparison and cycle-time equations were developed for five small tractors in select stand conditions. (See Table 1 for characteristics of the study sites.) The harvesting machines included a Pasquali 933, a Holder A60F, a Forest Ant Forwarder (Skogsmyran), a Same Minitaurus, and a Massey-Ferguson (Huyler and LeDoux 1989). This paper compares the productivity and cost of these five small tractors for select stand conditions.

Table 1.--Characteristics of the study sites

Tractor type	Study site No.	Average tree dbh	Basal area		Skidroad slope		Loaded skid direction	Type of cut
			Precut	Postcut	Primary	Secondary		
		-Inches-	--ft^2 per acre--		------Percent------			
Massey-Ferguson	1	9.4	109	80	4	22	Downhill	Selection
Massey-Ferguson	2	10.3	90	0	6	17	Uphill	Regeneration clearcut
Massey-Ferguson	3	10.3	90	0	6	2	Uphill	Regeneration clearcut
Same	4	11.0	110	85	5	15	Downhill	Selection
Pasquali	4	8.6	116	76	0	14	Uphill	Low thinning
Holder	4	8.6	116	76	0	14	Uphill	Low thinning
Forest Ant	5	8.4	96	71	0	12	Uphill	Low thinning

MACHINE DESCRIPTION

The Pasquali Model 993 tractor is manufactured in Italy and was designed for use on small farms, landscaping projects, and light construction work in municipalities. It is powered by a 30-horsepower engine and has an articulated frame with four-wheel drive. The tractor is equipped with a 3-point hitch, live power takeoff (PTO), and a JL-25 Farmi logging winch. The winch has a 5,500-pound line pulling capacity, spooled with 100 feet of 3/8-inch cable. The Pasquali tractor is 4-1/2-feet wide and 8-feet long, excluding a 4-foot bucket. Safety options include liquid loaded front and rear tires, roll bar, skid pan, and wheel chains.

The Holder A60F tractor is manufactured in Germany and was designed for farm use and light forestry operations. It is powered by a 48-horsepower engine with an articulated frame. The tractor is equipped with a 3-point hitch, live power takeoff, and an Ingland Jones 3000 double-drum winch. The winch has a 6,600-pound-line pulling capacity, spooled with 120 feet of 3/8-inch cable. Safety options included wheel weight, forestry cab, roll bar, and skid pan.

The Forest Ant is manufactured in Sweden and was designed to forward stems to the main skid trails in large forest operations. This small four-wheel-drive tractor has a 12-horsepower engine with an articulated frame. It is equipped with a knuckleboom loader and clam bunk. The tractor steering and speed is controlled by a tiller bar in front. The machine has no cab and the operator walks at a comfortable speed with the machine following.

The Massey-Ferguson 184-4, manufactured in the United States, is a medium-size, four-wheel-drive farm tractor. It has a 60-horsepower diesel engine and is equipped with a 3-point hitch and live power takeoff, and a JL-456 Farmi winch with a line-pulling capacity of 10,000 pounds. Tire chains were used on the rear tires and extra weight added to the front tires. All tires were loaded with calcium chloride for weight.

The Same Minitaurus 60 is manufactured in Italy and designed for small farm use. It is a medium-size four-wheel drive tractor with a 60-horsepower engine. It is equipped with a 3-point hitch, live power takeoff, and a JL30 Farmi logging winch. The winch has a 6,600-pound line pulling capacity, spooled with 165 feet of 3/8-inch cable. Optional and safety equipment included a bucket loader, front wheel weights, loaded rear tires, wheel chain and rollover protection. (See Figures 1 through 5 for illustrations of each of the five tractors.)

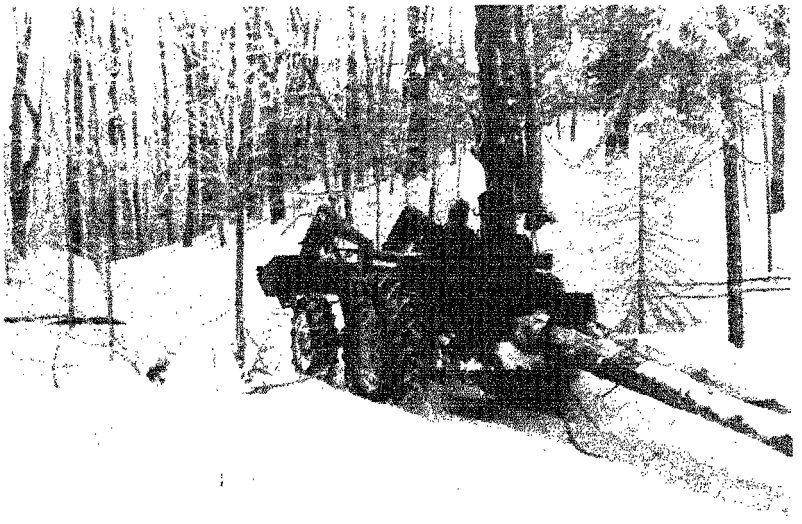

Figure 1. The Massey-Ferguson 184-4 equipped with JL-456 winch.

Figure 2. The Same Minitaurus with JL-30 winch, roll-over protection bars, and bucket loader.

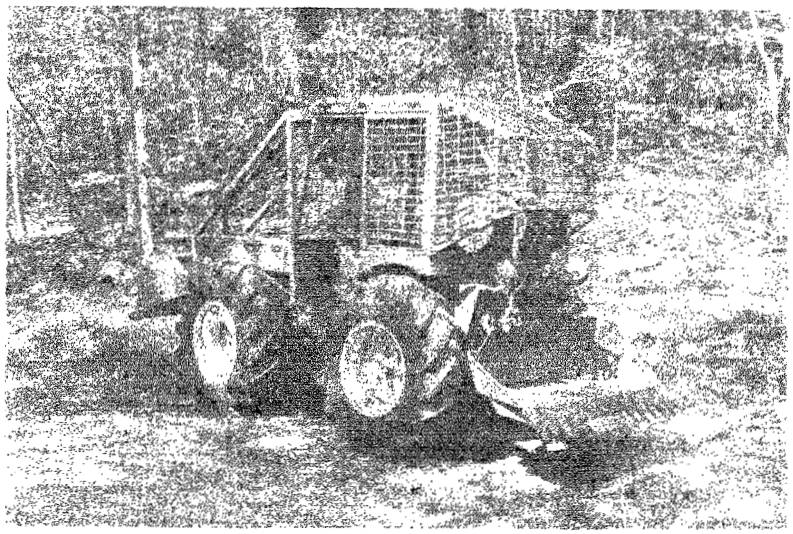

Figure 3. The Holder A60 F equipped with an Igland Jones double-drum winch and roll-over protection.

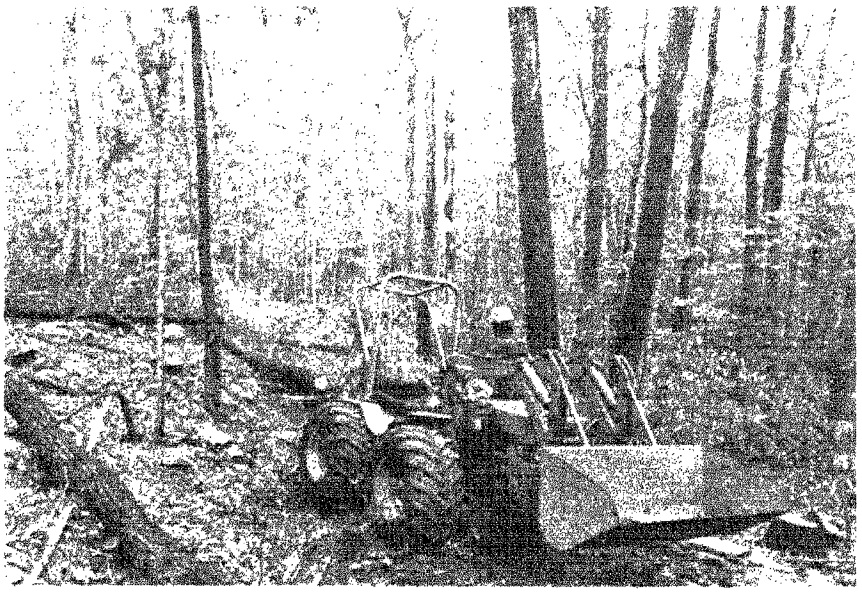

Figure 4. The Pasquali Model 993 with bucket, roll-over protection, and JL-25 single drum winch.

Figure 5. The Forest Ant equipped with clam bunk and knuckleboom loader.

The harvesting areas for both the Massey-Ferguson and Same tractors were in low-quality hardwood stands. Two sites were marked for selection cuts and two sites were marked for regeneration clearcuts. The precut basal area ranged from 90 to 116 square feet per acre for all sites.

Time-study data were summarized and cycle-time equations developed for each tractor. The cycle-time and production estimators were developed using similar variables: slope yarding distance, volume per turn, number of logs per turn, and volume per log. Using similar variables in each cycle time estimator simplifies the comparison of machine cost of production and any simulation effort. Table 2 gives the mean production data for each tractor. The Massey-Ferguson and Holder produced volumes of 46.9 and 50.3 cubic feet per turn, respectively. The Same produced the largest hitch size at 64.8 cubic feet while the Pasquali had the smallest at 18.6 cubic feet per turn. The Forest Ant was slightly higher than the Pasquali at 34.9 cubic feet per turn.

Table 2.--Mean production data for each tractor

Tractor (Number of observations)	Number of stems per turn	Volume per stem	Volume per turn	Mean skid distance
		--ft^3--	--ft^3--	--ft--
Massey-Ferguson (119)	3.78	15.46	46.94	878
Holder (45)	5.62	9.26	50.26	1,147
Same (32)	4.07	19.11	64.77	2,174
Pasquali (65)	3.89	5.19	18.63	947
Forest Ant (30)	7.10	5.15	34.94	253

Table 3 shows owning and operating and labor hourly rate for the five tractors. The investment cost for each tractor was based on 1988 new equipment cost and any added safety and optional equipment.

COMPARISON OF COST

To compare the cost of the five tractors for similar operating conditions, we developed a PC computer program that held certain of the production variables constant while allowing others to change in value, e.g., volume per turn, number of logs per turn, and volume per turn held constant while the slope yarding distance was varied. The four variables significantly influenced productivity and cost for these tractors.[2] The PC program was run several times for each machine and combination of variables. Results were then graphed for comparison.

Table 3.--Owning and operating and labor hourly rates for the Pasquali, Forest Ant, Massey-Ferguson, Holder, and Same tractors.

Machine	Owning and operating[a]	Labor[b]	Total hourly rate
	----------Dollars----------		
Pasquali	5.77	6.75	12.52
Forest Ant	4.27	6.75	11.02
Massey-Ferguson	5.40	6.75	12.15
Holder	14.42	6.75	21.17
Same	5.41	6.75	12.16

[a]Based on 1988 new equipment cost, depreciation, insurance, taxes, interest, storage, operating cost (fuel, oil, lubricants, maintenance, and repair).
[b]Labor rate at $5.00/hour plus 35-percent fringe benefits.

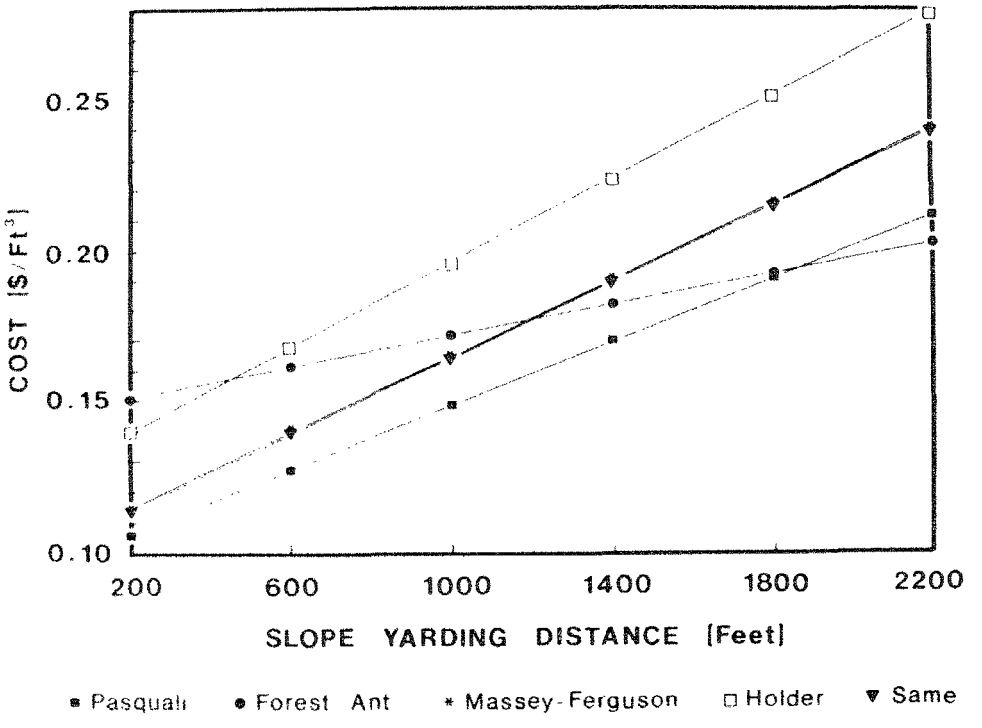

Figure 6. Cost per cubic foot by slope yarding distance for the Pasquali, Forest Ant, Massey-Ferguson, Holder, and Same tractors. Conditions: number of longs per turn=3, volume per turn=35.67 ft^3, volume per log=11.89 ft^3.

Figure 6 shows the impact of slope yarding distance on cost. Volume per turn was held constant at 35.67 cubic feet. Volume per log was held constant at 11.89 cubic feet with number of logs equal to 3. As slope yarding distance increases, the cost per cubic feet increases for all machines evaluated. The Pasquali tractor is the most competitive until a slope distance of about 1,800 feet is reached, at which time the Forest Ant is the most competitive. The Massey-Ferguson and Same tractors are equally competitive throughout the range of slope yarding distance. The Holder tractor is the least competitive throughout the variable range. At a slope yarding distance of about 1,200 feet, it is more economical to use the Forest Ant Forwarder than to skid the same turn with the Massey-Ferguson, Same, or Holder tractor. This illustrates the advantages of forwarding at longer skid distances.

Figure 7 shows the impact of slope yarding distance on cost with volume per turn, volume per log, and number of logs per turn held constant at 35.67 cubic feet, 4.46 cubic feet, and 8, respectively. For the combination of number of logs and volume per log, the Forest Ant forwarder is the most competitive throughout the range of slope yarding distance. The Same tractor is the next most competitive with the Pasquali close behind.

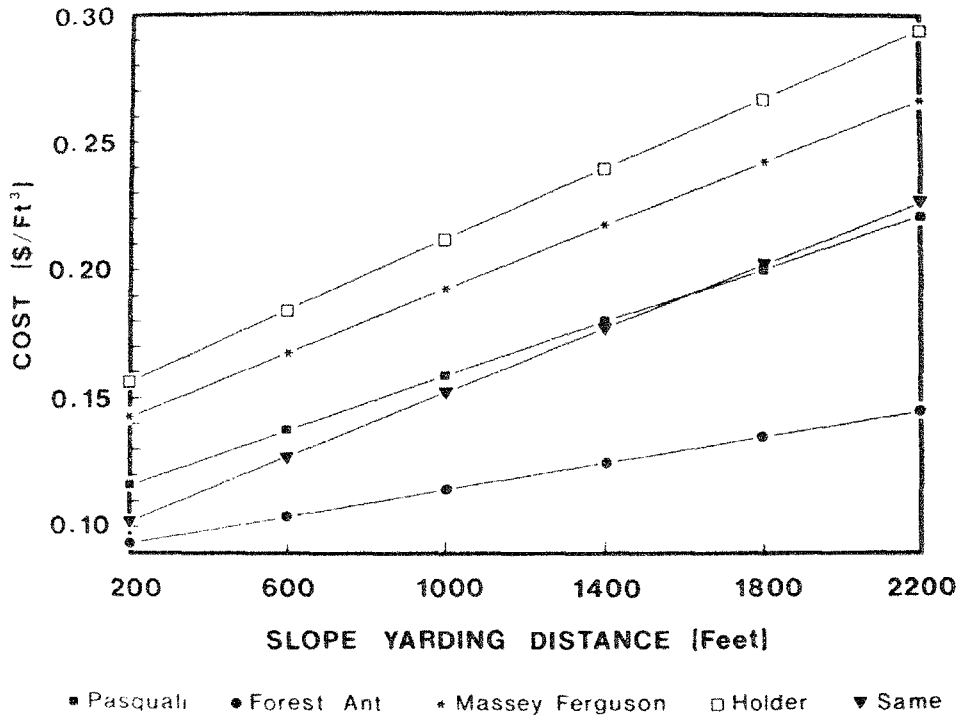

Figure 7. Cost per cubic foot by slope yarding distance for Pasquali, Forest ant, Massey-Ferguson, Holder, and Same tractors. Conditions: number of logs per turn=8, volume per turn=35.67 ft^3, volume per log=4.46 ft^3.

The Massey-Ferguson and the Holder tractors are the least competitive. This matches practical experience in that the tractors are not being used to capacity when this many small logs are being hooked. The Forest Ant is best when one is operating in stands where there are many and small logs.

The impact of number of logs per turn on skidding cost is shown in Figures 8 and 9. In Figure 8, number of logs per turn is allowed to change within the observed range of 1 to 7. The volume per log is held constant at 5 cubic feet with volume per turn ranging from 5 to 35 cubic feet. The slope yarding distance is held constant at 300 feet. The Forest Ant has a slight advantage over the Pasquali and Massey-Ferguson tractors. The Holder and Same are the least competitive, especially when there are 1 to 3 logs per turn and the volume per turn is 5 to 15 cubic feet. These results show that even when the slope yarding distances are short (300 feet), the Forest Ant is still at an advantage when small logs are skidded.

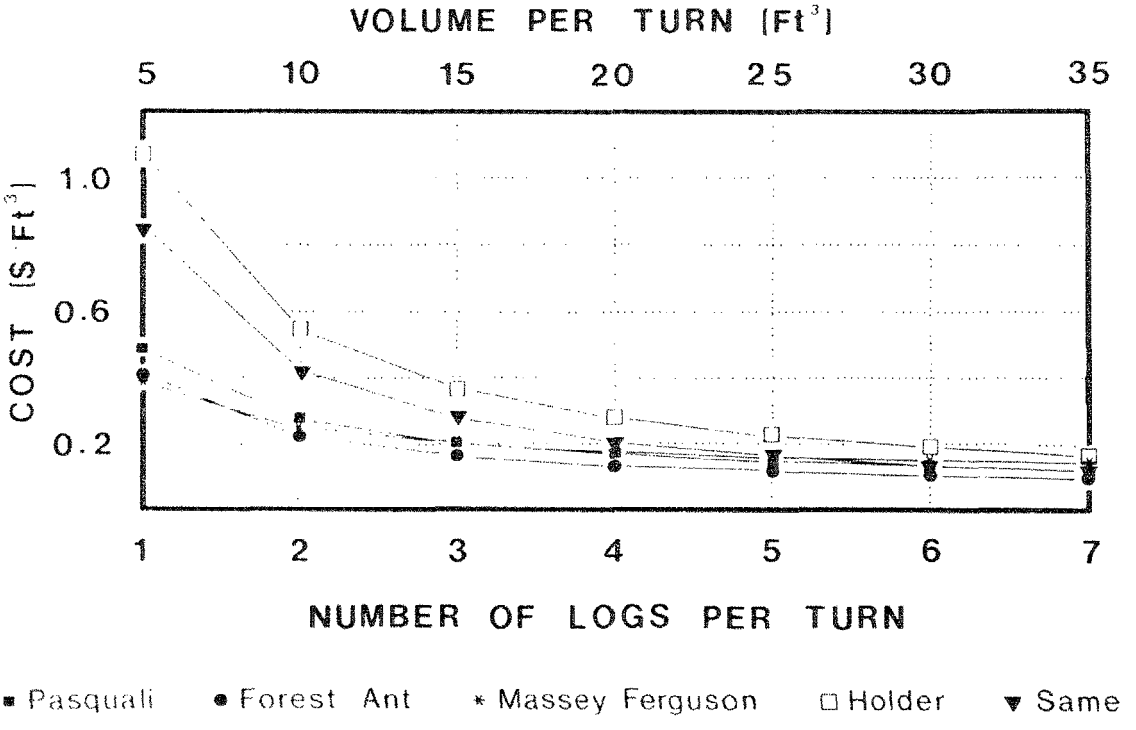

Figure 8. Cost per cubic foot by volume per turn (ft^3) and number of logs per turn for the Pasquali, Forest Ant, Masey-Ferguson, Holder, and Same tractors. Conditions: slope yarding distance=300 feet, voume per log=5 ft^3.

Figure 9 shows the impact of larger volumes per log and number of logs on skidding cost for a slope yarding distance of 300 feet. When the volume per log is 15 cubic feet, the Massey-Ferguson and the Pasquali are most competitive when 1 to 3 logs are hooked. With 4 or more logs per turn, all of the machines are about equally competitive with the Same showing a slight advantage. The Forest Ant forwarder is not competitive when handling 1 to

3 medium-size logs. These results are consistent with previous results in that the forwarder is most efficient when the logs are small.

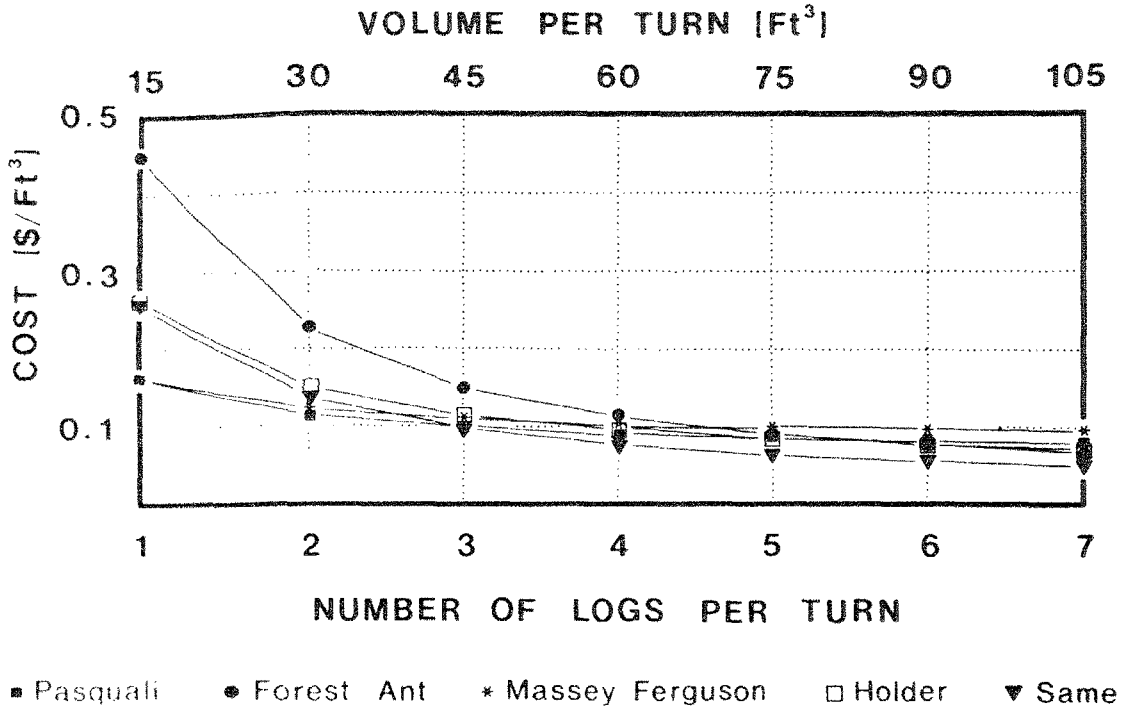

Figure 9. Cost per cubic foot by volume per turn (ft^3) and number of logs per turn for the Pasquali, Forest Ant, Massey-Ferguson, Holder, and Same tractors. Conditions: slope yarding distance=300 feet, volume per log=15 ft^3.

Figure 10 simply confirms previous results. Slope yarding distance and volume per turn were held at 300 feet and 30 cubic feet, respectively, while number of logs per turn and volume per log were allowed to change in value over the observed range. The Pasquali, Massey-Ferguson, and the Same are about equally competitive throughout the range. When the volume per log is 7.5 cubic feet and 4 or more logs are carried per skid, the Forest Ant is the most competitive. The skidding tractors are most efficient when skidding few large logs at short skid distances (Figures 1 and 5).

The impact of increasing volume per turn is shown in Figure 11. Slope distance is held constant at 300 feet with 3 logs per turn. It is interesting that when volume per turn is 25 cubic feet or higher, the cost curve for the Forest Ant is nearly constant. This is true of most forwarders at some payload level. The Massey-Ferguson, Pasquali, Same, and Holder, are about equally competitive when the volume per turn is about 40 cubic feet or larger, with the Same and Holder holding the advantage at volumes per turn of 55 cubic feet or larger. This also matches practical experience in that few large logs are best handled with the tractors and few small logs are best handled with the Forest Ant.

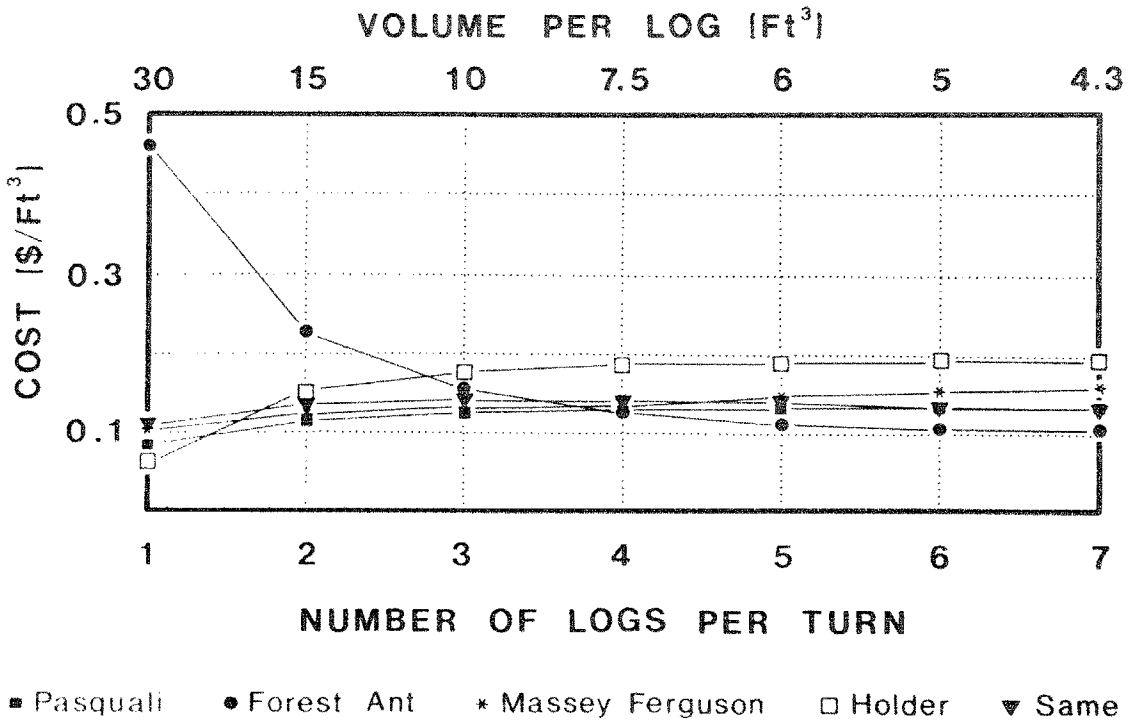

Figure 10. Cost per cubic foot by volume per log (ft^3) and number of logs per foot for the Pasquali, Forest Ant, Massey-Ferguson, Holder, and Same tractors. Conditions: slope yarding distance=300 feet, volume per turn=30 ft^3.

MACHINE APPLICATIONS

The use of small tractors as a harvesting tool in low-volume, small-diameter hardwood stands is feasible. Timing of entry, type of machine, and careful site selection and layout are critical factors for ensuring a profitable operation.

The Forest Ant should be used only as a forwarder and performs best in stands that have many small stems over both short (300 feet or less) and long (1,200 to 1,800 feet) skid distances. Also the terrain should be relatively uniform (slopes up to 15 percent). The skidding tractors--Holder, Pasquali, Same and Massey-Ferguson--are most efficient when used in stands with medium to large stems and with short distances up to 300 feet.

All of the small tractors have good maneuverability over most terrain and in dense small-diameter stands. Other significant advantages observed when using small tractors as a harvesting tool are less soil compaction, ease of movement to and from the harvesting area, and little damage to the residual stand.

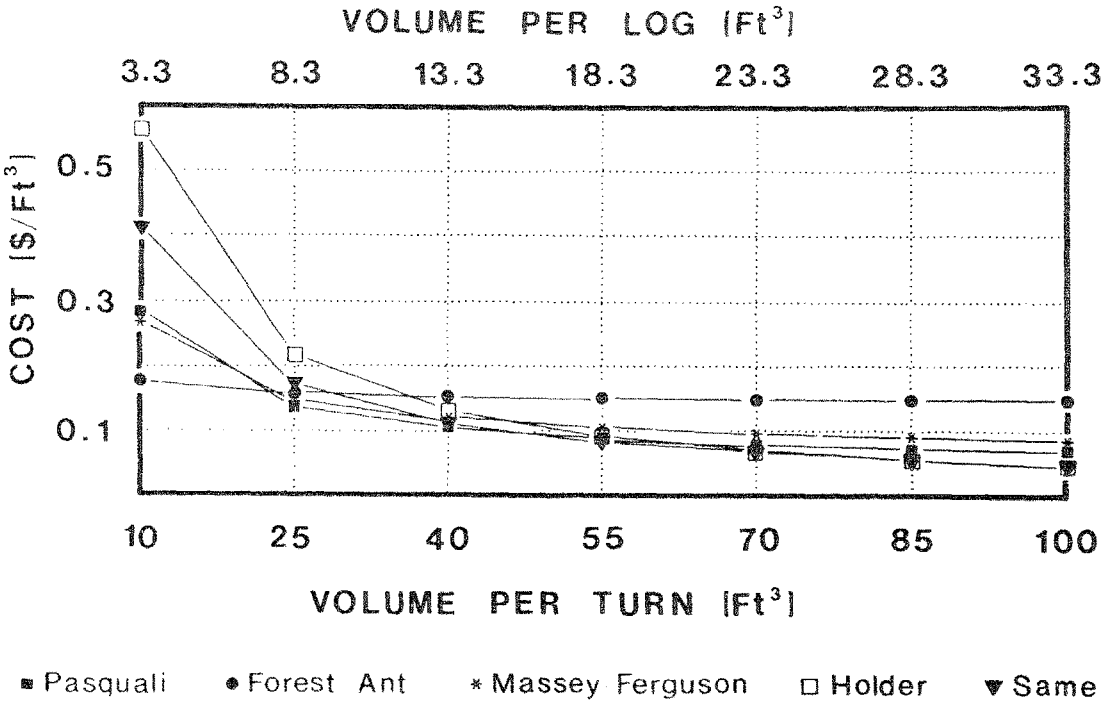

Figure 11. Cost per cubic foot by volume per log (ft^3) and volume per turn (ft^3) for the Pasquali, Forest Ant, Massey-Ferguson, Holder, and Same tractors. Conditions: slope yarding distance=300 feet, number of logs per turn=3.

CONSIDERATIONS FOR MANAGERS

These results should be valuable to forest managers and planners and to loggers in comparing the potential applications of small tractors operating in low-volume, small-diameter hardwood stands. Although this paper only summarizes the comparison of costs for four production variables, research is progressing to incorporate these and additional simulation results into a computer package for estimating stump-to-mill logging costs.

The cycle-time and production estimators will be developed so that similar variables such as slope yarding distance, volume per turn, logs per turn, and volume per log are included by machine in each cycle-time estimator. The similarity in production variables eases comparison of machine time and production. Including similar variables in each cycle-time estimator also simplifies simulation efforts.

The cycle-time and production estimators shown by machine, along with a range of stand and forest conditions, would be used as input to select various simulation models. The simulators

would be run repeatedly over the range of conditions of interest. The resulting cost or production data points by machine and forest condition would be summarized in mathematical equations suitable for incorporation into generalized stump-to-mill models. Computerized stump-to-mill methods that could be used for estimating costs and production would help managers, planners, and loggers determine where specific machines are applicable.

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COMPARING PARTIAL CUTTING PRACTICES IN CENTRAL APPALACHIAN HARDWOODS

Gary W. Miller and H. Clay Smith [1]

Abstract: Variations of diameter-limit and perhaps single-tree selection harvesting are used to regenerate and manage central Appalachian hardwood sawtimber stands. In practice, these methods differ in terms of cut rules, control of stand structure, and cultural treatment of immature stems. Preliminary information is provided to compare the effect of two differing harvest practices on the residual stand--species composition, tree quality, stand structure, and return on residual stand value. Data were obtained from second-growth central Appalachian hardwood stands managed under a given harvesting practice for 30 to 40 years. Results indicate that, for the short term, many single-tree selection goals may be achieved with an easy-to-apply diameter-limit harvest of mature trees. Economic considerations for practical application and potential long-term impacts of each harvesting method are discussed.

INTRODUCTION

Partial harvest practices, such as diameter-limit cutting and single-tree selection cutting, can be used to manage and regenerate central Appalachian hardwood stands. Appropriately applied, single-tree selection is classical unevenage management, while diameter-limit cutting is mentioned often when discussing unevenage management because it also involves periodic partial harvests. What are the on-the-ground differences between a high minimum diameter-limit and single-tree selection? These two practices differ in terms of cut rules, control of residual stand structure, and culture of immature growing stock. Selection represents more intensive silviculture by virtue of its strict control of stand structure, while diameter-limits simply remove all stems over a given size-class. Do these practices lead to residual stands with distinct characteristics and different implications for long-term management?

This paper provides additional information for comparing selection and high-minimum diameter-limit practices. Key factors affecting both economic returns and sustained yield are compared for second-growth stands managed under each harvesting method for 30 years. Comparisons are based on changes in: species composition, tree quality, residual stand structure, and return on residual stand value. Finally, economic considerations for applying these harvesting methods over extended planning periods are discussed.

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Repeated partial harvests over long periods can influence species composition and quality of merchantable products. Intolerant species have difficulty developing under partial shade maintained by periodic partial harvests. So, even a stand initially composed of largely intolerant species will regenerate to more tolerant species over time. How do selection and diameter-limit practices differ in their influence on species composition?

Partial harvest practices may also have some affect on product quality. For example, selection practices afford an opportunity to culture immature stems by removing undesirable stems and providing available growing space to trees of better potential grade. By contrast, diameter-limit harvests commonly make no removals below a specific d.b.h. size-class, so this practice provides little direct influence on quality of the residual trees. How do selection and diameter-limit practices differ in their influence on product quality?

Forest managers should make provisions for sustained yield of wood products when applying a partial harvest practice over long periods of time, say 100 years or more. Single-tree selection, as applied in these stands, controlled residual basal area (RBA), largest diameter tree (LDT), and diameter distribution quotient (q-factor) to provide for long-term sustained yield (Smith and Lamson 1982). The diameter-limit practice did not have residual stand targets as in the selection practice. As applied in this study, the d.b.h. cutting limit was 17.0 inches, relatively high for most eastern hardwood markets. The higher limit allows trees to become large enough for grade 1, the highest sawtimber grade, before harvest. How do selection and diameter-limit practices differ in their ability to establish desirable regeneration following each harvest and provide a sustained yield of wood products?

Each factor discussed has an important influence on financial returns from timber production using a partial harvest management system. Frequency and value of periodic revenues are directly related to growth characteristics and product quality of the species which regenerate following each harvest. In addition, within a particular species group, individual tree quality plays an equally important role in determining the unit value of merchantable products sold each cutting cycle. And finally, a harvest practice must provide for sustained yield or else periodic revenues may be interrupted in the future, requiring costly, unexpected stand reestablishment. How do selection and diameter-limit practices compare in terms of potential rate of return?

The information presented here provides a basis for evaluating partial harvest practices. The preliminary results shed light on the returns possible during transition from a second-growth evenaged stand to an unevenaged stand in which periodic yields are regular. Trends observed also indicate the likely species composition, tree quality, and regeneration potential for stands managed over long periods with partial harvest practices. Information regarding the transition period and clues about the character of the future stand make it possible to estimate the long-term returns possible from selection and diameter-limit practices.

In summary, the information presented here can help the forest manager evaluate two types of partial cutting practices and decide which practice is best suited to management objectives.

DATA

Data were obtained from stands located on the Fernow Experimental Forest near Parsons, West Virginia. The study area receives about 55 inches of precipitation annually, distributed evenly throughout the year. Stands compared in this study are located on site index 70 for northern red oak (*Quercus rubra* L.). Management began in the early 1950's when the second-growth stands were about 45 years old. Some old residuals from the early logging in 1905 and some stems resulting from regeneration following death of the American chestnut in the 1930's were present in the study area when the first partial harvests were made. The study stands contained three age classes when management began.

Stand data were obtained from 100 percent cruises taken every 5 years and before each harvest. Small reproduction consisted of any woody species from 1.0 foot tall to 0.99 inches d.b.h., tallied on 1/1000-acre plots randomly located throughout the study areas. Large reproduction was composed of any woody species 1.0 to 4.9 inches d.b.h., tallied on 1/100-acre plots randomly located throughout the study areas. Sawtimber quality was measured using U.S. Department of Agriculture, Forest Service log grades on a random sample of trees measured during the periodic inventories. Current (at the time of harvest) average stumpage prices for each species group were used to determine harvest and residual stand values.

TREATMENTS

In this study, diameter-limit cutting was applied using 17.0 inches as the minimum cutting diameter. Harvests were planned on a 15-year cutting cycle. Two diameter-limit areas totalling 87 acres have been cut three times since the early 1950's. Cultural practices such as vine control were applied throughout the stand before logging, but culls and undesirable growing stock below the 17.0-inch diameter limit were not cut. Cut trees were marked during the 100 percent inventory, thus relieving the logging contractor of the responsibility of measuring d.b.h.

Single-tree selection was applied according to guidelines described by Smith and Lamson (1982). In this study, selection stands were marked to achieve a residual basal area of 65 sq ft per acre (including trees 5.0 inches d.b.h. and larger) with a largest tree of 26 inches d.b.h. and a q-factor of 1.3. Marking was controlled by cut ratios for each 2-inch-diameter class, 11.0 inches d.b.h. and larger. Vines and culls were cut during each harvest operation. Harvests are planned on a 10-year cutting cycle. Since the early 1950's, two selection areas totalling 54 acres have been cut three and four times, respectively.

Data from two control areas totalling 83 acres also were included to detect changes not related to the cutting treatments. Control areas were unmanaged over the study period and received no vine control or cull treatments.

RESULTS AND DISCUSSION

In general, both selection and diameter-limit practices provided adequate regeneration to continue making periodic harvest cuts for at least an additional 40 years. Development of advance regeneration also was favorable for continued management using these harvest methods. The first 40 years of applying partial harvest practices promoted the establishment of tolerant species. Moreover, evidence from surveys of small and large reproduction indicated that continued partial harvests eventually will eliminate intolerant species, and, that sugar maple (*Acer saccharum* Marsh.), red maple (*Acer rubrum* L.), and American beech (*Fagus grandifolia* Ehrh.) will dominate harvest volume as long as these practices are continued.

The first three or four cutting cycles in managing second-growth hardwoods using partial harvest practices resulted in economical, commercial harvests which provided periodic income. The early cutting cycles also provided valuable clues about the nature of periodic income in the distant future. Results from the initial 30 years of management may improve the reliability of growth and value projections for the next several cutting cycles and beyond.

Initial Harvests

The study areas were 45-year-old second-growth stands when partial harvests were first applied in the 1950's. In single-tree selection stands, initial harvests removed old residuals, undesirable species, and high-risk trees throughout merchantable size-classes. In diameter-limit stands, no attempt was made to condition smaller merchantable growing stock, but some merchantable trees below the 17.0-inch d.b.h. cut limit were removed for roads and incidental damage.

Stand data for the initial harvest treatments are presented in Table 1. Planned cutting cycles were 15 years and 10 years for the diameter-limit and selection practices, respectively. Periodic annual merchantable volume growth is expected to be about 350 bd ft/acre, so periodic harvests could range from 3000 to 5000 board feet per acre, depending on the cutting cycle. Eventually, periodic harvests will equal periodic growth, but as exhibited in this study the initial cuts may exceed growth as old residuals are removed.

Initial harvest treatments removed 25 to 42 trees per acre. Cut trees averaged 16 inches d.b.h. in the diameter-limit, 14 inches d.b.h. in the selection stand. Harvest volume in the selection stand was slightly higher due to removal of several large old residuals and some removals in small sawtimber to achieve residual stand goals. Note that residual stands from both treatments were similar following the initial partial harvests. This initial similarity helped clarify the effect of cutting practices as the stands developed over the next 30 to 40 years. Once the old residuals were harvested, a review of subsequent harvests clarified actual differences between diameter-limit and selection practices.

Table 1.--Stand data for initial partial harvests in 45-year-old second-growth Appalachian hardwoods, 5.0 inches d.b.h. and larger.

Treatment	Stand	No. trees/a	BA/ac	Bd ft/ac	Cu ft/ac
Control	Initial	156	98	9,200	2,200
D-Limit	Initial	158	89	7,900	1,950
	Cut	25	33	4,900	840
	Residual	133	56	3,000	1,110
Selection	Initial	144	91	8,800	2,040
	Cut	42	44	5,700	1,070
	Residual	102	47	3,100	970

Later Harvests

The diameter-limit stands were harvested two additional times: 17 years and 32 years after the initial harvest. Selection stands also were harvested two additional times: 15 years and 25 years after the initial harvest. Cutting cycles were slightly longer after the initial harvest to allow the stands to rebuild growing-stock volume following the relatively heavy initial harvests. However, the time between the second and third cuts was equal to the desired cutting cycle: 15 years for diameter-limit and 10 years for selection. Data collected at these third harvests can be compared because these stands have been under management for about the same length of time. Trends are beginning to develop and harvests will be made on a regular cycle in the future. The comparison also sheds light on stand changes that occur during the transition to long-term unevenage management.

Table 2 contains stand data for the third diameter-limit and selection harvests. Note that harvest volume is roughly equal to periodic growth, although the diameter-limit harvest is still a little heavy. Both practices removed about twenty trees per acre, but cut trees in the diameter-limit averaged 17 inches d.b.h. compared with 14 inches d.b.h. in selection. Once again, the residual stands to begin the growth period before the next harvest were similar. Stocking in the diameter-limit stand was slightly lower than in the selection stand, but the cutting cycle was longer and harvests were heavier and less frequent than in this selection practice.

Stand data presented in Tables 1 and 2 indicate only slight differences between the treatments. And the difference in cutting cycle length may be the primary cause of slight dissimilarities at this point in the transition period. Because the stands were similar to begin with, and both have been cut three times, it is not surprising that the stands are similar after 30 years.

Table 2.--Stand data for partial harvests after 30 years of management, 5.0 inches d.b.h. and larger.

Treatment	Stand	No. trees/ac	BA/ac	Bd ft/ac	Cu ft/ac
Control	Recruise	132	151	19,900	3,720
D-Limit	Recruise	163	110	11,600	2,500
	Cut	19	31	5,300	790
	Residual	144	79	6,300	1,710
Selection	Recruise	171	107	10,200	2,400
	Cut	21	22	2,900	540
	Residual	150	85	7,300	1,860

At this point, it may be helpful to examine changes in species composition, tree quality, and stand structures to enhance the comparison of these practices. After all, timber sale revenues and sustained yield are influenced greatly by these factors over time. Changes occurring now, in the transition period, will affect profitability and feasibility of these practices in the future. A closer look also may reveal important modifications needed to improve the effectiveness of these harvesting systems in achieving landowner goals.

Changes in Species Composition

Preliminary evidence indicates that harvest revenues in the future will be based primarily on sales of sugar maple stumpage. The species diversity characteristic of evenage second-growth stands is giving way to commercial tolerant species such as sugar maple, American beech, and red maple. The merchantable growing stock (11.0 inches d.b.h. and larger) after 30 years of management under a partial harvest system still contains valuable intolerant species such as black cherry (*Prunus serotina* Ehrh.) and yellow-poplar (*Liriodendron tulipifera* L.), as well as northern red oak, white ash (*Fraxinus americana* L.), and other species of intermediate tolerance. Three harvest cuts have removed larger sawtimber trees and provided growing space for advance regeneration present in the 1950's to develop into the sawtimber trees present today (Figure 1). In fact, the species composition in merchantable sawtimber size-classes has changed very little over the study period. There are a few more sawtimber trees per acre in all treatment areas including control, but in general, changes in merchantable species composition will not be evident for several more cutting cycles.

A slight increase in the proportion of tolerant species is evident in the poletimber in each treatment area (Figure 2). Under full shade of the control area and partial shade of the managed stands, intolerant species are not replacing established intolerant poles as they grow into sawtimber sizes. In the diameter-limit stands, however, some intolerant species are

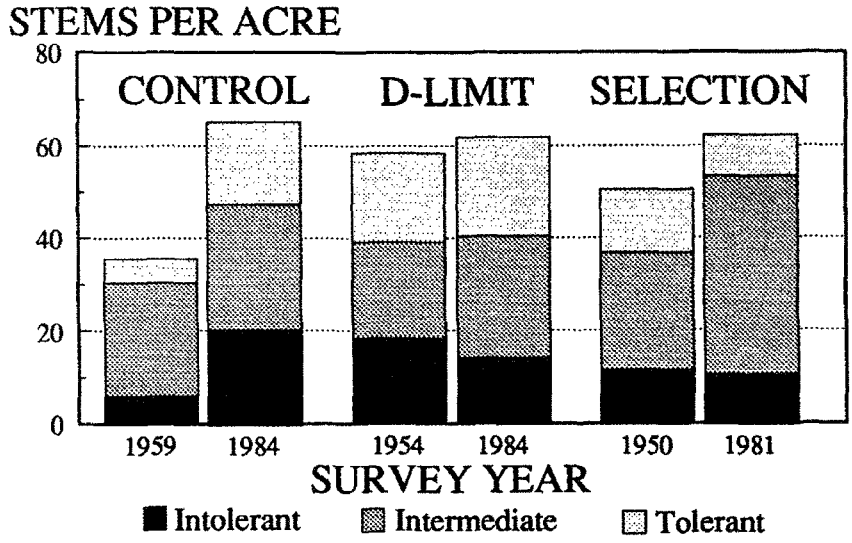

Figure 1. Species composition of sawtimber by tolerance.

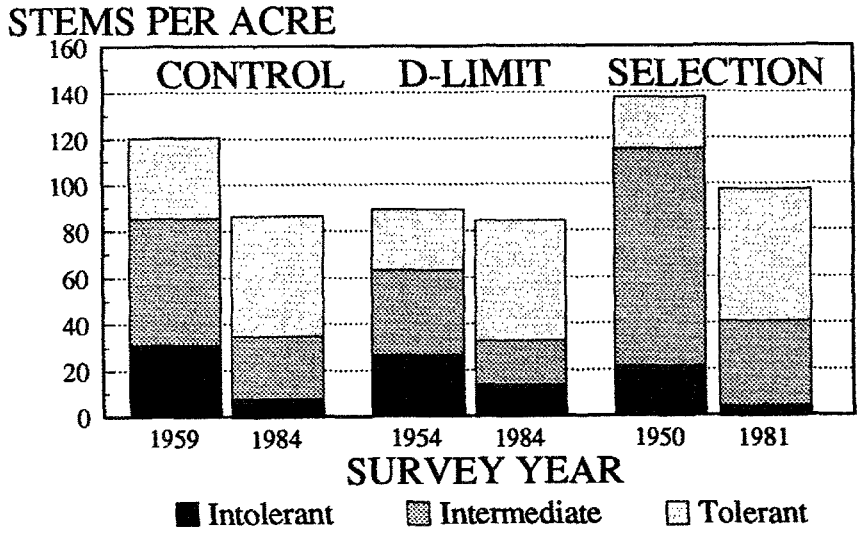

Figure 2. Species composition of poletimber by tolerance.

developing in the poletimber classes. In the selection stands, an effort is made to distribute the cut evenly throughout the stand, if possible. Openings large enough for intolerants to flourish are less likely in selection practices than in diameter-limits. Still, a small proportion of the stand will have some intolerant species develop for either practice, but more intolerants will develop under a diameter-limit practice.

Surveys of large reproduction indicate a decrease in the total number of saplings per acre in all treatments, with the vast majority of advance reproduction made up of tolerant sugar maple in these study areas (Figure 3). Although intolerant species made up a minor part of large reproduction at the beginning of the study when the canopy was closed, only the diameter-limit stands showed an increase in the proportion of intolerant species over the study period.

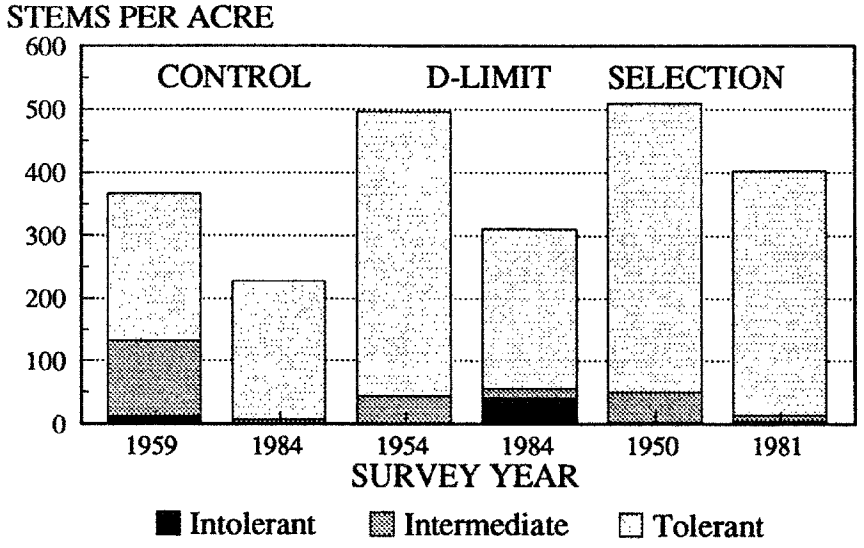

Figure 3. Species composition of large reproduction by tolerance.

Trees were aged in the study area to determine when regeneration was established. Intolerant poles in the treated areas were less than 40 years old, indicating they were established as a result of the partial regeneration harvests made since management began. Only the smaller (1 to 2 inches d.b.h.) tolerant saplings became established as a result of management. Other tolerant poles were probably small saplings in the understory when the first cuts were made in the 1950's.

Small reproduction contained a minor component of intolerant species after 30 years of management. Diameter-limit stands contained the most intolerant reproduction, about 500 stems per acre (Figure 4). Selection stands contained over 5,000 sugar maple seedlings per acre at the 30-year survey, almost twice as many as the control or diameter-limit areas. Although surveys of small reproduction show that regeneration is established after every partial cut, they do not indicate adequately the future stand composition (Trimble 1973). Some intolerants like black cherry can be tolerant when small and young, but without adequate light, they lose their early tolerance and die before they become part of the large reproduction. So, high counts of intolerants in the small reproduction do not indicate a component of merchantable intolerants in the distant future.

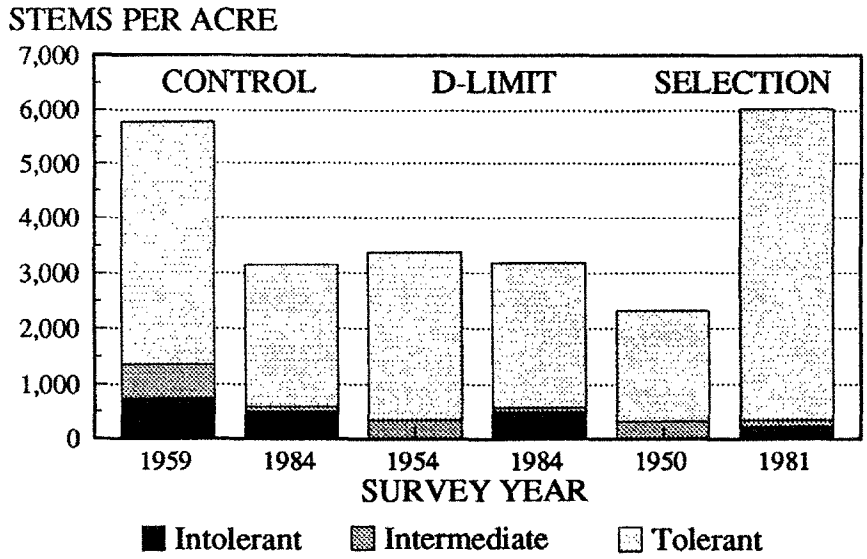

Figure 4. Species composition of small reproduction by tolerance.

Without question, continued application of partial harvest practices will lead to stands made up of tolerant commercial species if they are present and can be regenerated at each harvest. Results indicate, also, that diameter-limit cutting may allow more intolerants to become established compared to selection practices. The longer cutting cycle with a heavier, less frequent harvest is a major reason why the diameter-limit areas contained more intolerants. Also, removal of clumps of mature trees also created favorable light conditions for intolerants to develop. Forecasting species composition in the distant future is often difficult, but trends indicate that sugar maple will dominate these stands. Some intolerants will continue to play a minor role. In comparing the practices, diameter-limit stands will be composed of 10 to 20 percent intolerants, black cherry, and yellow-poplar in the study area, while selection stands will be 5 to 10 percent intolerants. The actual impact of the intolerant component will depend on how stumpage prices compare with sugar maple prices at each of the partial harvests. If the intolerant species is black cherry, the added revenue may give diameter-limit a slight advantage over selection, other things equal. If the intolerant species is yellow-poplar, the practices may provide similar returns because sugar maple and yellow-poplar prices differ only slightly in many markets. Thus, there may be no incentive to choose diameter-limit cutting to favor development of some additional intolerants if they are not high-value species.

Changes in Tree Quality

An important difference between selection and diameter-limit management is the cultural treatment of immature stems. Selection harvests remove some trees from all merchantable

diameter classes. The main objective in cutting throughout a range of d.b.h. classes is to control stand structure, but selection also cultures immature merchantable stems. So in addition to controlling numbers of stems, the selection practice affords an opportunity to influence quality of the residual stand. Diameter-limit, on the other hand, disregards stand structure and tree quality development in stems smaller than the cut limit.

Samples of butt-log grade taken during preharvest cruises provided a basis for comparing the effects of selection and diameter-limit cutting on stand quality development. Some improvement in grade is due to trees growing into larger size-classes where grade rules are more forgiving of surface defects. Total board foot stand volume in grades 1 and 2 (highest sawtimber grades) increased by about 10 percent in unmanaged stands over a 25-year period (Figure 5). Diameter-limit areas had a similar increase in stand quality over a 30-year period, but there was a slight decrease in quality between the 15- and 30-year sample. Apparently, quality in the diameter-limit areas may fluctuate as it does in an unmanaged area because trees below the cut limit are not improved through periodic harvests.

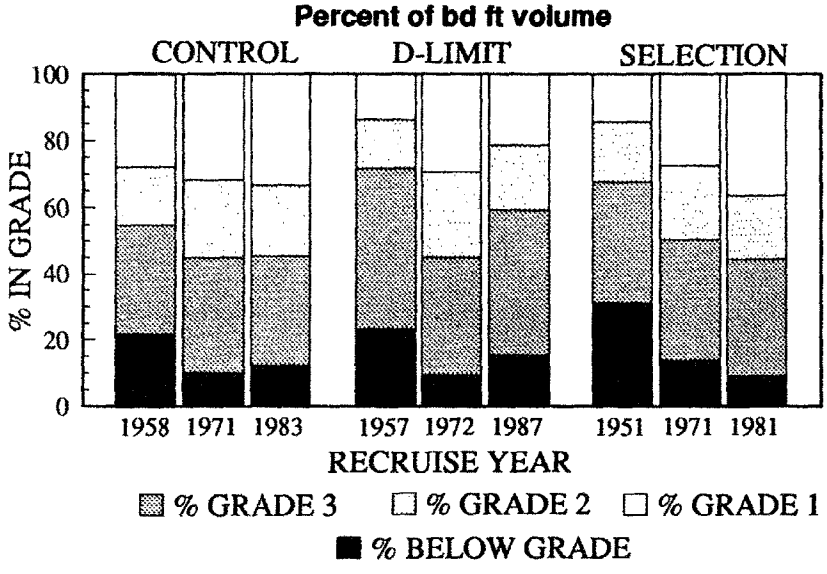

Figure 5. Distribution of sawtimber by volume by butt-log grade.

In selection stands there was a distinct improvement in quality over 30 years. These stands were cut three times, continually reducing the proportion of volume in trees below sawlog grade. Most of the quality improvement was from an increasing proportion of volume in grade 1 and a decreasing proportion of volume below grade. Proportion of volume in grades 2 and 3 remained relatively stable.

Each harvest removed trees of lower grade, leaving behind trees with the greatest potential for making grade 1. As the chosen residual 12- and 14-inch trees grow into larger d.b.h. classes, the percent of volume in grade 1 or 2 increases. Because the number of 12- and 14-inch

d.b.h. trees is fairly stable under selection management and these classes are too small for grade 1, it is understandable that the percent of volume in grades 2 and 3 is fairly stable also. Percent of volume in grade 1 increases as stands are converted to unevenage management because the larger sawtimber growing stock is made up of "best" trees favored at each periodic harvest.

Volume in grades 1 and 2 increased by 35 percent in selection areas and only 15 to 20 percent in the diameter-limit areas. For the next three or four periodic harvests, selection areas will yield 15 to 20 percent more grade 1 and 2 sawtimber volume than diameter-limit areas. Stumpage prices and sale revenues will reflect the higher quality products. As stands under both management systems are converted to predominantly unevenaged tolerant species, grade differences will be more predictable because grade variations among various species groups will be eliminated.

For projecting grade distributions for managed unevenaged stands, Table 3 contains an unbiased estimate of sugar maple butt-log grade distribution. Data were obtained from grade samples taken in stands managed under single-tree selection for 30 years or more, each stand cut from 3 to 5 times. Proportions of trees in each grade by diameter class can provide an estimate of tree quality for repeated selection harvests. Note that well over half of the residual trees in a managed stand are in grades 1 and 2.

Table 3.--Butt-log grade distribution for sugar maple in managed selection stands.

D.b.h.	No. Trees	% Grade 1	% Grade 2	% Grade 3	% Below Grade
12	32	-	-	91	9
14	29	-	52	45	3
16	31	39	35	23	3
18	29	55	31	14	0
20	30	44	23	33	0
22	37	41	32	27	0
24	41	51	17	27	5
26 plus	99	48	26	24	1
Total	328				

Changes in Residual Stand Structure

Providing for sustained yield is an important consideration when applying partial harvests over long planning horizons. Selection harvests are planned with a goal residual stand in mind, primarily to ensure enough trees in smaller diameter classes to continue periodic harvests in the near future. In addition, residual basal area goals are set to ensure adequate

regeneration after each harvest and to provide continual recruitment of trees for the distant future.

In the central Appalachians, partial harvests using an 18-inch diameter-limit have not created deficit d.b.h. classes which could lead to disruptions of regular periodic yield. Prior to the most recent harvest, both diameter-limit and selection stands had stand structures similar to the original stand structures when management had begun 30 years earlier (Figure 6). There were adequate numbers of trees in each merchantable d.b.h. class to meet a residual stand goal suitable for sustained yield.

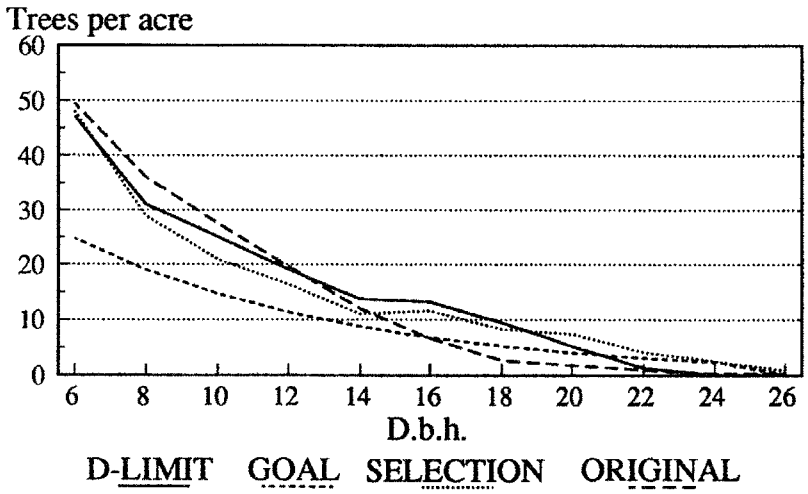

Figure 6. Stand structure before most recent harvest.

Selection harvests were made to achieve gradually a residual stand goal, so it is not surprising that after four harvests stand structure is very near the goal (Figure 7). There is still a small surplus in the 16- to 18-inch d.b.h. classes, reflecting a conservative attitude toward marking in the early periodic harvests, before marking guidelines were fully evaluated. Future harvests will bring the residual stand closer to the goal because preliminary results indicate that it is adequate for regeneration and sustained yield, and retaining surplus trees is no longer warranted.

Forest managers may question the feasiblity of diameter-limit cutting because the cut rule does not ensure that sustained yield conditions can be maintained over time. A review of residual stand structures revealed that diameter-limit areas met some of the residual stand targets used to practice selection even though periodic harvests were not explicitly planned to do so. For example, the diameter-limit areas had a residual basal area of 79 sq ft per acre, similar to the selection practice. In addition, the residual stand structure had adequate numbers of trees in each d.b.h. class to meet a stand structure goal for a q-factor equal to 1.3 (Figure 7). So, the diameter-limit stands appear to provide adequate regeneration and tree recruitment throughout merchantable diameter classes to continue the practice for at least three or four cutting cycles in the future. Although a 17.0-inch d.b.h. cut limit was

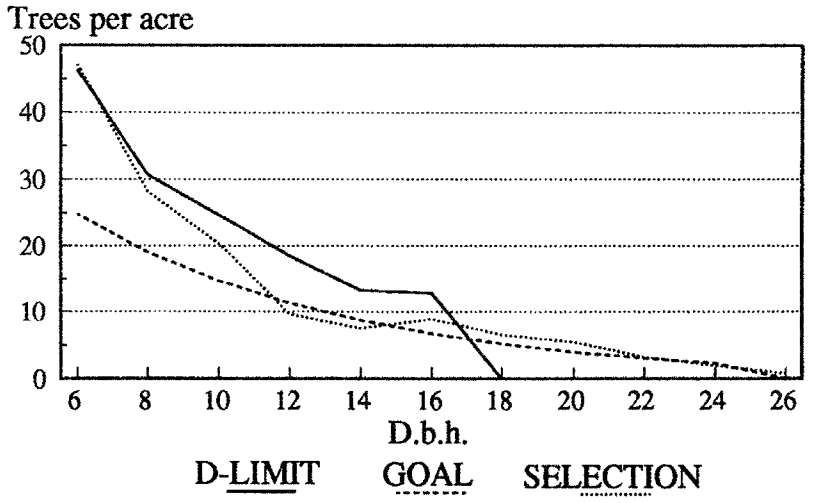

Figure 7. Stand structure after most recent harvest.

appropriate for the stands studied, a higher limit may be needed in some stands to avoid overcutting. Still, residual basal area goals can be achieved using either selection or diameter-limit practices.

Both partial harvest practices examined here have brought about adequate regeneration and recruitment of smaller trees to meet sustained yield guidelines over the first 40 years of application. Preliminary results indicate that these practices can be used for up to 80 years, allowing six to eight periodic commercial timber sales. Further study will define in more detail implications of partial harvest practices over even longer periods. For now, forest managers can apply partial harvest practices so long as a desirable tolerant species is present and can be regenerated after each periodic harvest. Later, adjustments may be needed to account for changes in species composition that are certain to occur.

Return on Residual Stand Value

Actual stumpage revenues from selection and diameter-limit harvests were used to compute periodic rates of return during the study period. For computing real returns, stumpage values at the time of each harvest were adjusted for inflation using Producer's Price Index for all commodities. Inflation averaged 3.7 percent during the study period.

The two-diameter-limit cutting areas earned an average 9.8 percent market rate of return and a 5.9 percent real rate of return. These rates were competitive with other long-term investments available during the same period. Earnings in the two single-tree selection areas averaged 10.0 percent market rate of return and 6.1 percent real rate of return. Selection areas earned slightly higher average returns because one area was harvested four times

compared to three times in other treatment areas. The additional payoff helped boost average rate of return. For the control stand, where no harvests were made, earnings averaged an 8.3 market rate of return and a 4.4 real rate of return.

Managed stands provided higher earnings than the control stand mainly because periodic partial harvests reduce the time required to receive income. Periodic annual board-foot-volume growth was about the same for each of the three treatments, 370 to 400 board feet per acre. Thus, the main reason for higher average earnings in managed stands is the more frequent harvest income. Comparing single-tree selection and diameter-limit cutting, as applied in this study, earnings were about the same over the first 30 years of management.

SUMMARY

Partial harvest practices can help meet a range of management objectives. Evidence indicates that commercial sales 10 to 15 years apart can provide periodic timber income for 80 years or more without adverse effects on residual growing stock. In visually sensitive areas, these practices provide a continuous cover of trees while growing and harvesting timber products.

Each practice has important advantages and disadvantages. Single-tree selection improves tree quality and affords explicit control of residual stocking for sustained yield. Selection can be more difficult to apply, in practice, because it requires marking by cut ratios and accurate counts of cut and leave trees during marking. Yield from selection harvests is distributed among small and large sawtimber, thus increasing the unit harvesting costs and reducing stumpage value compared to diameter-limits.

Diameter-limit cutting is very easy to apply. Harvest volume is in relatively large trees (18 inches d.b.h. and larger) so harvesting costs are lower than for selection cutting, other things equal. Stands observed in this study did regenerate following each harvest, and residual stand structure was adequate for sustained yield even though no attempt was made to achieve a given residual stocking. The greatest drawback of diameter-limit cutting is the lack of influence on the quality of immature merchantable trees. The quality of trees growing into larger sizes classes is left to chance.

Trimble, Mendel, and Kennell (1974) suggested a compromise between single-tree selection and diameter-limit cutting for managing hardwood stands using a partial cutting practice. Mature trees are harvested using a flexible diameter-limit based on financial performance of residual trees. In addition, merchantable immature growing stock receives an improvement cut at each periodic harvest. Residual basal area guidelines are used to adjust the minimum d.b.h. cut limits for mature trees to provide for sustained yield. This method offers the simplicity of diameter-limit cutting in the field--each species has its own minimum d.b.h. cut limit. It also offers the intensity of selection management--the forest manager can control residual stand stocking and quality better.

Partial cutting practices, if properly applied, can earn competitive returns on residual growing stock while providing the nonmarket benefits of continuous forest cover. In this study, average annual volume growth was 370 to 400 bd ft per acre for selection and diameter-limit, respectively. Harvests of periodic stand growth in the future will yield 3,000 to 5,000 bd ft per acre every 10 to 15 years, varying only slightly with each cutting cycle. Using local stumpage prices near the study area, periodic income will be $250 to $500 per acre depending on the length of the cutting cycle.

Assuming observed trends continue in the study stands, real (net of inflation) return on residual stand value will be 5.4 percent for diameter-limit and 4.9 percent for selection. These rates compare favorably with alternative investments available to forest landowners. This is not to say that diameter-limit cutting is more profitable in all cases. But once again, diameter-limit cutting (with a high minimum d.b.h. limit) and single-tree selection as applied in this study, are similar.

Results from this study indicate that partial cutting practices have merit, and diameter-limit cutting achieves many of the residual stand goals of single-tree selection. Selection did result in improved stand quality. However, the diameter-limit practice earned a similar rate of return and may earn a higher rate of return in the future because periodic timber sales are made up of mostly larger trees. Both practices established desirable regeneration following each harvest, and had enough residual trees to provide for sustained yield. Diameter-limits also promoted the development of some valuable intolerant species, although, in general either practice will lead to a stand of mostly tolerant species over time.

A high minimum-diameter-limit appears to be a much easier method for applying partial cutting management in central Appalachian hardwoods than single-tree selection. The observable effects on development of the residual stand and economic benefits were similar in this study. If diameter-limit practices are used, trees should be allowed to reach minimum requirements for a grade 1 butt log (16 inches d.b.h.). A higher minimum d.b.h. cutting limit is recommended--at least 17.0 inches as applied in this study.

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INTEGRATING FOREST GROWTH AND HARVESTING COST MODELS TO IMPROVE FOREST MANAGEMENT PLANNING

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Abstract: Two methods of estimating harvesting revenue -- reported stumpage prices - and delivered prices minus estimated harvesting and haul costs were compared by estimating entry cash flows and rotation net present value for three simulated even-aged forest management options that included 1 to 3 thinnings over a 90 year rotation. Revenue estimates derived from stumpage prices indicated that all thinnings were economically feasible and that net present value was maximized by initiating thinning at age 40. Revenue estimates derived from estimated harvesting costs and delivered prices revealed that thinning at age 40 yielded the lowest net present value due to high harvesting costs and negative first-entry cash flows. Stumpage-based revenue estimates also were very unstable and highly dependent upon the sawtimber utilization assumptions of the economic analysis. The results show that integrating harvesting cost models with growth-and-yield simulators can provide more stable and reliable revenue estimates over the wide range of harvesting conditions required to evaluate forest management alternatives.

INTRODUCTION

The recent development of mathematical forest growth-and-yield models has provided researchers and forest managers with very powerful and versatile tools. Models applicable to eastern hardwoods include: FIBER, OAKSIM, TWIGS, SILVAH, and STEMS (Shifley 1987). One application of these computer models is regional inventory projections (Solomon and Hosmer 1987). Another application of growth-and-yield projections, and the focus of this paper, is the economic analysis of forest management alternatives. Several of the available growth-and-yield models have been utilized to evaluate management practices such as precommercial and commercial thinnings; comparing economic returns resulting from these practices with returns from the no-thin option (Risbrudt and Pitcher 1986). This and numerous other studies have evaluated forest management alternatives by applying reported stumpage prices to projected product yields. Because stumpage prices are an integral part of those economic analyses, it is important to identify potential limitations of stumpage-price applications and to define a more reliable alternative.

Stumpage prices represent the unit price paid to forest-land owners for standing timber. The mean or median and range of prices for each tree species are reported for a state or

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geographical regions within a state (Ohio Agric. Stat. Serv. 1989, Pa. State Univ. 1988). The price range reported for each tree species generally indicates that stumpage prices are extremely variable. Consequently, published price reports often caution users that average prices reflect only market trends and largely ignore the harvest tract attributes that affect stumpage prices. These attributes include tree size, species composition, tree quality, volume harvested per acre, tract volume, accessibility, and distance to roundwood markets. As a result, reported average stumpage prices are adjusted so that prevailing regional or local harvesting and market conditions are reflected in the stumpage price paid for a specific tract.

Valuable insight regarding the application of reported stumpage prices can be obtained from the surveys of nonindustrial private forest-land (NIPF) owners conducted in four major hardwood producing states: Kentucky (Birch and Powell 1978), Ohio (Birch 1979), Pennsylvania (Birch and Dennis 1980), and West Virginia (Birch and Kingsley 1978). These survey results define the source of stumpage prices with respect to the attributes of the NIPF timber harvests representing most of the reported prices. Collectively, these surveys indicate that NIPF harvests are cash-flow oriented with little concern for silvicultural treatments. Results also indicate that sawlogs and veneer logs are the products of primary interest; that diameter limit and selection cutting account for half of the acres harvested; and that foresters are involved in tree selection on only 9 to 32 percent of the acres harvested. The harvests described often equate to high grading, or removing only the most valuable timber. Accordingly, average reported stumpage prices probably reflect the least costly method of obtaining the most valuable sawtimber.

If the average stumpage prices applied are not sensitive to stand attributes and harvesting practices, their application to the economic analysis could introduce substantial error. Prices derived from prevailing harvesting practices may not be consistent with the tree selection and wood utilization assumptions of a specific growth-and-yield projection. This can be very important when the growth-and-yield projections include thinnings in young stands, or removal of low-quality growing stock in regeneration cuts. Furthermore, applying constant stumpage prices to all scheduled entries largely ignores harvesting cost trends that have been documented for ground-based systems (Stuart 1982) and for cable-yarding systems (LeDoux 1987). These and other studies show harvesting costs decreasing with increasing tree volume and volume per acre. This trend is particularly important when growth projections include revenue estimates from early thinning, which are costly to harvest.

The objective of this study was to compare two methods of estimating net revenue from thinning and regeneration entries. One method applied reported stumpage prices. The other method estimated revenue as the residual of reported delivered-product prices minus estimated harvesting and hauling costs. This residual is often termed conversion return or conversion surplus. Comparisons include entry cash flows and the net present value (NPV) ranking of selected forest management options. These comparisons were conducted to determine the effects of stand age, harvesting conditions, and sawtimber utilization practices on estimated harvesting revenue.

METHODS

The revenue analysis utilized stand tables representing trees harvested from thinnings at ages 40 to 70 years and even-aged regeneration cuts at age 90. The growth projections were made using the OAKSIM model (Hilt 1985) to simulate growth of even-aged upland oak stands on site index 70. The initial stand table represented a fully-stocked upland oak stand at age 40 (Schnur 1937). The three even-aged forest management options compared were:

Forest Management option	Thinning	Regeneration
	---------- Age (years) ----------	
1	40,55,70	90
2	50,70	90
3	60	90

These options were selected to provide variable ages at first thinning and number of thinnings, yet conform to the 50-year projection-period constraint imposed by the OAKSIM model. All simulated thinnings reduced residual stocking to 60 percent of full stocking.

Costs and revenues were estimated for each scheduled entry using a computer program to simulate the timber harvesting operation and to estimate product yields (Baumgras 1990). This program performs two primary functions: (1) simulation of the harvesting system production rate, and (2) estimation of product yields that include factory grade sawlogs, sawbolts, and pulpwood-fuelwood. The production-rate estimates provide information required to predict stump-to-truck harvesting costs. The product-yield estimates are the basis of revenue estimates.

The timber harvesting simulation is a stochastic process that applies logging-machine-cycle time equations and delay-time distributions developed from time-and-motion study data collected in West Virginia. Machine production is modeled as a function of cut stand attributes. System production is modeled as a function of system component production to reflect system interactions. The simulated system included manual chainsaw felling with two saw operators, one mid-sized rubber-tired skidder, and a loader-slasher combination to handle bucking, sorting, and truck loading.

The simulated harvesting assumed a 50-acre tract with a maximum skid distance of 1,600 feet and a 200-foot spacing between parallel skid roads. To satisfy silvicultural objectives, all cut trees 3 inches diameter at breast height (dbh) and larger in the cut-stand tables obtained from OAKSIM were felled in each thinning or regeneration entry. However, only trees 8 inches dbh and larger were skidded and utilized. Cost rates required to estimate harvesting costs from simulated production times were based on 1989 wage rates sampled from West Virginia loggers ($6.50/hour to $8/hour plus 33 percent payroll costs) and machine investment requirements and operating costs reported by Burgess and Cubbage (1988). The resulting harvesting-cost estimates represent the cash flow required by the logger to cover all expenses

and to provide an after-tax cash flow to cover capital investment plus a 12-percent return on invested capital.

The harvesting simulation did not include trucking. Instead, estimated trucking costs were deducted from delivered prices. Trucking costs were estimated from rates published by Koger (1981), which were updated using current truck machine rates (Burgess and Cubbage 1988). Hauling cost estimates were based on a tractor-trailer combination hauling 1 mile over woods roads, 2 miles over gravel roads and the balance over 2 lane-paved roads. To estimate the impact of haul distance on net revenue, the analysis included one-way haul distances of 15, 30, and 60 miles.

The procedure for estimating product yields employs tree taper functions developed for Appalachian hardwood tree species (Martin 1981). The procedure also estimates sawlog volume by USDA Forest Service factory log grades by applying the sets of equations developed by Yaussey and others (1988), together with equations for estimating tree grade distributions by species and dbh developed for oak stands from Pennsylvania forest survey data (Dale and Brisbin 1985). Estimated sawlog volume included only logs with a scaling diameter 10 inches diameter inside bark (dib) and larger, a limit imposed by many mills that saw grade lumber. The primary analysis also imposed a 14-inch dbh limit on sawtimber trees, with limits of 12 to 15 inches tested in a sensitivity analysis.

The stumpage prices and prices paid for delivered roundwood are based on 1988 prices reported for Ohio (Ohio Agric. Stat. Serv. 1989) and Pennsylvania (Pa. State Univ. 1988). These two sources report stumpage price by species and delivered prices by species and grade. Sawlog stumpage and delivered prices represent a simple average of 1988 Ohio and Pennsylvania prices (Table 1). Pulpwood prices include a delivered price of \$45/100 ft^3 cubic feet of wood and bark (Ccf), approximately \$15/ton; and a stumpage price of \$6/Ccf, approximately \$2/ton. The pulpwood prices also were obtained from the Ohio and Pennsylvania price reports and were consistent with other published price reports.

Net revenue derived from stumpage prices (NRSP) is the product of estimated product volume and stumpage prices, where sawlog prices and yields are based only on tree species. Net revenue estimates derived from delivered prices (NRDP) reflect species, grade, harvesting costs, and haul distances of 15 miles ($NRDP_{15}$), 30 miles ($NRDP_{30}$), and 60 miles ($NRDP_{60}$). Sawtimber net revenue is the product of estimated sawlog volume and reported delivered prices minus haul costs, where volume and price reflect both species and log grade. Haul costs also were deducted from delivered pulpwood price. To simplify the analysis it was assumed that pulpwood and sawlogs were hauled the same distance.

RESULTS

The following comparisons define the potential limitations of stumpage prices when cash flows are affected by harvesting cost trends, haul costs, and sawtimber utilization practices.

These results also demonstrated the potential advantages of integrating harvesting cost models with forest growth-and-yield models to improve revenue estimates.

Table 1.--Average reported sawtimber stumpage prices and prices paid for sawlogs delivered to sawmills; for Ohio and Pennsylvania in 1988.

Tree species	Stumpage[1] price	Delivered price log grade[2]		
		1	2	3
	----------	$/Mbf, Int. 1/4	----------	
White oak	158	341	180	95
Red oak	234	412	238	104
Others[3]	80	160	109	86

[1]Reported only by tree species.
[2]USDA Forest Service factory log grades.
[3]Includes yellow-poplar and red maple.

Stand Attributes and Harvesting Cost

Important differences between thinning and regeneration entries are demonstrated by the cut-stand attributes and harvesting costs estimated for each entry (Table 2). The differences in harvesting costs largely can be attributed to total volume harvested and average merchantable volume per tree, with larger trees and heavier removals resulting in lower costs. Because of this, the timing of the first thinning is very important. Estimated first-entry stump-to-truck costs range from $59/Ccf at age 40, to $34/Ccf at age 60. Postponing of thinning for 20 years, until age 60, permitted total volume harvested to increase from 3.5 Ccf/acre to 10.1 Ccf/acre. Average volume per tree increased from 10.9 ft^3 to 16.0 ft^3 (Table 2).

Successive thinning entries of forest management options 1 and 2 also show significant harvesting cost reductions. Under option 1 estimated harvesting costs decline from $59/Ccf at age 40 to $28/Ccf at age 70 (Table 2). In contrast, harvesting cost estimates were very similar for all three regeneration entries.

The results presented in Table 2 demonstrate very important harvesting cost trends that affect potential harvesting revenue from thinning versus regeneration entries. These cost estimates are a function of the equations and distributions incorporated into the simulation model and the cost rates applied to the simulation results. Because these entries are subject to variation, the results are also variable. However, more important than the estimated cost levels are the

trends that indicate cost reductions and potential revenue gains with increasing age and volume, results supported by numerous harvesting studies.

Table 2.--Simulated cut stand attributes and stump-to-truck harvesting costs for each entry tested.

Forest mgt. option	Harvesting entry[1]	Volume harvested[2]		
		Total	Average tree	Cost
	- type-age -	- Ccf/ac. -	- ft^3 -	- $/Ccf -
1	T-40	3.5	10.9	59
	T-55	4.2	15.6	38
	T-70	5.3	23.9	28
	R-90	35.7	33.3	18
2	T-50	6.9	13.5	41
	T-70	6.8	21.2	30
	R-90	35.5	32.0	18
3	T-60	10.1	16.0	34
	R-90	37.4	29.4	20

[1]Thinning = T, Regeneration = R, age = years
[2]Trees 8-inches dbh and larger to a 4-inch top dib.

Cash Flow

The variations in estimated harvesting costs are directly reflected in the comparisons of estimated net revenue (Table 3). Revenue estimates derived from average reported stumpage prices necessarily yield a positive cash flow. However, deducting estimated harvesting and haul costs from reported delivered prices yielded several negative cash flows. These include: all age 40 thinnings, thinning at age 55 with 60-mile haul, and first thinning at age 50 with 30- or 60-mile hauls (Table 3). These negative cash flows indicate that harvesting would not be economically feasible for the logger, and would require the landowner to subsidize the thinnings. Estimates of thinning revenue derived from average stumpage prices always were greater than or equal to estimates derived from delivered prices.

Table 3.--Estimated net revenue per entry by method of estimating revenue and haul distance.

Forest mgt. option	Entry[1]	Net revenue estimate[2]			
		NRSP	$NRDP_{15}$	$NRDP_{30}$	$NRDP_{60}$
	- Type-Age -	---------- dollars/acre ----------			
1	T-40	21	-59	-69	-83
	T-55	25	15	5	-12
	T-70	123	109	96	73
	R-90	1382	1417	1321	1152
2	T-50	41	7	-10	-38
	T-70	139	110	93	64
	R-90	1283	1360	1265	1100
3	T-60	85	85	60	18
	R-90	1247	1306	1206	1036

[1]Thinning = T, Regeneration = R, age = years
[2]NRSP = stumpage based estimate
NRDP = estimate based on delivered price, harvest cost, haul cost for hauls of 15, 30, and 60 miles.

Given the relatively low cost of harvesting large sawtimber and the NIPF survey results that indicate most stumpage prices are derived from sawtimber harvests, it is not surprising that the two methods of estimating revenue produced similar results from the three regeneration entries tested. At haul distances of 15 and 30 miles, the two types of revenue estimates differed by only 2.5 to 6.0 percent of the stumpage price estimate. Increasing haul distance to 60 miles results in significant revenue reductions for all entries, a variable not reflected in stumpage prices.

Net Present Value

To compare the net present value of each forest management option, all cash flows in Table 3 were discounted to time = 40 years, using a 4 percent real interest rate and constant product prices (Table 4). Age 40 represents the time the decision is made to thin at age 40 or to postpone thinning. However, the discount period affects only the magnitude of all NPV's, not the NPV ranking of forest management options. Were a management option selected, using

the NPVs derived from stumpage prices, option 1 would be selected (Table 4). The positive cash flows from each entry and the increased final harvest revenue resulting from early thinning all favor option 1. By contrast, option 1 consistently yields the lowest ranking NPV when cash flows reflect varying harvesting and haul costs. These NPV's favor option 2 at haul distances of 15 and 30 miles, and option 3 when all products are hauled 60 miles. Furthermore, if the landowner is reluctant to invest in thinning and requires a positive cash flow from all entries, then management option 2 is also infeasible with a 30-mile haul because of the negative first-entry cash flow (Table 3).

Table 4.--Net present value of discounted harvesting cash flows for each forest management option, by method of estimating net revenue.

Forest mgt.	Source of revenue estimates			
Option	NRSP	$NRDP_{15}$	$NRDP_{30}$	$NRDP_{60}$
	NPV (dollars/acre)[1]			
1	268[2]	182	149	95
2	251	230[2]	200[2]	149
3	214	222	197	154[2]

[1]Net cash flows discounted to time = 40 years.
[2]Maximum NPV for method and haul distance.

These results indicate that the method of estimating harvesting cash flows can have a large impact on estimated NPV and forest management decisions. If we assume that the harvesting and hauling cost estimates are reasonably reliable, depending solely on stumpage prices and ignoring cost trends did not identify infeasible entries or the NPV-maximizing management options. Furthermore, ignoring harvesting cost trends implicitly assumes that the harvesting firm, not the landowner, absorbs the high cost of harvesting wood from early thinnings. Given the large supply of low-quality hardwoods, this is an unlikely scenario.

Sensitivity Analysis

The results in Tables 2 through 4 were developed applying a 14-inch dbh limit to sawtimber trees by calculating sawlog volumes only for trees 14 inches dbh and larger. Trees 8 to 13 inches dbh were utilized only for pulpwood. Although smaller trees can yield 8-inch dib grade-3 sawlogs, communications with several forest products utilization specialists in the northeast indicates that many sawmills manufacturing factory grade lumber buy only logs 10 or 12 inches dib and larger. To determine the impact of minimum sawtimber dbh on estimated revenue, dbh limits of 12 to 15 inches were evaluated with both revenue estimating methods. This comparison was conducted using the cut-stand table representing the regeneration harvest under management option 1.

Increasing the minimum sawtimber dbh reduced total sawlog volume from 9.1 Mbf/acre to 4.6 Mbf/acre, but increased the proportion of total sawlog volume in log grades 1 and 2 from 37 percent to 57 percent (Table 5). These results also show NRSP decreasing 40 percent in direct proportion to the sawlog volume reduction, declining from $1833/acre to $1093/acre (Table 5). Conversely, when decreasing the minimum sawtimber dbh from 15 to 12 inches the NRSP estimate assumes that the unit value of the incremental volume of small low-grade logs equals that of the larger sawlogs. NRSP applies the same unit value to all sawlog volume of a given species. $NRDP_{30}$ reflects both tree species and log grade. As a result, $NRDP_{30}$ decreased only 6.6 percent; from $1,349/acre to $1,258/acre (Table 5). Most of the sawlog volume reduction resulting from the increased minimum dbh was low-value grade 3 logs. When these logs are marketed as pulpwood, the relative reduction in $NRDP_{30}$ is much less than the relative reduction in sawlog volume.

Table 5.--Estimated sawlog volume harvested, percent of harvested sawlog volume by factory log grades, and net revenue by minimum sawtimber dbh. Results represent the regeneration entry under management option 1.

Minimum[1] sawtimber Dbh	Total sawlog volume	Log grades 1 and 2	Net revenue[2]	
			NRSP	$NRDP_{30}$
- Inches -	- Mbf/acre -	- Percent -	------ Dollars/acre ------	
12	9.1	37	1833	1349
13	7.9	42	1636	1345
14	6.2	50	1382	1321
15	4.6	57	1093	1258

[1]Trees smaller than minimum dbh are used only for pulpwood.
Total volume of pulpwood and sawlogs remains constant at 35.7 Ccf/acre.
[2]Harvesting cost is constant for all minimum dbh levels.

The implicit assumption of the stumpage-based estimate is that unit stumpage value is independent of wood utilization practices and the resulting log grade mix, or the wood utilization assumptions incorporated in the analysis are representative of the harvesting practices reflected in the reported stumpage prices. The large variation in NRSP estimates reflect the magnitude of the error that could result if these assumptions were invalid. For example, if reported stumpage prices reflected a 15-inch dbh limit, yet the economic analysis applied a 12-inch dbh limit with no unit price adjustment, the results would overestimate revenue by 68 percent. By comparison, the relative stability of $NRDP_{30}$ significantly lessens the impact of erroneous wood utilization assumptions (Table 5).

DISCUSSION

Both methods of projecting harvesting revenue are subject to the uncertainties affecting all economic forecasts. However, since stumpage prices represent actual landowner receipts, then these prices are conceptually a better estimator of expected revenue. Revenue estimates derived as the residual of delivered prices minus extraction costs represent only maximum stumpage payments consistent with estimated harvesting and hauling costs. Although conceptually superior, reported average stumpage prices appear to be reliable estimators only when applied to harvesting conditions and utilization practices similar to those prevalent in the stumpage price sample. When this is not the case, results indicate that large errors could occur. Whereas stumpage prices indicate that it is economically feasible to thin at ages 40 or 50 years, the inclusion of harvesting costs in the revenue estimate indicates that these thinnings could lose $10 to $83/acre (Table 3). Furthermore, erroneous assumptions regarding stumpage prices and prevalent sawtimber utilization practices could overestimate regeneration revenue by $740/acre (Table 5). In terms of cash flows, the differences in regeneration-cut revenues greatly exceed the differences in thinning revenues estimated by each method. However, the NPV effects of the two sources of error are similar.

The two methods of estimating revenue produced similar results when applied to regeneration entries and moderate haul distances, assuming a 14-inch dbh limit for sawtimber trees. This result can be interpreted as a validation of the NRDP estimates since landowner survey results indicate that stumpage prices are generally derived from sawtimber harvests, and grade lumber mills seldom utilize small grade 3 logs. For other harvesting conditions and utilization options, the large difference between revenue estimates demonstrates that estimates derived from average reported stumpage prices are insensitive to stand attributes and are very unstable over a range of sawtimber utilization options.

This research indicates that the application of delivered prices and estimated extraction costs can provide more stable and reliable revenue estimates over the wide range of harvest entries required to simulate economic returns to forest management alternatives. To reflect harvesting conditions accurately for each simulated entry, the cut stand attributes required to estimate harvesting cost can be obtained from the stand tables produced by the growth simulations. The stochastic harvesting simulation model applied in this study is not yet available. However, cost estimating programs currently available include EASTCOST (LeDoux unpub.), as well as the Auburn Harvesting Analyzer, the Harvest System Analyzer, and the Harvest System Simulator (Reisinger and others 1988). MANAGE (LeDoux 1986) is one of the few available forest planning models that integrates growth-and-yield results with detailed stump-to-mill cost estimates for eastern hardwoods.

To utilize fully the capabilities of growth-and-yield models it is important that developments in the economic analyses of forest management alternatives keep pace with the developments in growth-and-yield modeling. This requires harvesting revenue estimates that accurately reflect quality and value as well as volume, and that harvesting cost trends are an integral part of the economic analysis. Results presented demonstrate the potential effects of revenue estimation methodology on revenue estimates and management decisions. These results also

indicate the importance of integrating harvesting cost models with growth-and-yield models to improve revenue estimates.

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COMPUTERIZED ALGORITHMS FOR PARTIAL CUTS

Richard L. Ernst and Susan L. Stout[1]

Abstract: Stand density, stand structure (diameter distribution), and species composition are all changed by intermediate treatments in forest stands. To use computer stand-growth simulators to assess the effects of different treatments on stand growth and development, users must be able to duplicate silviculturally realistic treatments in the simulator. In this paper, we review the computer algorithms for partial cuts associated with the FIBER, NE-TWIGS, OAKSIM, SILVAH and YIELD-MS computer programs. We assess these algorithms with respect to flexibility, comprehensiveness, and their ability to mimic cuts prescribed in management guides for timber production. The paper also suggests directions for developing a new algorithm that incorporates the strengths of several of the existing algorithms.

INTRODUCTION

One effect of the microcomputer revolution on forestry has been the development of computer-based growth simulators and their use to test the projected outcome of alternative treatments in forest stands. The utility of these tests is greatest if the computer can duplicate effects achieved on the ground with a minimum of user effort. This paper examines the partial-cutting algorithms in five forest growth simulators, and contrasts them with respect to flexibility, comprehensiveness, and ability to duplicate the kinds of treatments recommended by silvicultural research for the production of timber products. Our focus will be on the algorithm used to implement intermediate thinnings under even-aged silviculture, but we will indicate which of the programs make provisions for other partial cuts, such as those for stands being managed under uneven-aged silvicultural systems.

Among the principal effects of intermediate thinnings are changes in stand density, stand structure, species composition, the average quality of residual trees, and spacing and uniformity of the residual stand. Silvicultural guidelines for mixed hardwoods managed for timber production, including the central and northern hardwood types of the northeastern United States (Leak and others 1987, Marquis and others 1984, Roach 1977, Roach and Gingrich 1968), consistently recommend that intermediate treatments should remove poor-quality and high-risk trees and improve residual spacing and uniformity. Residual stand density is specified through either stocking guides or residual basal area, and may vary with

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stage of stand development. We will report how each of these parameters is controlled in the thinning algorithms of the different computer programs.

COMPUTER MODELS

The life cycle of a growth and yield model typically includes periods of data collection, data analysis, model development, and finally implementation of the model in computer program code. The data collected usually cover a long span of time, in stands that have been managed in various ways. The analysis strives to identify the factors that are most highly associated with tree growth. The mathematical representation of those processes are built into a computer program.

In these models, the processes of stand development (ie. growth, mortality, management) are simplified and stated as algorithms. These algorithms are the steps that are systematically followed to mimic each actual process, much like a recipe from a cookbook. The algorithms can then be translated into computer code for inclusion into the growth and yield simulator.

Model developers make several assumptions in developing the algorithms. For all the models described in this paper, there is an assumption that the stand is uniform throughout with respect to size, species composition, quality and spacing. If a user inputs data from a stand for which this assumption is not true, the results can be absurd. As an extreme example, suppose a user entered as a single stand data from an area that was predominantly poletimber in its eastern half and and predominantly medium sawtimber in its western half. The average stand characteristics such as diameter or volume are not appropriate to either half of the stand. Any recommendation for intermediate thinning would likely be inappropriate also. In such a stand, applying a cut that emphasizes removal of small trees or large trees may result in wiping out one half of the stand while leaving the other half untouched.

Another assumption is made about growth of residual trees. The data used in building these models come from carefully controlled experiments. If the user requests removals from stands in ways that were not tested, the predicted growth response may not bear any resemblance to reality. For example, in most even-aged research plots used to develop growth response models, the residuals after intermediate treatments are some of the biggest and best trees in the stand. A simulator developed from such data would likely do a poor job of predicting growth after a cut that removed all of the big trees, leaving suppressed and intermediate trees.

Intermediate management in even-aged stands is generally in the form of thinnings. Most computerized growth and yield models allow the user to interact in some way to specify thinnings. Options range from the very interactive (such as allowing the user to specify individual trees to be removed) through completely automatic procedures. The lowest levels are very tedious and require considerable specification by the user to implement a thinning. On the other hand, the automatic modes fully control density and structure, relieving the user

of making the detailed specifications. In this paper, we review the manual specifications in the next section, then progress to the more automatic procedures in the following.

The models explored in this paper were developed using data from mixed hardwood stands in the Eastern United States. The primary purpose of these models is to estimate growth and yield from forest stands of mixed hardwoods managed primarily for the production of wood products. Each contains at least one procedure for simulating partial cuts. The procedures range from manually selecting trees from an on-screen tree list to fully automatic procedures or algorithms that simultaneously control several important characteristics of the residual stand. The following sections describe the models and the associated thinning procedures.

The simulators in FIBER, NE-TWIGS, OAKSIM, SILVAH, and YIELD-MS are distance-independent, individual-tree or stand-table projection types of simulators. They all begin with an enumeration of trees by species and diameter, and all are capable of producing a similar enumeration after projection. All simulators are available for public use on IBM compatible microcomputers. Most are being used by forest managers in central and northern hardwood forest types. Further basic information about the simulators and associated programs follows.

FIBER Version 2.0 (Solomon and others 1987)

FIBER was developed for the spruce-fir and northern hardwood forest types of New England. It is based on data from 359 spruce-fir research plots in Maine and 48 northern hardwood research plots in New Hampshire. In addition, some 2,500 growth plots, mostly from forest industry, were utilized; these plots are scattered throughout Maine, New Hampshire, Vermont, and northern New York.

Variables used in FIBER growth and mortality equations include: d.b.h., initial stand basal area, residual stand basal area, percent hardwoods, and percent species (for ingrowth).

FIBER is a two-stage matrix model. One stage is a set of linear regression equations that predicts transition probabilities of tree growth and mortality as a function of stand density, tree size, and proportion of hardwoods. These predicted probabilities are the elements of stand projection matrices used to project the distribution of diameters over a 5-year period. Projection periods in FIBER are 5 years. Minimum tree size is 5 inches; maximum tree size is 30 inches. FIBER is the one of two programs tested that currently contains an ingrowth function.

A run of FIBER is defined at the outset, and thinning can be performed during a simulation either by specifying the interval between thinnings in years or by specifying a volume or basal area that will trigger a thinning.

Various thinning strategies can be specified with a few simple parameters. The user specifies when and how much to thin. The residual level for the partial cut is specified as a basal area,

a volume, or the B-level on northern hardwood, mixed-wood, or spruce-fir stocking guides reproduced in the FIBER documentation.

Thinning treatments can be specified as 1) no thinning, 2) thin-from-above, 3) thin-from-below, 4) diameter class removal, 5) uniform thinning, and 6) q-line thinning. The no thinning option continues to grow the stand. For the thin-from-above, -below, and uniform, a percentage of the total cut to remove from each species must be specified. If that specification results in removing more than is present, then the excess is distributed to other species in the priority that the user assigns to each species. With the thin-from-above option, the user specifies a beginning diameter and the program removes trees starting at that diameter and continues to smaller size classes until the amount specified has been removed. The thin-from-below is similar except that the program removes trees starting at the specified diameter and continues to larger diameters. The uniform thinning spreads the amount to be removed from each species evenly over all diameter classes of that species. The diameter class removal option is used interactively, and allows the user to specify the number of trees to remove from a given species and diameter class. The final option, q-line thinning, allows the user to specify the structure for an uneven-aged cut.

NE-TWIGS Version 2.0 (Hilt and Teck 1989)

NE-TWIGS was developed for general use throughout the Northeastern United States. It used the large data base of the Forest Inventory and Analysis Unit, which includes more than 4000 permanent 0.20 acre plots. Growth records on these plots cover an average of 12 years and include all forest types and species growing in the Northeast.

NE-TWIGS utilizes the computer shell developed by the North Central Forest Experiment Station for their Lake States and North Central TWIGS simulators (Belcher 1982). However, the growth and mortality equations in the NE variant differ in several ways from the NC and LS variants.

NE-TWIGS is a distance-independent, individual tree simulator. It works either from a tree list or a stand table, and is capable of handling fractional trees (it will accommodate a unit as small as 0.1 tree/acre).

Variables used in NE-TWIGS to estimate growth and mortality include: species, d.b.h., BAL (basal area in trees larger than the tree in question), and site index. As with the other TWIGS models, the NE variant calculates potential growth, then reduces that growth by competitive position (BAL). NE-TWIGS projects in growth periods of 1 year. Minimum diameter is 1 inch; maximum diameter is 30 inches. NE-TWIGS is one of two programs tested that currently contains an ingrowth function.

Runs of NE-TWIGS can be automatic, with user-defined interactive management at specified intervals, or highly interactive, with user specifications of reports, management activities, and additional projections at the end of each projection period. There is no mode in which

management occurs whenever simulated stand development reaches a threshold basal area or relative density.

Thinnings are specified by creating a list of priorities from nine different removal procedures. Up to five procedures may be combined to generate the marking rules used by practicing foresters. Of the nine removal procedures, the first six specify the trees to be removed until the target residual-basal area is reached. The last three are procedures that override the target residual-basal area. The procedures are, 1) remove rough and rotten from size class, 2) remove smallest trees of all species not specified to leave, 3) remove largest trees of all species not specified to leave, 4) remove smallest trees of specified species, 5) remove largest trees of specified species, 6) shelterwood cut leaving the largest diameter and highest crown ratio trees, 7) reduce the number of trees to specified residual level, 8) remove overtopping trees, essentially a diameter limit, and 9) remove all trees of a user specified size and species.

OAKSIM (Hilt 1985a, 1985b)

OAKSIM was developed for oak-hickory forests of the upland central hardwood region. Growth and mortality data come from 20-year records on 77 permanent growth and yield plots in southern Ohio and southeastern Kentucky. White oak, black oak, and scarlet oak were the most common species on the plots, with other upland hardwoods represented in varying amounts. A single growth equation is used for all species, but there are four mortality equations; one each for black oaks, white oaks, other trees (primarily hickory), and understory trees. Adjustments are made to total stand growth by use of equations from GROAK (Dale 1972), a stand level simulator developed from the same data set.

Variables used in OAKSIM equations include: d.b.h., quadratic mean stand diameter (QMD), total stand basal area, site index, and species (mortality only).

OAKSIM is a distance-independent, individual tree simulator. It works from a tree list and treats each tree in that list (each sample) as an entity, either killing it or growing it in its entirety.

Runs of OAKSIM are defined at the beginning of a run. Thinnings are scheduled by the user, who specifies the age, residual density, the intensity codes for each species group, and the residual density (in percent stocking by the Oak Stocking Chart) for each thinning.

If a thinning is desired, the user specifies the residual density, and the entire distribution is done automatically. The distribution of cut is based on a mathematical model of actual thinnings. Application of this thinning algorithm ensures residual stands that duplicate as closely as possible the actual study plot residuals. The percentage to cut from any diameter class is a function of the residual density and the cumulative frequency of live trees in the stand. While this ensures that irregularities in the original stand are not increased, it does nothing to alter these irregularities.

The user can specify three options to control the species composition effects of this thinning algorithm. While the number of trees to cut within any diameter class is fixed by an equation, the user can specify the allocation of that cut across species within each class. The choices are to 1) maintain the same proportion in each species as in the unthinned stand, 2) double the cut for a species, or 3) eliminate a species.

There are no provisions for partial cuts under uneven-aged silvicultural systems or for user-designed cuts in the OAKSIM program. The research plots that were used to provide the data from which OAKSIM was developed were all even-aged.

SILVAH Version 4.04 (Marquis 1986)[2]

SILVAH was developed for use in hardwood forests of the Allegheny Plateau region of Pennsylvania, New York, West Virginia, Maryland, and Ohio. The SILVAH program is primarily a decision-support system used in making silvicultural decisions, but it includes a stand growth simulator as an important component.

Growth data in SILVAH comes from two major sources. Data on the cherry-maple and beech-birch-maple types came from approximately 370 tallies of long-term research plots in northwestern Pennsylvania, some of which span 55 years of continuous record. These data have been used to develop separate growth and mortality equations for black cherry, red maple, sugar maple, and American beech. Other non-oak species are calculated from the equations of one of these species. Equations for growth of species of the oak-hickory type in SILVAH came from OAKSIM. The equations were simply taken from OAKSIM, and used for all oak species. Growth adjustments included in OAKSIM based on the stand growth simulator GROAK are not included in SILVAH.

Variables used in SILVAH growth and mortality equations include: species, d.b.h., relative diameter (d.b.h./stand diameter), relative stand density (total basal area for oaks), and site index (oaks only). SILVAH is a modified stand table projection simulator. SILVAH works with per acre data, and permits fractional trees/acre to die or move in d.b.h. class.

SILVAH offers a range of run options, from interactive through automatic. In the most automatic mode, partial cuts are triggered by growth to a program-set threshold density. Volumes available for cutting must also meet user-specified levels for the program to implement an automatic cut. In the most interactive mode, a user selects any treatment(s), including customized ones, at the end of each growth period. SILVAH does not include a facility for editing the current stand table as one way of describing a partial cut.

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[2]Marquis, David A. and Richard L. Ernst. In preparation. User's guide to SILVAH: a stand analysis, prescription, and management simulator program for hardwood stands of the Alleghenies. Available from the authors.

The thinning algorithm in the SILVAH programs is described in detail elsewhere[3]. For even-aged partial cuts, the distribution procedure uses a negative exponential function to ensure that a specified proportion of the cut density is removed in trees smaller than the medial stand diameter (MD). The medial stand diameter represents the point where half the basal area is below and half the basal area is above. This distribution procedure does not account for any irregularities in the existing diameter distribution, however, and can result in severe cutting in some size classes in stands with irregular distributions. For all-aged cuts, an idealized inverse J-shaped curve, based on q, is transformed into the equivalent relative density. All density in excess of this curve is removed. If the original stand is deficient with respect to the target density in any size class, additional density is left in smaller classes to compensate. The automatic thinning algorithm assigns a cut proportion to each diameter class, and maintains the species composition of each diameter class as it was in the unthinned stand.

In addition to the automatic prescription generation option, users may either select a standard silvicultural prescription (alternatives include precommercial, combined precommercial/commercial, and commercial thinnings, thin-harvests, shelterwood seed cuts, and selection system cuts). Users may also design a partial cut by combining information about species, density, and structure. For each of these criteria, a single value, or a range of values can be specified; trees that simultaneously meet all three conditions are removed. In addition, this option allows the user to specify the priority for each removal; the user specifies those trees that are to be removed unconditionally, or subject to a minimum residual density.

YIELD-MS Version 1.1 (Hepp 1988)

YIELD-MS is the timber yield and planning module of the Tennessee Valley Authority's (TVA's) package of inventory, analysis, and economic analysis programs for timber managers working in mixed species stands. The YIELD-MS component is where the user has the opportunity to impose management procedures, such as partial cuts, and obtain stand growth projections.

Growth projections in YIELD-MS are stand table projections. Each species group and diameter class has a d.b.h. growth rate and a survival probability. Users may enter d.b.h. growth rates from a file, from increment core data particular to a stand, or by direct user entry. However, the preferred mode of growth projection is use of growth and survival probability equations from any of four other stand-growth simulators. These are OAKSIM, SILVAH, TWIGS (Shifley 1987), and G-HAT (Harrison and others 1986a, 1986b). The growth projection routine in YIELD-MS uses these equations but does not use any modifiers from the original programs. So, the results of simulating the growth of a stand with YIELD-

[3]Ernst, Richard L. and Susan L. Stout. In preparation. A computerized method for developing marking guides for forest stands. Available from the authors.

MS, using the OAKSIM equations, for example, may not be the same as simulating the growth of that stand using OAKSIM.

Data entry and inventory processing are accomplished in other programs in the TVA package. Diameters must be in 1-inch classes. Minimum diameter is 1 inch; there is no apparent maximum diameter.

Runs of YIELD-MS are interactive. Selecting trees for thinning can be in manual or automatic tree marking modes. The automatic tree marking mode allows the user to specify a percentage of a species, product, and size to remove. The program calculates the basal area in all trees that meet the three criteria, then removes the proportion of those trees as specified by the user. The product criteria consists of specifying grades 1 through 5 and pulpwood. The size criteria allows the user to specify that the removals occur equally across all diameters, from the biggest trees, from the smallest trees, from the most valuable trees, or from the least valuable trees.

The manual marking mode allows the user to edit the contents of the individual cells of a stand table on-screen. Although tedious, this method allows the most flexibility. The stand table is displayed on the screen, and it can be in any of the units supported such as number of trees, volume, value, and so on. The user changes the value in the cell, and the tables for cut and leave are adjusted.

SUMMARY OF PARTIAL CUT ALGORITHM OPTIONS

Tables 1 and 2 summarize the partial-cut options in these computer programs. In Table 1, the options for automatic partial-cut implementation are summarized. These are the options that allow the user to specify a few characterizing parameters, from which the computer program develops a comprehensive description of the cut. Table 2 summarizes the tools each program provides for users to develop customized partial cuts. The array of possibilities is extensive, as these tables and this summary show. There are uniquely advantageous features in each program, but no program includes all features.

Our assessment of the flexibility and comprehensiveness of the partial-cut procedures in these programs is necessarily subject to our own biases, experience, and computer use styles. We suggest that those programs with many customizing features in Table 2 are the most flexible. Those with many automatic features in Table 1 are the most comprehensive. Mastering any of these computer programs requires a learning period. While this period may be shorter for programs with the fewest options on both tables, those with many automatic features are easiest to use if many alternatives are to be tested. It is possible to construct most common silvicultural treatments with FIBER,NE-TWIGS, SILVAH, and YIELD-MS.

Table 1.--Automatic cut generation features

Simulator	Thinning timing[1]	Density control[2]	Even-age structure control[3]	Uneven-age structure control[4]	Other[5]
FIBER	A, Y, T, I	BA, V, ST	D	Q, MX	Q
NE-TWIGS	Y, I	BA	-	Q, MX	Q
OAKSIM	A,Y	ST	F	-	Q, S
SILVAH	Y, T, I	RD	P	Q, MX	Q, N
YIELD-MS	I	BA	-	-	Q

[1]A = Thin at given age, Y = thin after given number of years, T = thin when stand reaches threshold, I = interactive
[2]BA = basal area, V = volume, NT = number of trees, RD = relative density, ST = stocking guide level
[3]D = default quality and species removal priorities, P = power function, F = fitted function to research data
[4]Q = quotient, MX = max tree size
[5]Q = quality adjustment, S = species adjustment, N = select treatment by name

Table 2.--Customized cut generation features.

Simulator	Density control[1]	Cut from above	Cut from below	Cut uniform	Cut species	Save species	Cut dia class	Cut poor quality	Combine	Tree list edit	Other[2]
FIBER	BA, V, ST	•	•	•	•		•				
NE-TWIGS	BA	•	•		•	•	•	•	•		
OAKSIM	ST				•		•				
SILVAH	RD			•	•		•	•	•		N
YIELD-MS	BA				•		•	•	•	•	

[1]BA = basal area, V = volume, NT = number of trees, RD = relative density, ST = stocking guide level
[2]N = select treatment by name

AUTOMATIC CUTS FOR EVEN-AGE STRUCTURE CONTROL

Three of the programs considered in this paper offer automatic structure control when applying even-aged thinnings. These automatic cutting options are important for a variety of reasons. The first is that these automatic cutting algorithms usually represent the model developer's best effort to mimic the kind of thinnings implemented on the research plots from

which the model was developed, and the model should most closely mimic the growth of real stands cut in these ways. The second is that because these options are often the easiest to implement, users take advantage of them, and a fuller understanding of their consequences improves use of the models. As we will show in this paper, the algorithms act in different ways on stands with different structures. An understanding of these differences also improves use of the models. Finally, a discussion of the algorithms actually used in different programs will enable those working on future model development to draw on the best of several existing algorithms.

Users of FIBER may request a thinning to the B-line of any of the stocking guides reproduced in the FIBER documentation (Solomon and others 1987), but this documentation does not describe the implementation of this procedure. Both OAKSIM and SILVAH use mathematical functions to distribute removals among diameter classes and species.

We will show the effects of these two procedures on two different oak stands, with quite different original structures. The first example is based on Schnur's (1937) yield table for 90-year-old oak on a site index 70 site (Figures 1a and 1b). This stand is typical of the structure and species composition of stands used to develop the OAKSIM model. The second stand is from a transition oak stand in northwestern Pennsylvania (Figures 2a and 2b), and is typical of the stand structure, density, and species composition found in that region and other areas in which stands of northern red oak and northern hardwood species are common (Stout in press). It is similar in structure to the stands used to develop the growth and yield model in SILVAH.

The OAKSIM procedure is described in detail in the OAKSIM documentation (Hilt 1986b). The function used was developed to describe the removals on the research thinning plots that yielded the data used to develop OAKSIM. Users may adjust the application of this procedure by species and residual density, but may not adjust the minimum cutting diameter, which is set at the smallest diameter class in the stand. The function determines the cut frequency in each diameter class as a function of the cumulative frequency from the smallest class and of the residual thinning density. This procedure automatically ensures that in irregularly small classes, the cut will be small, and in irregularly large classes, the cut will be large, still ensuring that the designated total cut is achieved. Nothing is done to smooth such irregularities. Figures 1a and 2a show the diameter distribution of Schnur's SI 70, 90-year-old oak stand and the Pennsylvania oak stand, respectively, with each diameter class separated into cut or leave trees according to the OAKSIM thinning function.

The SILVAH procedure uses a modified negative exponential function, which guarantees that for cuts from below (those in which more than half the cut will come from trees lower than MD), the largest proportion of the cut will come from the smallest class for cutting, and each successive class will have a slightly smaller cut. After the equation is applied to 1- or 2-inch diameter classes, the cut from several adjacent classes (the 6- through 11-inch classes for poletimber, for example) is accumulated into a class proportion. This reduces the smoothness of the cut, but yields a more realistic marking guide for woods use. Users may adjust the residual relative density and the proportion of the cut to be made in trees less than MD. Users have some control over the minimum diameter in which cutting is to occur. The

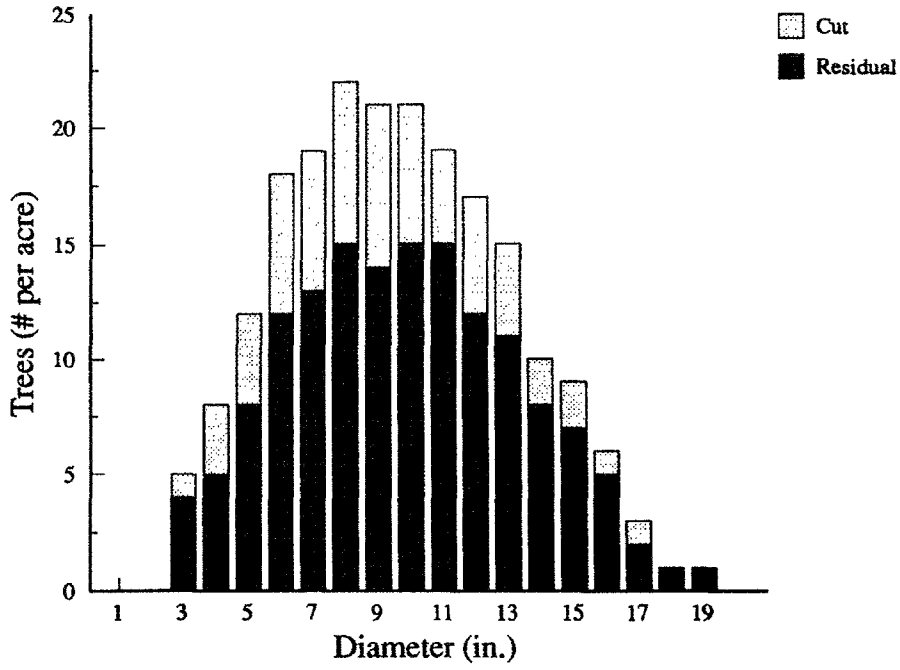

Figure 1a. Cut and residual trees in Schnur's SI 70, 90-year-old stand after a thinning as prescribed by OAKSIM.

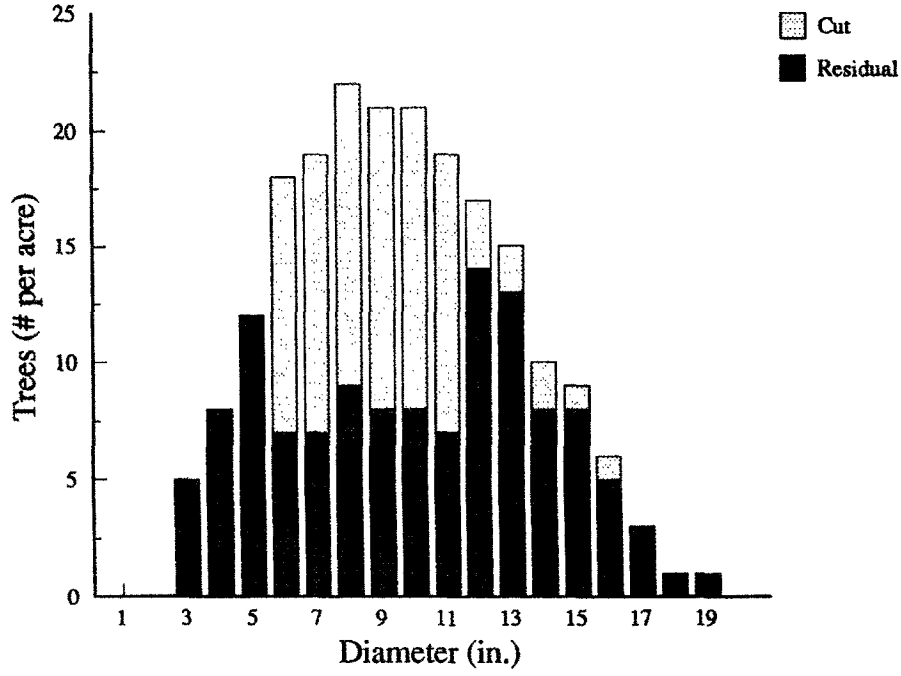

Figure 1b. Cut and residual trees in Schnur's SI 70, 90-year-old stand after a commercial thinning with 75 percent of the density removed in trees smaller than MD as prescribed by SILVAH.

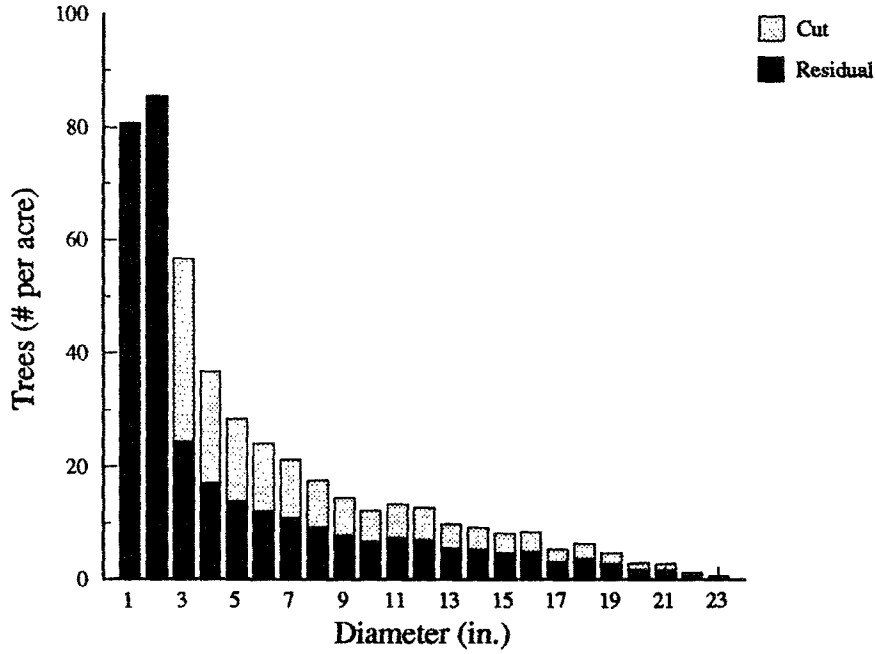

Figure 2a. Cut and residual trees in a Pennsylvania oak stand after a thinning as prescribed by OAKSIM.

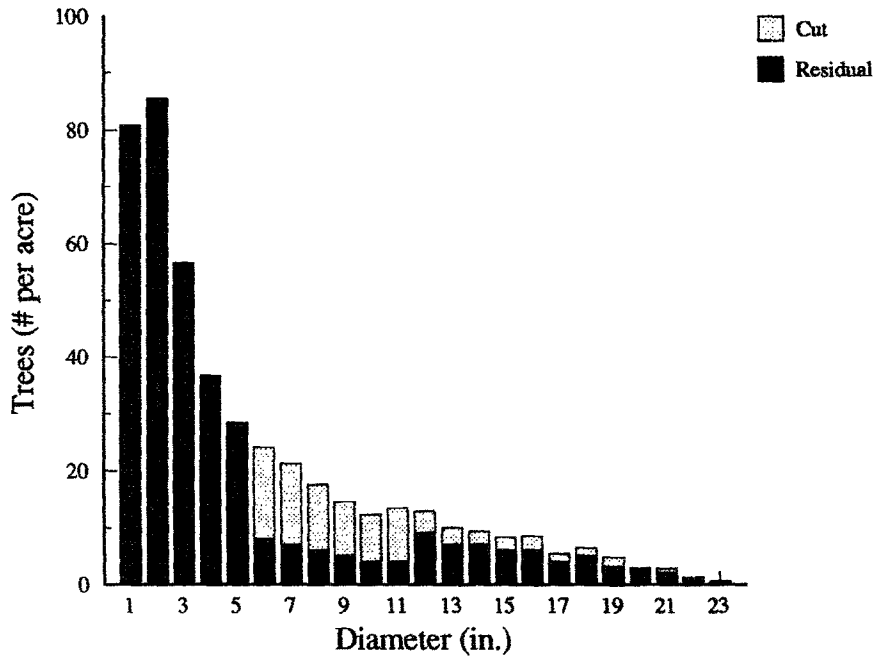

Figure 2b. Cut and residual trees in a Pennsylvania oak stand after a commercial thinning with 75 percent of the density removed in trees smaller than MD as prescribed by SILVAH.

procedure largely ignores irregularities in the original diameter distribution, although adjustments are made when the procedure calls for removal of more trees than are present in a diameter class.

Figures 1b and 2b show the same stands as Figures 1a and 2a, with each diameter class divided into cut or leave trees according to the SILVAH default function for a commercial thinning. The two procedures have quite different effects on both of these stands. In each stand, there are differences in the smallest size classes and differences in the overall structure of the residual stand. Each of these differences is a consequence of the thinning algorithm and its constraints.

The Schnur stand has the even-aged stand structure, or diameter distribution, traditionally associated with forest types in which the species are similar in growth rate and tolerance to shade. In this stand, the OAKSIM algorithm identifies trees for cutting from the 3-inch through the 17-inch class, all in proportion to their presence in the existing stand (Figure 1a). SILVAH's algorithm includes no cutting in the sub-merchantable size classes in this stand. In addition, SILVAH's algorithm stipulates that 75% of the density to be removed will be in trees with diameters smaller than MD. In this stand, this results in a much heavier cut in the poletimber classes and somewhat lighter cut in the sawtimber classes (Figure 2a). Both residual stands have a bell-shaped distribution in the merchantable classes. In the OAKSIM distribution this bell-shape extends into the sub-merchantable classes.

The Pennsylvania transition oak stand has the inverse-J shaped diameter distribution frequently found in even-aged hardwood stands with a mix of species of different growth rate and tolerance for shade. Once again, differences in threshold diameter for cutting are apparent in the residual stands, although in this stand, the fact that trees less than 3 inches in diameter are not processed by OAKSIM is apparent. SILVAH's algorithm concentrates the cut in this stand in the 6-, 8-, and 10-inch classes, and establishes a bell-shaped distribution, particularly in the 10- through 24-inch classes. The residual from the OAKSIM thinning algorithm retains its original, inverse-J shape.

A comparison of the effects of thinning algorithms on different stands is made more difficult by the absence of a universal measure of relative density. Both algorithms use relative density to control the total amount of removals, but the density measure is different. OAKSIM uses the Oak Stocking Guide (Roach and Gingrich 1968), while SILVAH uses a tree-area ratio based measure with three species groups (Marquis and others 1984, Stout and Nyland 1986).[4] In stands with species from more than one species group, similar basal areas may represent different densities, and similar densities may represent different basal areas (Stout and others 1987). It is very difficult to impose thinnings that leave residual stands that are similar in both absolute and relative density across the two measures. For the purposes of focusing on the thinning algorithms, we have concentrated on the structure of the cuts, rather than on the absolute amounts removed.

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[4]Ernst, Richard L. and Susan L. Stout. In preparation. A computerized method for developing marking guides for forest stands. Available from the authors.

Both procedures allow the user to specify the residual density for thinnings in the density measure associated with the model. OAKSIM uses the residual density in the cumulative cut function and varies both the absolute amount to be cut in each class and the proportion of the cut assigned. SILVAH maintains the same proportions for the cut, but increases or decreases the absolute amount in each size class according to the selected residual densities. Users may, however, specify the proportion of the cut to be assigned to diameter classes below MD, and hence the proportion of the cut in each size class.

CONCLUSIONS

This examination of the computerized procedures for implementing partial cuts in computerized forest stand-growth simulators points to an opportunity to develop a new procedure for implementing even-aged thinnings automatically. OAKSIM uses a cumulative distribution function, but is inflexible with respect to structure. While SILVAH is flexible, its procedure is relatively insensitive to the original stand structure. Both procedures are tightly tied to the structure of the stands in the data bases from which they were developed. Neither procedure alters the prescribed residual to compensate for irregularities in the existing distribution, and the SILVAH procedure actually can worsen these irregularities if applied blindly.

One new approach would be to use a distribution function for the cut, as SILVAH does, and then to distribute it on a cumulative basis as OAKSIM does. This would eliminate the shortcomings of both methods. Such a function could include built-in flexibility to handle different structures for thinnings or shelterwood cuts near stand maturity, for example.

Another approach would be to develop automatic procedures for partial cuts under even-age systems that mimic the procedures in wide use for partial cuts under uneven-age systems. The procedures for distributing partial cuts under uneven-age systems involve description of a target residual distribution by size class and removal of those trees that exceed the target distribution. Some procedures include a step to modify the target distribution to compensate for deficiencies in the present stand. The various silvicultural guides in use throughout the Central Hardwood region suggest that even-age thinnings should be applied to increase the stand diameter (shorten the rotation length), and favor the biggest and best trees. Some guides specify narrowing the range of diameters. These characteristics could be translated to a target residual structure for even-aged stands and a procedure used that would prescribe cutting the trees in excess of the target distribution.

This examination of the computerized partial cut procedures available in commonly used computer stand-growth simulators has demonstrated the wide range of alternatives available, and can form the basis for development of an integrated, flexible, comprehensive and user-friendly set of procedures for future versions of existing simulators or new decision support programs, such as that being developed under the auspices of the Northeastern Forest Experiment Station (Marquis 1990). All programs examined here control density, quality, and structure in the residual stands either directly or indirectly. A complete partial cutting module

could be derived by using the best components of each of the individual procedures. Such a module should allow for totally automatic distribution of cut that controls density, quality, and structure. It should also allow complete and flexible manual intervention.

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THE INTERACTIVE IMPACT OF FOREST SITE AND STAND ATTRIBUTES AND LOGGING TECHNOLOGY ON STAND MANAGEMENT

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Abstract: The impact of selected site and stand attributes on stand management is demonstrated using actual forest model plot data and a complete systems simulation model called MANAGE[2]. The influence of terrain on the type of logging technology required to log a stand and the resulting impact on stand management is also illustrated. The results can be used by managers and planners in making decisions on how best to manage the hardwood resource.

INTRODUCTION

Intensive management of immature eastern hardwood stands has received increased attention (U.S. Department of Agriculture 1981, Smith and Eye 1986). Economic returns to management activities in these stands are affected by logging and processing technology and transport costs (LeDoux 1988a). Hardwood market trends, stand growth-and-yield response, stand composition, and landowner objectives also influence hardwood management decisions.

Decision makers and planners need to know which site and stand attributes affect costs and benefits and to understand how these variables interact for a particular management plan. Plans must incorporate short- and long-term effects of site and stand variables on management. Additionally, the choice of logging technology significantly can constrain stand management options.

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[2]The computer program described in this publication is available on request with the understanding that the U.S. Department of Agriculture cannot assure its accuracy, completeness, reliability, or suitability for any other purpose than that reported. The recipient may not assert any proprietary rights thereto nor represent it to anyone as other than a Government-produced computer program.

METHODS

In this article, the effect of site and stand attributes, and logging technology on stand management is evaluated with a complete systems simulation model called MANAGE (LeDoux 1986). MANAGE, a computer program written in FORTRAN 77, integrates harvesting technology, silvicultural treatments, market prices, and economic criteria over the life of a stand. The simulation combines discrete and stochastic subroutines to model harvesting cost, silvicultural treatments, growth projections, and to conduct discounted cash flow (SEV) analysis. The model can be used to develop optimal management guidelines for eastern hardwoods. The results also can help planners and managers understand the impact of site and stand variables on costs, benefits, and returns to management practices.

Stand Tables

The stand tables used to initiate the simulations were those published by Schnur (1937) for even-aged upland oak forests (Table 1). These tables represent projected conditions by site index and age for fully stocked upland oak stands. To insure that all first thinning entries were economically feasible, the ages of the stand tables selected to initiate the simulations varied by site index. For example, the average diameter of the initial stands averaged about 8 inches and the starting volume averaged about 2500 ft^3/acre (Table 1). Because it takes longer to attain average d.b.h. of 8 inches or poor sites than better sites, simulation begins later for low site indexes.

The initial tree lists by site index were entered into MANAGE and the growth and yield was projected for a variety of management scenarios. Cable and ground-based logging technology were evaluated by site index for each stand. The costs and benefits by site index were simulated and summarized on a cash flow and discounted cash flow soil expectation basis.

Logging Technology

The interaction of logging technology and stand attributes by site index was evaluated by assuming that the stands shown in Table 1 were located on both steep and gentle terrain. The Clearwater[3] yarder (LeDoux 1987) was used to simulate harvesting of the stands for the steep terrain applications. The Clearwater yarder is a medium size yarder capable of yarding small and large logs. A John Deere 540B rubber-tired skidder was used to simulate the harvest of

[3]The use of trade, firm, or corporation names in this publication is for the information and convenience of the reader. Such use does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that may be suitable.

the stands on gentle terrain applications (LeDoux 1985; LeDoux 1988b). The John Deere 540B is a medium size skidder capable of skidding small and large logs. Figures 1 and 2 show the John Deere 540B and Clearwater yarder, respectively. The costs for the above machines were estimated using EASTCOST (LeDoux 1988b). The streams of cost and benefits were summarized by treatment, site index, and logging technology and presented on a soil expectation basis. The delivered product prices used are shown in Table 2 and were obtained from Coastal Lumber Company, Hopwood, PA and Forest Product Price Bulletins (Ohio, 1989; Penn State, 1989; Tennessee, 1989).

Table 1.--Initial attributes of timber stands; average d.b.h., ft^3 volume, age, trees, and species mix, by site index, for even-aged upland oak stands.

					Species				
Site index	Mean DBH	Vol	Age	Trees/ acre	Red maple	White ash	White oak	Red oak	Hickory
	Inches	Ft^3/ acre	Years		Percent				
50	8.3	2535	90	284	5.0	6.0	57.0	25.0	7.0
60	8.4	2474	70	271	6.0	6.0	51.0	32.0	5.0
70	8.8	2596	60	258	5.0	6.0	45.0	38.0	6.0
80	8.9	2612	50	249	5.0	6.0	38.0	45.0	6.0

Table 2.--Delivered prices for sawlogs and fuelwood/pulpwood by species.

Species	Large[1] sawlogs	Medium[2] sawlogs	Small[3] sawlogs	Fuelwood/[4] pulpwood
	$/Mbf (Doyle Rule)			-$/Cord-
Red Maple	210	160	80	30
White Ash	500	300	100	30
White Oak	500	300	100	30
Red Oak	600	350	100	30
Hickory	210	160	100	30

[1]Minimum small end diameter $\geq$ 13 inches, length $\geq$ 10 feet.
[2]Minimum small end diameter $\geq$ 11 inches, length $\geq$ 8 feet.
[3]Minimum small end diameter $\geq$ 10 inches, length $\geq$ 8 feet.
[4]89 ft^3/cord, minimum small end diameter $\geq$ 4.0 inches that will not make large, medium, or small sawlogs.

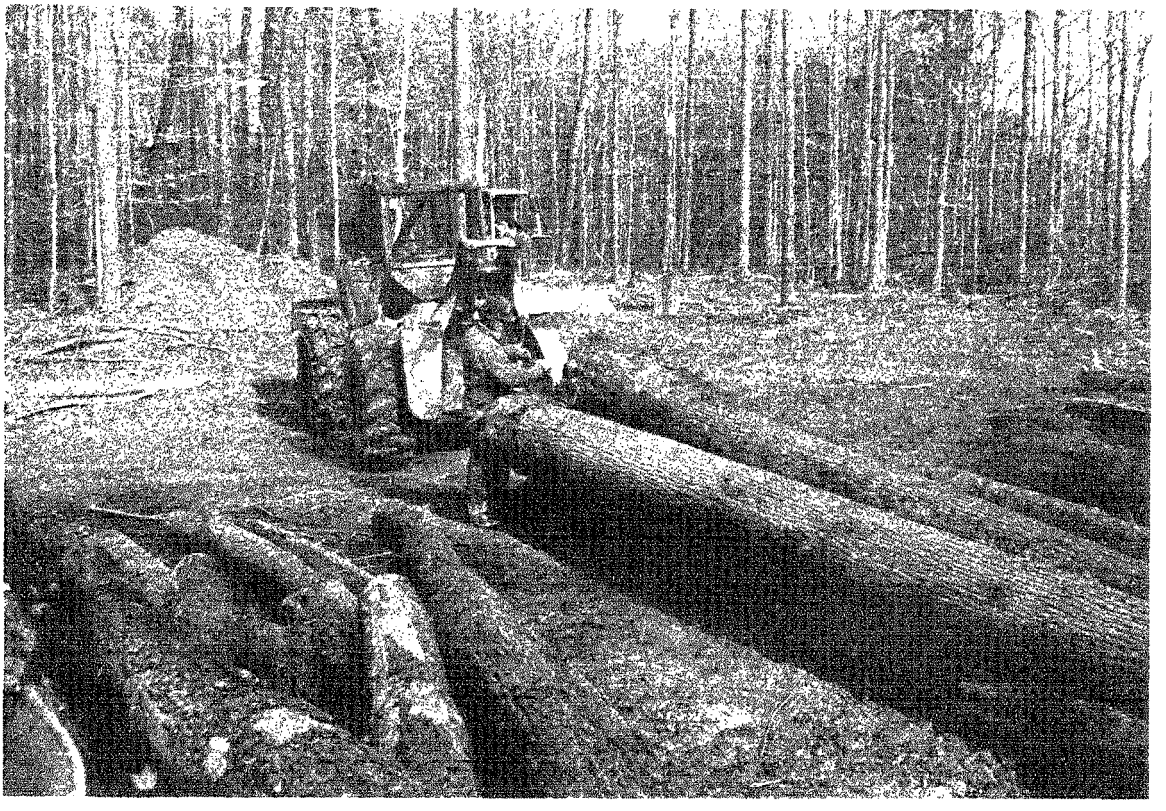

Figure 1. The John Deere 540B skidder.

Management Objectives

For comparison purposes, the stands were subjected to one thinning and then projected to optimal (The maximizing of SEV.) rotation age by logging technology. Soil expectation value (SEV) is used to compare returns[4]. Initial thinning ages were defined as the earliest age that a stand could be commercially thinned by the logging technology specified and pay for itself or at least break even. Area versus crop-tree-release thinnings were simulated with the objective of producing quality sawlogs at final harvest.

[4]The soil expectation value is a maximizing of the present net worth of revenues minus costs from an acre of bare ground and all future stands on that acre.

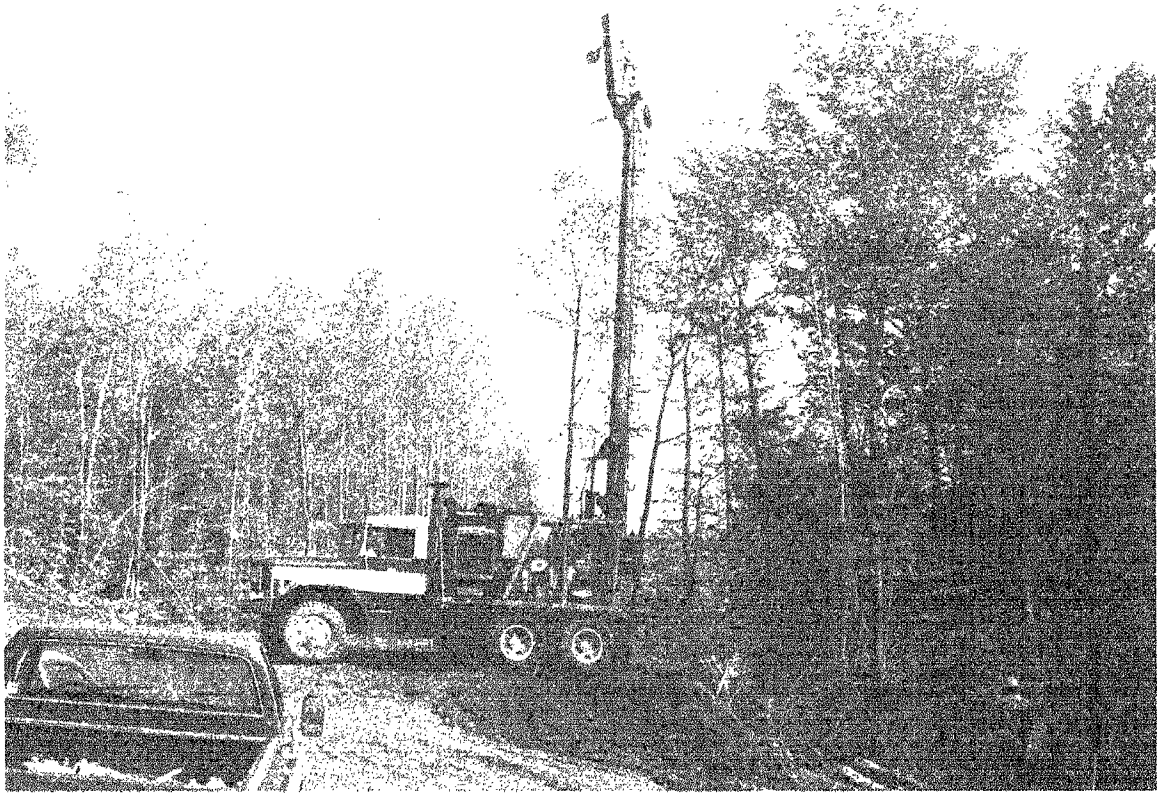

Figure 2. The Clearwater cable yarder.

RESULTS

The results indicate that lower site-index stands have lower soil expectation values and longer optimal rotations. Comparing the optimal rotation length for the John Deere 540B skidder by site index shows the effect of site index on soil expectation and rotation length. For example, site index 50 has a soil expectation value of $2.03/acre with an optimal rotation age of 195 years. By contrast, a site-index-80 stand has a soil expectation value of $32.55/acre with an optimal rotation age of 130 years (Fig. 3). Higher site indexes generally resulted in larger average d.b.h. trees at optimal rotation and greater yields. It is interesting to note that the optimal rotation ages generally are producing trees that average 15 to 16 inches d.b.h.

The effects of logging technology also are shown in Figure 3. Generally, use of cable logging to harvest the stands resulted in optimal rotation lengths 10 years longer than when using the ground-based system, the John Deere 540B skidder. This is due to delaying of thinnings by 5 years and harvesting more trees and volume from thinnings to offset the high

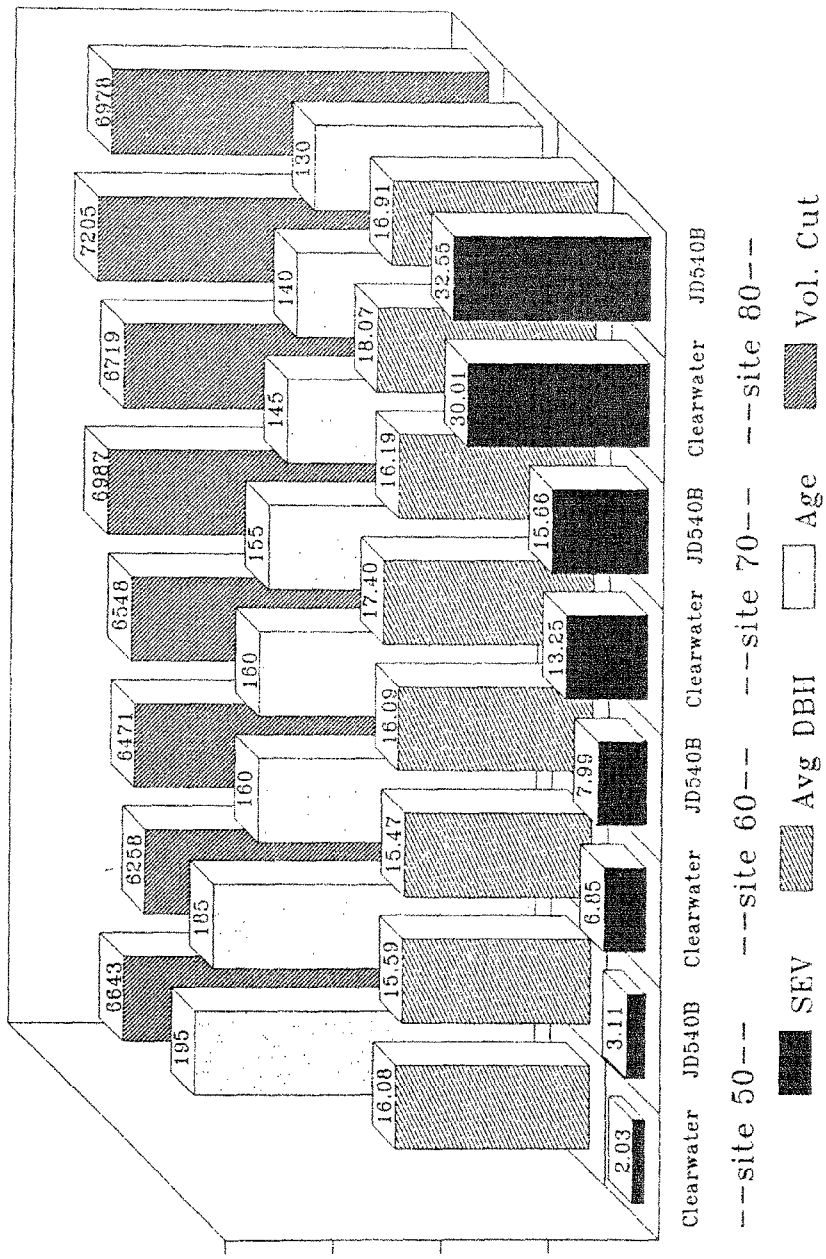

Figure 3. Soil expectation, average d.b.h., optimal rotation length, and total volume harvested at optimal rotation age by site index and logging technology.

costs of expensive skyline logging systems. As a result, the average d.b.h. and value of trees removed in thinning were greater when cable logging technology was applied. The increase in average d.b.h. results from stands being grown 10 years longer than when ground-based systems were used. Figure 3 shows the soil expectation value for the optimal rotation length by site index. The results include cash flows from both thinnings and final harvests.

Table 3.--Net cash-flow components from commercial thinning (CT) and final harvest (FH) by logging technology and site index.

Entry (years)	Average d.b.h.	Volume removed	Gross revenue	Total stump-to-mill cost	Net cash flow
	Inches	ft^3/acre	Dollars/acre		
		Site Index 50 and John Deere 540B			
CT-110	12.51	2304.80	1063.09	939.94	123.15
FH-185	12.59	3952.73	3435.14	1368.7	22066.42
		Site Index 50 and Clearwater			
CT-115	13.05	2493.32	1280.99	1180.98	100.01
FH-195	16.08	4149.84	3692.20	1749.54	1942.66
		Site Index 60 and John Deere 540B			
CT-90	12.65	2558.52	1142.38	1019.43	122.95
FH-160	16.09	3989.97	3690.82	1364.11	2326.71
		Site Index 60 and Clearwater			
CT-95	13.17	2781.67	1477.27	1307.57	169.70
FH-160	15.47	3689.72	3051.62	1589.45	1462.17
		Site Index 70 and John Deere 540B			
CT-75	12.65	2462.80	1089.15	987.70	101.45
FH-145	16.19	4256.28	4469.47	1443.78	3025.69
		Site Index 70 and Clearwater			
CT-80	12.94	2911.28	1533.95	1379.20	154.75
FH-155	17.40	4075.24	4496.52	1655.87	2840.65
		Site Index 80 and John Deere 540B			
CT-65	12.83	2663.76	1187.14	1047.97	139.17
FH-130	16.91	4313.79	4960.93	1438.74	3522.19
		Site Index 80 and Clearwater			
CT-70	13.11	3096.87	1712.40	1455.60	256.80
FH-140	18.07	4108.00	4893.95	1641.78	3252.17

Table 3 shows the average d.b.h., volume harvested (ft^3), undiscounted cash flows by entry and final harvest for each site index and logging technology. Generally, stands could be thinned at an earlier age for each site index when using ground based systems. This is due largely to the use of cable systems resulting in higher harvesting cost and the thinning delayed by 5 years until the trees were larger and were valuable. Thinnings become economical for the rubber-tired skidder when the trees average about 12 inches d.b.h. By contrast, the stands need to average about 13 inches for the Clearwater. The 12- and 13-inch-d.b.h. economic-feasibility limits range from a stand age of 70 to 110 years for site index 80 versus a site index of 50. Further, in most cases the initial commercial thinning must remove

approximately 2,300 ft^3/acre when using ground-based systems and approximately 2,500 ft^3/acre when using cable technology. Earlier thinnings would require either subsidy by the landowner or higher prices for low quality roundwood.

CONSIDERATIONS FOR MANAGERS

We deliberately started with stands of different ages but similar mean d.b.h., volume, and species composition so that reasonable comparisons could be made between site indexes and logging technology. Results show that one commercial thinning can be initiated at age 65 on site index 80 with ground-based technology and at age 115 on site index 50 with cable-logging technology. Optimal rotation ages for the residual stands range from age 130 on site index 80 with ground-based technology to age 195 on site 50 with cable-logging systems. Cash flows for the thinnings range from about $100/acre on poor sites to $257/acre on good sites. Cash flows for the final harvest at rotation age range from $1,462/acre on poor sites to $3,522/acre on good sites.

The average tree d.b.h. and volume removed per acre significantly affect logging costs and the way a stand is managed to maximize soil expectation value. Site index, in turn, influences d.b.h. and volume growth, thus having an important influence on the way even-aged oak stands are managed. The terrain on which a stand is located dictates the kind of logging technology that must be used during thinnings and harvests. As we have shown, logging technology can influence timing of thinning entry and optimal rotation age. For example, soil expectation values can range from $2.03/acre on site index 50 to $32.55/acre on site index 80 or a difference of about 1503 percent when using cable-logging technology. By contrast, soil expectation values range from $30.01/acre to $32.55/acre when using the Clearwater and John Deere 540B on site index 80, or a difference of about 8 percent. The effect of logging technology on soil expectation is more pronounced on poorer sites (53 percentage difference) than on good sites (8 percentage). SEV was maximized using the John Deere 540B on all sites.

The objective of this paper was to demonstrate the interactive impacts of site and stand attributes and logging technology on the way a stand is managed. We did that for two logging technologies and five site indexes with a fixed set of delivered prices to a sawmill. Although the timing of thinning entry and optimal rotation ages are specific to the values and stands used in this evaluation, the results do show the importance of considering site and stand attributes during planning of stand management scenarios.

The results for timing of thinning entry and optimal rotation age will change with other site indexes, species composition and mix, logging technology, and delivered prices. However, the impact of site and stand attributes on stand management still remain significant. Other scenarios could be evaluated by making additional simulation runs.

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EFFECTS OF DROUGHT AND SHADE ON GROWTH AND WATER USE OF *QUERCUS ALBA, Q. BICOLOR, Q. IMBRICARIA* AND *Q. PALUSTRIS* SEEDLINGS

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Abstract: Growth and water use efficiency were determined for 2-year-old white oak (*Quercus alba*), swamp white oak (*Q. bicolor*), shingle oak (*Q. imbricaria*) and pin oak (*Q. palustris*) seedlings grown under three shade treatments (30, 55 and 73%) and two irrigation regimes (container capacity and mild drought). With species and water regimes combined, the dry weight increment, root, stem, leaf, shoot dry weight and water use efficiency of the oaks decreased significantly as shade level increased from 30 to 73%. Shade had no effect on height increment, while shoot/root dry weight ratio increased with increasing shade. White oak and swamp white oak closely followed this overall pattern, but the only response shingle oak and pin oak exhibited to increasing shade levels was an increase in shoot/root ratio of 24 and 26%, respectively.

With species and shade levels combined, experimentally imposed drought reduced the oak seedling dry weight increment, root, leaf, and shoot dry weights, caliper increment and water use efficiency. The drought treatment had no effect on seedling height increment, but increased the shoot/root dry weight ratio. Under the drought regime, white oak and shingle oak had the highest water use efficiency values (1.65 and 1.73 mg cm^{-3}) compared with values of 1.46 mg cm^{-3} for pin oak and 1.01 mg cm^{-3} for swamp white oak. White oak and shingle oak also had the lowest shoot/root ratios (0.60 and 0.87) when compared with pin oak (0.96) and swamp white oak (1.08).

Upland white oak and shingle oak seedlings had the lowest specific leaf areas (158.7and 157.7 cm^2/g) while the bottomland pin oak (176.1 cm^2/g) and swamp white oak (174.8 cm^2/g) had the highest. Pin oak and shingle oak seedlings flushed more times (2.5 and 1.9) during the growing season than swamp white oak (1.6) and white oak (1.0). Drought reduced the number of flushes of all the tested oak species with the exception of white oak, while shade had no detectable effect on oak seedling flushing.

INTRODUCTION

The effects of shade on growth and development of oak seedlings have been examined in numerous studies by growing seedlings under shadecloth or similarly altering radiation levels

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(Shirley 1929, McGee 1968, Loach 1969, Musselman and Gatherum 1969, Phares 1971, Farmer 1975, Johnson 1984, Gottschalk 1985). The results of these studies have sometimes been inconsistent with one another. For example, in some cases height growth increased with increasing shade (Shirley 1929, Musselman and Gatherum 1969), in other cases it decreased with shade (McGee 1968, Johnson 1984). Others studies indicated that shade had no effect on oak height growth (Farmer 1975) or that peak growth occurred at intermediate irradiance levels with height decreases in both directions (Phares 1971, Shirley 1929). One reason for such inconsistencies may be the use of first year seedlings inmost of these studies. Early survival and growth of oak seedlings is strongly influenced by the stored carbon and nutrient reserves of the hypocotyledons (Crow 1988). However, once seedlings establish root systems adequate for supplying water and nutrients to the plant, increased irradiance levels will usually result in increased growth rates. Another factor not considered in many of these studies is the possibility of interaction between irradiance and soil moisture. Together with shade, competition for water and nutrients in the understory of forest stands with an abundance of dominant tree roots in surficial soil can reduce seedling growth (Carvell and Tryon 1961, Ferrell 1953). Oak seedlings will benefit from light shade because it moderates temperatures and water use (Kramer and Kozlowski 1979). Exposure to full solar irradiance can induce severe water stress in plants, especially during times of drought. Root growth of northern red oak (*Quercus rubra* L.) is particularly sensitive to even moderate drought. Red oak seedlings subject to various degrees of drought did not regenerate new roots at -0.6 MPa (-6 bars) (Larson and Whitmore 1970). However, white oak roots have been reported to be able to continue growth when the surrounding soil water potential was -1.2 MPa (Teskey *et al.* 1978). Farmer (1980) found that white oak seedlings have lower shoot/root ratios than northern red oak and it has been reported that white oak also has a deeper root system than northern red oak (Stout 1968, Hinckley *et al.* 1980).

Few studies of any oak species have examined the combined effects of shading and drought on growth and water use of seedlings (Gatherum *et al.* 1963, Musselman and Gatherum 1969). Consequently growth and water use of four oak species under varying shade and soil moisture conditions were examined in this study. Two of the oak species studied belong to the subgenus Leucobalanus, the white oaks [swamp white oak (*Quercus bicolor* Willd.) and white oak (*Q. alba* L.)] and two belong to the subgenus Erythrobalanus, the red oaks [pin oak (*Q. palustris* Muenchh.) and shingle oak (*Q. imbricaria* Michx.)] (Harlow et al. 1979). Within each subgenus a bottomland species (swamp white oak and pin oak) and an upland species (white oak and shingle oak) were included in this study. Shingle oak and swamp white oak were selected because they have been little studied to date.

Because various silvicultural methods call for the reduction of overstory canopy to stimulate oak reproduction, there is a need to more precisely determine which irradiance levels provide the best survival and growth conditions for seedlings of a given oak species. Since competition by roots for soil moisture is often severe in the understory of forest stands, and since this competition also limits the ability of plants to tolerate understory conditions, this study was designed to determine the combined effects of reduced irradiance and soil moisture on growth and development of oak seedlings. The objectives of this study were to determine if there are differences in growth and water use efficiency (mg/cm^{-3}) within each oak species

among three shade levels and two soil water regimes and to determine if differences were associated with oak species, oak subgenus, or ecological niche of a species.

METHODS

The study was conducted during the summer of 1989, in a greenhouse constructed with iron-free glass located at the University of Illinois in Urbana-Champaign. Iron-free glass allows penetration of solar radiation of a spectral quality more similar to natural radiation in comparison with the glass normally used in greenhouses. Temperatures in the greenhouse ranged from 23-26°C during the day and 20-23°C during the night. The seedlings were grown under natural light and photoperiod between May 22 and October 16. One hundred 2-0 bare-root dormant seedlings each of white oak, swamp white oak, pin oak, and shingle oak were obtained from commercial nurseries in the midwestern U. S.. All seedlings were in the 15-30 cm shoot height class, with the exception of white oaks which ranged from 30-46 cm in shoot height. The seedlings were measured for initial stem height and caliper (diameter) at 1 cm above the root collar and then planted in a steam pasteurized 1:1:1 fertile loamy soil: perlite: sphagnum peat moss mixture (pH of 5.5) in 60 cm tall by 10 cm diameter cylindrical pots. The pH did not change appreciably during the course of this study. No fertilizers were added to the soil mixture. The initial fresh weights of all seedlings and pot weights were determined. In each pot, a seedling was planted in 2.6 kg of the air dry soil mixture. The seedlings then were watered daily with tap water and allowed to break bud and grow for five weeks. After five weeks, 30 seedlings of white oak, 25 seedlings of swamp white oak, and 20 seedlings of pin oak and shingle oak (unequal replicates due to mortality) were placed under each of three shade tents with advertised shade values of 30%, 55%, and 73% of incident light. The advertised shade percentages of these tents were found to correspond exactly with the percentage reductions in PAR ($\pm$1%) measured with a Li-Cor Integrating Photometer at noon and 4 p.m. (Model LI-188B with quantum sensor, Li Cor Inc., Lincoln, Nebraska). The shade tents were 1.33 m wide x 1.67 m long and had 1.33 m walls on each of four sides. An additional three seedlings per species were destructively measured to obtain an estimate of total, root, stem, leaf and shoot (sum of leaf and stem) fresh and dry mass. These ratios of initial dry weight to fresh weight measurements were used to obtain a value of seedling dry weight at this stage of the study. Dry weight increments were estimated by difference from the dry seedling weights at the end of the study. The proportions of dry to fresh weight obtained for the three seedlings per species were highly consistent, differing by no more than 5% in any case. The estimated initial dry weight means and standard deviations were 33.34 $\pm$9.76 g for white oak, 8.13 $\pm$ 2.20 g for swamp white oak, 7.48 $\pm$ 3.33 g for shingle oak, and 7.51 $\pm$ 1.82 g for pin oak seedlings.

The seedlings were grown for 2-3 weeks with regular watering to allow them to acclimate to the shade. Then all pots were watered to the drip point, allowed to drain for 24 h, and weighed to determine container water capacity, (the difference between total pot weight 24 h after watering and the sum of container, dry soil mixture, and initial plant fresh weights). Half of the seedlings of each species under each shade treatment were maintained at 90-95%

of container water capacity while the remaining seedlings had drought imposed by withholding watering.

Three pots with seedlings maintained at container water capacity for each shade and species combination were sampled randomly every 2-5 days and weighed to monitor the water lost from the pots. All pots were then watered accordingly to restore container-capacity weight and the amount of water added at each watering was recorded. Three pots without seedlings for each shade treatment and watering regime were mixed in with the other seedling pots, weighed, and watered periodically in the same manner as the respective pots containing seedlings in order to estimate pot evaporation. Water use for each plant between bimonthly weighings was calculated as the change from initial weight of watered pots containing seedlings plus the amount of water added during the interval minus the water loss of the corresponding check pots lacking seedlings. The water in the system due to increasing seedling weight was not considered because it constituted an insignificant proportion of transpired water.

The dry weights of seedlings at the beginning of the treatment period were estimated by destructively sampling a second set of three seedings of each species just prior to treatment initiation. Initial estimated dry weights of seedlings were increased according to mean proportionate increase in dry weight calculated for the samples of the respective oak species. The proportionate increase in dry weight for a species did not vary by more than 4% from the mean proportion. A change in whole plant dry weight for the final two-month treatment period was estimated by subtracting the estimated dry weights of seedlings at the beginning of the treatment period from the final dry weights. A water use efficiency value was calculated from the estimated change in whole plant dry weight divided by the estimated water use over the final 2 month treatment period.

The pots that were allowed to dry for the drought regime were weighed every 2-3 weeks after the initial 2-week acclimation period and watered with measured amounts of tap water when needed to maintain 25-30% relative water capacity (RWC), which was found to be at or just above that which caused partial stomatal closure in red, white and bur oak seedlings grown under the same conditions (unpublished data). This range also corresponds to predawn leaf water potentials of the same red, white, and bur oak seedlings, of -1.0 ± 0.3 MPa determined with the use of a pressure bomb (Soilmoisture Plant Water Status Console Model 3005, Santa Barbara, California).

The artificially imposed drought regime lasted for two months. Approximately 1 month was necessary to reach 25-30% RWC and seedlings were maintained for an additional month under mild drought conditions of -1.0 ± 0.3 MPa predawn seedling water potentials. The final seedling heights and calipers were also measured at this time. Then all seedlings were harvested by gently washing the soil mixture from the roots in water and root, shoot, and foliage fresh and oven-dry (70°C for 24 h) weights were determined.

Analysis of variance was used to determine variation due to species, shade and irrigation regimes in a 4x3x2 factorial treatment design with the use of the General Linear Models procedure of SAS (SAS Institute 1982). The experimental design was a systematic split-split

plot with shade as main plots and species and irrigation as subunits and sub-subunits respectively. Individual seedlings were randomly assigned to sub-subunits and rerandomized twice during the treatment period. Interactions between these three variables were also included in the model. Scheffe's multiple-comparison procedure was used to determine differences of all main effects (Steel and Torrie 1980).

The number of flushes (foliar growth and expansion between periods of bud set) per tree were also tabulated throughout the study. Specific leaf area was determined at the end of this study by cutting a total of 60 leaf discs 1-cm in diameter (from fully expanded leaves randomly selected from seedlings in each of six shade x drought treatments) for each species and determining the oven-dry weights. The total area of the leaf discs were then divided by the total dry weight to obtain the specific leaf area (cm^2/g).

RESULTS

Irradiance

Growth of oak seedlings of all species combined varied significantly with irradiance levels (Tables 1 and 2). Mean dry weight increment, caliper increment, root and shoot dry weights, and water use efficiency decreased significantly as shade levels increased from 30% to 73%. The shoot/root ratio increased as shade levels increased from 55% to 73%. The caliper increments were similar for the 55% and 73% shade levels, which were 20 percent less than those at the 30% shade level. The mean dry weight increment at the 73% shade level was 56 and 42 percent less than at the 30% and 55% shade levels respectively. The water use efficiency declined 42 percent between the 30% and 73% shade levels. Shading had no significant effect on leaf dry weight or height increment.

The effect of irradiance, or shade levels, on white oak followed the same trends as for the regression model with species and irrigation levels pooled, except that shading did not affect the shoot/root ratio (Table 3). The dry weight increment for white oak was 83% less at the 73% shade level compared with the 30% shade level. There were consistent increases at the 55% shade level for shoot, root and stem dry weight. The increases were not statistically significant, however, but may have been due to an intermediate-shade reduction of evapotranspiration.

The effect of irradiance on the growth and water use of swamp white oak differed from the overall pattern for all oak species combined in that only mean dry weight increment, root dry weight and shoot dry weight were affected. The mean dry weight increment declined 52 percent from the 30% to the 73% shade level. The root and shoot dry weights were least, though not significantly so, at the intermediate (55%) shade level (Table 4).

Table 1.--Analysis of variance for growth and water use variables of four oak species grown under wet and dry irrigation regimes and three shade levels.

Source of variation	Degrees of freedom	Mean squares for					
		Dry Wt. Increment	Water Use Efficiency	Root Dry Wt.	Stem Dry Wt.	Leaf Dry Wt.	Top Dry Wt.
Oak Species	3	87.76*	27.90**	6144.32**	583.94**	108.56**	1176.32**
Shade Regime	2	288.67**	25.25**	358.49**	30.40**	15.57	70.52*
Spec. x Shade.	6	70.95*	7.12	214.96**	24.60*	10.79	62.90**
Irrigation Regime	1	1331.51**	78.48**	1131.52**	9.78	43.29**	94.21*
Spec. x Irr.	3	26.61	14.43**	75.55	0.64	1.50	3.20
Shade x Irr.	2	149.76**	4.52	45.40	5.20	4.81	18.53
Spec. x Shd. x Irr.	6	21.73	0.90	24.27	2.73	2.63	9.87
Error	256	29.77	3.68	44.65	4.46	5.51	16.66

Source of variation	Mean squares for		
	Shoot/Root Ratio	Caliper Increment (x1000)	Height Increment
Oak Species	1.91**	18.54**	79.01
Shade Regime	0.23*	1.73**	60.89
Spec. x Shade.	0.17*	1.36**	79.65
Irrigation Regime	2.66**	7.81**	16.78
Spec. x Irr.	0.20*	1.10	77.60
Shade x Irr.	0.05	0.19	89.49
Spec. x Shd. x Irr.	0.06	0.28	54.47
Error	0.06	0.32	55.61

* Significant at the 0.05 level
** Significant at the 0.01 level

Table 2.--Mean growth and water use values for oak seedlings grown at three shadelevels, with four oak species and two soil moisture levels pooled.

GROWTH VARIABLE	PERCENT SHADE		
	30	55	77
Observations (n=)	95	92	93
Dry Weight Increment (g)	6.23 a*	4.66 a	2.72 b
Water Use Efficiency ($mg\ cm^{-3}$)	2.45 a	2.11 a	1.42 b
Root Dry Weight (g)	12.80 a	13.30 a	9.42 b
Stem Dry Weight (g)	3.79 a	4.02 a	2.86 b
Leaf Dry Weight (g)	4.47 ns	3.91	3.64
Shoot Dry Weight (g)	8.26 a	7.94 ab	6.51 b
Shoot/Root Ratio (dry weight)	0.75 ab	0.72 b	0.82 a
Caliper Increment (mm)	0.34 a	0.27 b	0.26 b
Height Increment (cm)	15.02 ns	13.72	13.57

* Means within a row followed by the same letter are not significantly different at 0.05 level according to Scheffe's test.

The shoot/root ratio was the only growth variable significantly affected by shading in pin oak and shingle oak seedlings. The shoot/root ratio increased 25 percent from the 55 to 73% shade level for both pin and shingle oak (Tables 5 and 6).

Table 3.--The effects of shade on growth and water use variable means of white oak.

WHITE OAK

Percent Shade	Irrigation Level	N	Water Use Efficiency	Root Dry Weight (g)	Stem Dry Weight (g)	Leaf Dry Weight (g)	Shoot Dry Weight (g)
30	CC#	15	2.78	28.91	7.89	7.12	15.02
	DR	15	2.27	20.61	6.82	5.41	12.23
	Mean+	30	2.53a*	24.76a	7.36a	6.27ns	13.62a
55	CC	14	2.51	33.92	9.74	6.99	16.74
	DR	15	2.34	24.64	8.41	5.31	13.72
	Mean	29	2.42a*	29.28a	9.08a	6.15	15.23a
73	CC	13	0.60	18.82	4.83	4.34	9.17
	DR	15	0.34	16.64	5.71	4.32	10.03
	Mean	28	0.47b	17.73b	5.27b	4.33	9.60b

Percent Shade	Irrigation Level	N	Dry Wt. Increment (g)	Shoot/Root Ratio	Caliper Increment (mm)	Height Increment (cm)
30	CC	15	13.43	0.52	0.38	13.73
	DR	15	4.17	0.63	0.038	15.20
	Mean	30	8.80a	0.57ns	0.38a	14.47ns
55	CC	14	10.64	0.50	0.24	13.79
	DR	15	4.09	0.57	0.17	13.63
	Mean	29	7.36a	0.54	0.20 b	13.71
73	CC	13	2.32	0.53	0.15	10.74
	DR	15	0.75	0.60	0.09	10.20
	Mean	28	1.53 b	0.57	0.12 b	10.47

CC is the 90-95% container capacity regime, DR is the drought regime (20-25% container capacity).
+ Mean is for the pooled irrigation values at the given shade level.
* Means within a column followed by the same letter were not significantly different at 0.05 level according to Scheffe's test.
ns Not significant.

Table 4.--The effects of shade on growth and water use variable means of swamp white oak.

SWAMP WHITE OAK

Shade Level	Irrigation Level	N	Water Use Efficiency	Root Dry Weight (g)	Stem Dry Weight (g)	Leaf Dry Weight (g)	Shoot Dry Weight (g)
30	CC#	12	2.55	9.23	2.61	4.54	7.15
	DR	13	0.98	5.42	2.28	3.12	5.40
	Mean+	25	1.76ns	7.33a*	2.44ns	3.83ns	6.28ns
55	CC	11	1.43	6.55	2.12	2.77	4.89
	DR	12	0.93	4.07	1.81	2.78	4.59
	Mean	23	1.18	5.31 b	1.97	2.78	4.74
73	CC	14	1.44	7.06	2.06	3.21	5.27
	DR	11	1.14	4.86	2.76	2.76	4.94
	Mean	25	1.29	5.96ab	2.12	2.98	5.10

Shade Level	Irrigation Level	N	Dry WL Increment (g)	Shoot/Root Ratio	Caliper Increment (mm)	Height Increment (cm)
30	CC	12	8.81	0.79	0.27	19.29
	DR	13	1.63	1.01	0.03	16.65
	Mean	25	5.22a	0.90ns	0.15ns	17.97ns
55	CC	11	3.89	0.75	0.14	9.86
	DR	12	1.70	1.16	0.05	17.12
	Mean	23	2.79ab	0.96	0.10	13.49
73	CC	14	3.05	0.75	0.24	13.78
	DR	11	1.93	1.08	0.01	14.95
	Mean	25	2.49 b	0.91	0.12	14.37

CC is the 90-95% container capacity regime, DR is the drought regime (20-25% container capacity).
\+ Mean is for the pooled irrigation values at the given shade level.
* Means within a column followed by the same letter were not significantly different at 0.05 level according to Scheffe's test.
ns Not significant.

Table 5.--The effects of shade on growth and water use variable means of pin oak.

PIN OAK

Percent Shade	Irrigation Level	N	Water Use Efficiency	Root Dry Weight (g)	Stem Dry Weight (g)	Leaf Dry Weight (g)	Shoot Dry Weight (g)
30	CC#	10	2.88	9.67	2.99	3.52	6.52
	DR	10	1.57	5.05	1.76	2.42	4.18
	Mean+	20	2.22ns	7.36ns	2.38ns	2.98ns	5.35ns
55	CC	10	2.47	8.12	2.07	3.28	5.36
	DR	10	1.14	5.02	1.67	2.62	4.29
	Mean	20	1.81	6.57	1.87	2.95	4.82
73	CC	10	2.14	6.66	1.84	3.28	5.12
	DR	10	1.67	4.35	1.88	3.36	5.24
	Mean	20	1.91	5.50	1.86	3.32	5.18

Percent Shade	Irrigation Level	N	Dry Wt. Increment (g)	Shoot/Root Ratio	Caliper Increment (mm)	Height Increment (cm)
30	CC	10	8.42	0.68	0.56	15.85
	DR	10	2.11	0.82	0.51	10.25
	Mean	20	5.26ns	0.75 b*	0.54ns	13.05ns
55	CC	10	6.23	0.66	0.60	14.60
	DR	10	1.70	0.82	0.36	13.05
	Mean	20	3.96	0.74 b	0.42	13.82
73	CC	10	4.40	0.77	0.63	14.40
	DR	10	2.55	1.22	0.44	16.30
	Mean	20	3.48	1.00a	0.54	15.35

\# CC is the 90-95% container capacity regime, DR is the drought regime (20-25% container capacity).

\+ Mean is for the pooled irrigation values at the given shade level.

* Means within a column followed by the same letter were not significantly different at 0.05 level according to Scheffe's test.

ns Not significant.

Table 6.--The effects of shade on growth and water use variable means of shingle oak.

SHINGLE OAK

Shade Level	Irrigation Level	N	Water Use Efficiency	Root Dry Weight (g)	Stem Dry Weight (g)	Leaf Dry Weight (g)	Shoot Dry Weight (g)
30	CC#	10	5.08	8.33	1.53	4.39	5.92
	DR	10	1.79	6.14	1.54	3.82	5.35
	Mean+	20	3.44ns	7.24ns	1.54ns	4.10ns	5.63ns
55	CC	10	3.91	7.22	1.31	3.09	4.40
	DR	10	2.09	5.44	1.21	2.86	4.07
	Mean	20	3.00	6.33	1.26	2.98	4.24
73	CC	10	3.61	7.42	1.70	4.38	6.08
	DR	10	1.29	4.48	1.10	3.23	4.33
	Mean	20	2.45	5.98	1.40	3.80	5.20

Shade Level	Irrigation Level	N	Dry Wt. Increment (g)	Shoot/Root Ratio	Caliper Increment (mm)	Height Increment (cm)
30	CC	10	7.17	0.74	0.33	17.05
	DR	10	2.70	0.89	0.32	11.35
	Mean	20	4.94ns	0.81ab*	0.33ns	14.20ns
55	CC	10	4.26	0.62	0.40	14.40
	DR	10	3.00	0.74	0.34	13.00
	Mean	20	3.63	0.68 b	0.37	13.70
73	CC	10	6.03	0.81	0.38	16.35
	DR	10	1.86	0.99	0.34	14.15
	Mean	20	3.93	0.90a	0.36	15.25

CC is the 90-95% container capacity regime, DR is the drought regime (20-25% container capacity).
+ Mean is for the pooled irrigation values at the given shade level.
* Means within a column followed by the same letter were not significantly different at 0.05 level according to Scheffe's test.
ns Not significant.

Mean growth values for all oak seedlings combined (Table 1) and individual oak species (Table 7) varied significantly with irrigation regimes. Experimentally-imposed drought reduced the mean dry weight increment, root, leaf and shoot dry weights, caliper increment and water use efficiency, while it increased the shoot/root ratio. There were reductions of 65 percent in mean dry weight increment, 42 percent in water use efficiency and 31 percent in caliper increment for all oak species combined over the course of this study. The combined shoot/root ratio mean increased by 22 percent in the drought stressed oak seedlings compared with those at container capacity. Oak height increment was not significantly affected by drought in this study.

Drought decreased the mean dry weight increment of white oak by 67 percent and the dry root weight 25 percent, while it increased the shoot/root ratio by 17 percent relative to seedlings grown with an adequate water supply (Table 7). Drought had no statistically significant effect on water use efficiency, caliper increment, stem, leaf and shoot dry weight, although the values for these variables decreased due to drought at each shade level (Table 3).

The effect of drought on swamp white oak (Table 7) followed the pattern for all oak species combined with the exception that drought did not significantly affect the stem, leaf, and shoot dry weights. Declines were 66 percent in mean dry weight increment, 43 percent in water use efficiency and 87 percent in caliper increment. The root dry weight declined 37 percent and the short/root ratio increased 42 percent relative to well-watered swamp white oak seedlings. Growth and water use values declined with drought, while shoot/ratio increased with drought for all shade levels and stem dry weight increased with drought at the 73% shade level (Table 4). Under the drought regime, water use efficiency increased with shade, but this interaction was not significant.

For pin oak, drought had no detectable effect on stem, leaf, and shoot dry weights (Table 7). Reductions of 67 percent in mean dry weight increment, 42 percent in water use efficiency, 27 percent in caliper increment and 41 percent in root dry weight occurred relative to well watered pin oak seedlings. The mean shoot/root ratio increased 30 percent overall due to drought.

The effect of drought on shingle oak (Table 7) was to decrease the mean dry weight increment by 57 percent and water use efficiency by 59 percent. The dry root weight declined 30 percent and the shoot/root ratio increased 21 percent with drought. Decreases in all variables except shoot/root ratio were found due to drought at all shade levels (Table 6). Shoot/root ratio increased due to drought at each shade level.

A shade x irrigation interaction occurred for the mean dry weight increment of swamp white oak. The mean dry weight increment decreased with shade at container pot capacity, but increased (non-significant) with shade under the drought regime (Table 8).

Table 7.--The effects of drought on the growth and water use of white (WO), swamp white oak (SWO), pin oak (PO) and shingle oak (SO).

Species	Irrigation Level	N	Water Use Efficiency	Root Dry Weight (g)	Stem Dry Weight (g)	Leaf Dry Weight (g)	Shoot Dry Weight (g)
WO	CC#	42	1.96ns	27.45*	7.56ns	6.22ns	13.78ns
	DR	45	1.65	20.63	6.98	5.01	11.99
SWO	CC	37	1.79*	7.61*	2.26ns	3.51ns	5.77ns
	DR	36	1.01	4.80	2.09	2.90	4.99
PO	CC	30	2.50*	8.15*	2.30ns	3.36ns	5.66ns
	DR	30	1.46	4.81	1.77	2.80	4.57
SO	CC	30	4.20*	7.68*	1.51ns	3.95ns	5.46ns
	DR	30	1.73	5.35	1.28	3.30	4.58
MEAN	CC	139	2.53*	13.74*	3.71ns	4.39*	8.10*
	DR	141	1.46	9.97	3.41	3.64	7.05

CC is the 90-95% container capacity regime, DR is the drought regime (20-25% container capacity).
* Means within the column pair for an oak species are significantly different at 0.05 level according to the F-test.
ns Not significant.

Table 7 (Cont'd).--The effects of drought on the growth and water use of white (WO), swamp white oak (SWO), pin oak (PO) and shingle oak (SO).

Species	Irrigation Level	N	Dry Wt. Increment (g)	Shoot Root Ratio	Caliper Increment (mm)	Height Increment
WO	CC#	42	9.06*	0.52*	0.30ns	12.82ns
	DR	45	3.00	0.60	0.21	13.01
SWO	CC	37	5.17*	0.76*	0.22*	14.40ns
	DR	36	1.74	1.08	0.03	16.29
PO	CC	30	6.35*	0.70*	0.59*	14.95ns
	DR	30	2.12	0.96	0.44	13.20
SO	CC	30	5.82*	0.72*	0.37ns	15.93ns
	DR	30	2.52	0.87	0.33	12.83
MEAN	CC	139	6.74*	0.67*	0.35*	14.37ns
	DR	141	2.39	0.87	0.24	13.85

CC is the 90-95% container capacity regime, DR is the drought regime (20-25% container capacity).
* Means within the column pair for an oak species are significantly different at 0.05 level according to the F-test.
ns Not significant.

Table 8.--Interaction of shade and drought on the dry weight increment (g) of swamp white oak.

	Shade Percentage			
Irrigation	30	55	73	Mean
Container Capacity	8.81 n=12	3.89 n=11	3.05 n=14	5.17**
Drought Regime	1.63 n=13	1.70 n=12	1.93 n=11	1.74
Mean	5.22 a	2.79 ab	2.49 b*	

* Means within a row followed by the same letter were not significantly different at 0.05 level according to Scheffe's test.
** Means in the column are significantly different at 0.05 level according to the F test.

There is a possibility that size and shoot/root ratio may be correlated and that treatments influencing seedling size influenced this ratio. However, the slopes and intercepts of linear regressions of final dry weight and shoot/root ratio were different for irrigation compared with shade treatments. This indicates that the treatments influenced shoot/root ratios independently from any total plant dry weight relationship.

Other variables measured were number of flushes and specific leaf area. Pin oak flushed the most with an average of 2.5, followed by shingle oak (1.9), swamp white oak (1.6), and white oak (1.0) (Table 9). The specific leaf area was greatest in bottomland pin oak (176.1 cm^2/g) and swamp white oak (174.8 cm^2/g) and lowest for the upland shingle oak (157.7 cm^2/g) and white oak (158.7 cm^2/g).

DISCUSSION

The results of this study are consistent, for the most part, with the findings of Musselman and Gatherum (1969), who found that stem, leaf, shoot, and root dry weight decreased with shade and with reductions in available soil moisture for northern red oak seedlings. In contrast with the Musselman and Gatherum results, we did not find any significant increase in height of four oak species with increased shade. Increases in shoot/root ratio with decreases in soil moisture were also reported by Gatherum *et al.* (1963) for species of two hardwood and three coniferous seedlings. Norby and O'Neill (1989) reported a greater water use efficiency for white oak (6.3 mg cm^{-3}) than our overall mean (1.81 mg cm^{-3}). However, this discrepancy may be due to their use of first year seedlings rather than third year seedlings from bare-root nursery stock as employed in this study.

Table 9.--The effect of irrigation regime on the observed number of flushes of four oak species.

Species	Observed Flushes: Container Capacity	Observed Flushes: Drought Regime	Mean	Range
White oak	1.00	1.01	1.00	1-2
Swamp white oak	1.68	1.61	1.64	1-3
Pin oak	2.70	2.30	2.50	1-4
Shingle oak	2.00	1.77	1.90	1-3

White oak is generally considered intermediate in shade tolerance and is more tolerant than the red oaks (Fowells 1965). Swamp white oak, a member of the white oak group, is also considered intermediate in shade tolerance (Fowells 1965). Pin oak, in the red oak group, is a common associate of swamp white oak. However, pin oak is considered to be intolerant of shade and it is recommended that pin oak receive at least 2/3 of full solar irradiance for successful regeneration (Fowells 1965). Shingle oak, another member of the red oak group, occurs on a variety of sites, from dry upland ridges to rich and moist river bank soils (Iles 1988). Although there is little published research on the biology of shingle oak, it is considered to be somewhat intolerant of shade (Elias 1980).

In this study (Tables 3 and 4), 55% shade did not markedly reduce growth or water use efficiency of the white oaks relative to 30% shade. However, reduction in irradiance caused by the 73% shading did reduce growth and water use efficiency significantly in comparison with lower shade levels. Hence, increases in solar irradiance above 45% will probably not benefit growth as markedly as decreases in solar irradiance below 45% will inhibit growth. This study revealed few differences among shade levels between 30 and 73% on growth and water use efficiency of shingle and pin oak (Tables 5 and 6) in comparison to the white oaks.

Although shingle oak and pin oak are considered shade intolerant, the only response these species exhibited to the tested shade levels was to increase shoot/root ratio with shade (Tables 5 and 6). This response is indicative of shade intolerant trees such as jack pine (*Pinus banksiana*)(Kimmins 1987) and yellow poplar (*Liriodendron tulipifera*)(Loach 1970). Shade intolerant trees show a greater increase in shoot/root ratio as shade increases than do more tolerant species. Newhouse and Madgewick (1968) have found that rapid shoot growth in tree species is associated with intolerance of shade. Other authors have noted that the more tolerant tree species are characterized by the maintenence of a uniform pattern of growth over a wide range of shade (Baker 1945, Loach 1967 and Loach 1970). Consistent with these patterns, shingle oak and pin oak (Tables 5 and 6) showed an increase in shoot/root ratio with increasing shade while the more tolerant white oak and swamp white oak did not (Tables 3

and 4). Additionally, shade intolerant and faster growing shingle oak and pin oak flushed more times than the more tolerant white oak and swamp white oak seedlings. Reich et al. (1980) stated that multiple flushes occur in white, bur and post oak seedlings during the spring under conditions of favorable light and moisture, while single flushes occur when unfavorable conditions are present. Shingle oak and pin oak seem to be able to flush repeatedly, and more times than the white oaks, even when conditions are only marginally favorable for growth.

White oak and shingle oak seedlings seem to be more drought tolerant than pin oak and swamp white oak seedlings. Four important characteristics that can be used to help indicate drought tolerance in a tree species are higher water use efficiency, lower shoot/root ratio, lower specific leaf area, and less stem diameter inhibition than drought intolerant species (Gottschalk 1985, Larcher 1980). White oak alone exhibited an ability to maintain similar water use efficiency values under either irrigation regime (Table 7). Under the drought regime, rankings for water use efficiency from highest to lowest were: shingle oak (1.73 mg cm^{-3}), white oak (1.65 mg cm^{-3}), pin oak (1.46 mg cm^{-3}) and swamp white oak (1.01 mg cm^{-3}). The rankings for shoot/root ratio under drought from lowest (most advantageous) to highest were: white oak (0.60), shingle oak (0.87), pin oak (0.96), and swamp white oak (1.08). With moisture and shade treatments combined (no significant differences among them in area to weight ratio), the upland white oak and shingle oak had the lowest specific leaf areas. Such low specific leaf areas are characteristic of drought avoiders (Larcher 1980). Caliper increment or radial stem growth of oaks is much more sensitive to stress and limiting factors than other variables such as height growth (Gottschalk 1985). The bottomland species, pin oak and swamp white oak, were the only species that showed a significant decrease in caliper increment due to drought. Swamp white oak was the most sensitive of the two as its caliper increment declined 86 percent, while pin oak's declined only 35 percent relative to the radial stem growth increments of well watered seedlings.

Under drought conditions, species that maintain a low shoot/root ratio are able to maximize water uptake by having a greater root surface to exploit scarce soil water and minimize evapotranspiration through reduced foliage quantity. Plants with a high water use efficiency under dry soil conditions can more efficiently use available water in producing phytomass (Larcher 1980). The two upland species, white oak and shingle oak, differed in their physiological responses to drought. Overall, white oak had a much lower shoot/root ratio (0.56) than shingle oak (0.80), while shingle oak had a much greater water use efficiency than white oak (Table 10). These differences may reflect different adaptive strategies to drought of these two upland oak species. The more shade intolerant shingle oak, with its high water use efficiency and high shoot/root ratio, is better equipped to compete both on droughty soils and on fertile sites where both soil moisture and irradiance may be limited due to competition from fast growing plants.

The two white oak species in this experiment exhibited higher shade tolerance and lower water use efficiencies than the two red oak species studied.

Pin oak and shingle oak are species which inhabit sites that may experience flooding and drought during the same growing season. Thus high water use efficiencies may be a

Table 10.--Sources of variation among species, with shade and irrigation levels pooled.

Species	Water Use Efficiency (mg cm^{-3})	Shoot/Root Ratio	Caliper Increment (mm)
White oak	1.81 b*	0.56 c	0.24 c
Swamp white oak	1.41 b	0.92a	0.12 d
Pin oak	1.98ab	0.83ab	0.52a
Shingle oak	2.96a	0.80 b	0.35 b

* Means within a column followed by the same letter were not significantly different at 0.05 level according to Scheffe's test.

physiological adaptation allowing pin and shingle oaks to grow on sites with alternating wet and dry periods. High water use efficiencies and high shoot/root ratios together allow a tree to compete well for solar radiation while at the same time efficiently using limited soil water resources on good sites where vegetative competition is great. Our results indicate that shingle oak is better able to maintain a high water use efficiency under drought conditions in comparison with pin oak. Furthermore, shingle oak does not drastically increase its shoot/root ratio in response to drought as does pin oak. This may be due in part to the coarse root system of shingle oak which is more sensitive to stress than the highly fibrous root system of pin oak (Struve and Moser 1984). Shingle oak is found more on dry upland sites than is pin oak, perhaps owing to the noted differences in functional and structural response to drought between these two species.

Of the white oaks, swamp white oak seems to be the most site specific. It had the lowest water use efficiency and highest shoot/root ratio for any of the oak species in this study (Table 10). This is consistent with its natural occurrence on poorly drained-upland depressions, swamp margins, stream banks and moist, peaty flats (Fowells 1965), sites which rarely undergo drought. Swamp white oak exhibited an irradiance x drought interaction (Table 8) in that at container water capacity the dry weight increment decreased with shade, but increased with shade under drought conditions. This interaction is probably due to a reduction in evapotranspiration of this midtolerant oak species caused by shade under drought conditions.

The extension of these data to ecological behavior of these oak species requires caution. In a forest not only is the quantity of light changed, but also the quality of light as the overstory canopy differentially absorbs and transmits various wavelengths of PAR and other solar radiation. Also, frequent dieback or browsing of advance oak regeneration will influence shoot/root ratios in the field. Hence the results of this study relate more to early establishment and growth of oak seedlings in forest understories than to the longer-term

patterns of growth and development of advance oak regeneration, and should be extrapolated to field conditions with caution until confirmed by field studies.

SUMMARY

This study has shown that both increasing shade and drought decrease the growth and water use efficiency of four oak species of the central United States. Overall, the red oaks (shingle and pin oak) had the highest water use efficiencies and flushed more than white oak and swamp white oak, consistent with the generally faster juvenile growth rates of intolerant species. Shingle and pin oak also increased markedly in shoot/root ratio in response to shade, which is a characteristic of shade intolerant trees. Swamp white oak and white oak have the characteristics of midtolerant species, maintaining similar shoot/root ratios under a range of intermediate shade levels, exhibiting fewer flushes and smaller caliper increments overall in comparison with the two red oaks.

Under drought conditions, white oak and shingle oak had the lowest shoot/root ratios, highest water use efficiencies and smallest specific leaf areas, appropriate to their observed ability to grow on dry sites. However, both white and shingle oaks seem to have broad ecological amplitudes with respect to soil water availability, growing on mesic sites and, in the case of shingle oak, also on moist soils and on poorly drained flats with pin oak and post oak. Pin oak, which was between white oak and swamp white oak in shoot/root ratio and water use efficiency values under drought conditions, and similar to swamp white oak in specific leaf area, occurs in bottomland areas subject to flooding and in pin oak-post oak flats with a fragipan creating alternating wet and dry conditions. Swamp white oak and pin oak, the bottomland species, were the only ones to exhibit a significant decrease in caliper increment with drought. Swamp white oak was the most sensitive of the four oak species to drought, consistent with its ecologically narrow niche of moist sites.

This study examined two of the most important factors influencing forest regeneration, irradiance and soil moisture. The results indicate that the two white oaks were more shade tolerant than the two red oaks and will, therefore, more successfully survive in smaller openings and under denser canopies than pin and shingle oak. The data show a tendency suggesting that on sites where soil moisture may be limiting part of the season, shade levels from 55-73% may reduce evapotranspiration and increase growth of swamp white oak seedlings compared with more open conditions on the same site. Shingle oak may be a suitable native tree for minespoil reclamation and urban planting due to its drought tolerance and high water use efficiency described in this study combined with its moderately fast growth rate, mast production for wildlife and tolerance of wide pH ranges (Iles 1968).

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HEIGHT AND DIAMETER VARIATION IN TWELVE WHITE ASH PROVENANCE/PROGENY TESTS IN EASTERN UNITED STATES

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Abstract: Results from 12- and 13-year-old rangewide provenance/progeny tests of white ash (*Fraxinus americana* L.) planted at 12 locations throughout the eastern United States are reported. Although heritability of white ash tree height and dbh is high at both the provenance and family levels, the trend in variance components is for increasing provenance and declining family components. Tree height is negatively correlated with latitude in southern outplantings and positively correlated with latitude in the north. Plantations with the tallest trees were those that had been clean cultivated for several years after establishment.

INTRODUCTION

Rangewide provenance/progeny tests of white ash (*Fraxinus americana* L.) were established in 1976 and 1977 with plantings at more than 20 locations throughout the eastern United States and Canada. The study was initiated because of the increased importance and value of the white ash. Several papers have reported early growth and survival results from that study, including preliminary white ash seed source recommendations for planting in different parts of the geographic species range (Bey et al. 1977, Clausen 1982, Clausen 1984, Clausen et al. 1981). Summarizing those early recommendations, at age 5 northward movement of seed or seedlings not exceeding 322 km (200 miles) generally resulted in some growth increases over local plant material, except in the northernmost parts of the species range where only local seed sources should be used. This paper reports growth results through age 13.

MATERIALS AND METHODS

Open-pollinated seeds were collected from up to 10 native parent trees at each of 59 locations throughout the natural range of white ash in 1973 and 1974 and then sown in a southern Illinois nursery (Bey et al. 1977, Clausen et al. 1981). Resulting 1-0 seedlings were used to establish 22 plantations throughout the eastern United States and Canada in 1976. By the 1988-1989 dormant season, when these data were collected, many personnel changes, budget

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constraints, and shifts in program emphasis among cooperating agencies had resulted in abandonment of test sites in northern Alabama, Tennessee, New York, and Ontario, Canada. In other cases, high tree mortality and poor growth precipitated abandonment of plantings in Minnesota, northern Wisconsin, and Missouri, as well as plantings in Ontario and New Brunswick, Canada. As a result, 13-year measurements were only available from 10 plantations; this paper is based on height and dbh data from trees 13 years after outplanting in those 10 plantations in addition to two plantings that were established 1 year later (Nebraska and Michigan) and from which measurements reflected growth 12 years after outplanting. The latter two provenance outplantings were established in 1977 with surplus stock after seedling distribution to the 1976 planting sites. Unfortunately, there were not enough seedlings of different open-pollinated families for a progeny test, and family identity of seedlings at the Michigan and Nebraska sites was not retained.

The number of provenances in each plantation ranged from 16 in Alabama to 35 in the Michigan plantation, and the number of families per plantation ranged from 39 to 52 (table 1). The geographic origins of the families also varied from plantation to plantation. Most plantations contained families from portions of the range near their particular geographic location in order to minimize mortality of more distant, nonadapted trees. Three plantations (OH, AL, and IL) were designed to have 45 families from 19 widely separated provenances in common so provenance x environment interactions could be evaluated. All plantations were established in a randomized complete block design with five-tree row plots and five replications at a spacing of 3.7 m except in OH where a completely random design (no blocks) was used.

Table 1.--Location of plantations and number of white ash provenances and families in each[1]

Plantation (state)	County	Latitude °N	Longitude °W	Number of provenances	Number of families
Ohio (OH)	Muskingum	40.0	82.0	21	49
Alabama (AL)	Macon	32.4	85.6	16	42
Illinois (IL)	Union	37.5	89.3	26	52
Kentucky (KY)	Rowan	38.2	83.4	23	43
West Virginia (WV)	Tucker	39.0	79.7	22	45
Kansas (KS)	Jefferson	39.0	95.2	27	44
Louisiana (LA)	St. Landry	30.4	92.0	19	45
Indiana (IN)	Crawford	38.2	86.3	22	39
Arkansas (AR)	Montgomery	34.6	93.6	18	42
Wisconsin (WI)	Iowa	43.0	90.1	24	40
Michigan (MI)	Kalamazoo	42.3	85.3	35	--
Nebraska (NE)	Adams	40.5	98.3	27	--

[1]Family identity of seedlings was not retained at the Michigan and Nebraska outplantings.

Differences in performance among provenances and families in each plantation were tested by the General Linear Model analysis of variance technique based on plot means to accommodate missing data. Variance components were calculated for between- and within-provenance comparisons. When appropriate, correlation and regression analyses were used to estimate the relationship between tree height and provenance latitude, longitude, and elevation. Data were analyzed using programs of the Statistical Analysis System (SAS Institute 1982).

Table 2.--Plantation averages for height, dbh[1], survival, standard deviations, and ratios of tallest to shortest trees[2]

Plantation	Height (m)	Standard deviation (m)	Ratio of tallest: shortest	Dbh (cm)	Standard deviation (cm)	Survival (%)	Number of surviving trees
OH	7.7	1.7	2.6	9.4	3.0	62	710
AL	7.0	0.9	1.5	7.9	1.1	97	1025
IL	6.8	1.1	1.7	7.7	2.7	92	1192
KY	4.0	0.7	2.0	4.9	1.2	63	676
WV	3.5	0.7	1.9	3.8	1.2	52	581
KS	3.2	0.6	2.0	3.2	0.9	93	1031
LA	3.0	1.3	5.0	2.7	1.5	74	829
IN	3.0	1.0	7.2	---	---	69	670
AR	2.9	0.8	3.2	3.3	1.4	50	525
WI	2.5	0.5	2.0	2.5	0.7	57	570
MI	5.7	0.6	2.0	5.8	0.9	83	726
NE	3.3	0.5	1.9	4.5	0.8	56	375

[1] Dbh data for the Indiana outplanting were not available.
[2] Michigan and Nebraska data reflect age 12 measurements. Data for all other plantations reflect age 13 measurements.

RESULTS AND DISCUSSION

After 13 years in the field, survival ranged between 97% and 50% (table 2). Average height of white ash trees ranged from 2.5 m at the southern Wisconsin site to 7.7 m in Ohio (table 2), a threefold difference in height growth between outplantings with the slowest and fastest growth, respectively. As observed earlier by Clausen (1984), the three plantations with the fastest growth (OH, AL, and IL) were all clean cultivated during the first 2 to 3 years after outplanting. The implication is that white ash is extremely sensitive to competition from weeds and brush during the early establishment phase and that the effects of plantation maintenance persist for a long time thereafter.

The trend in diameters at breast height (dbh) closely mirrors the pattern in tree height; as expected, on the average the tallest trees tend to have the greatest diameters (table 2). The overall correlation of height with dbh was 0.78. The height-to-height ratios for the of tallest to shortest provenances ranged from 1.5 at the Alabama plantation to 7.2 at the Indiana plantation (table 2).

Analysis of variance for height and dbh indicates a predominance of statistical significance, as indicated by probabilities of greater F-values (table 3). The provenance effect was statistically significant at all outplanting sites for both height and dbh at age 13 (table 3). In an earlier report on this study, the provenance effect for height was nonsignificant at the Indiana, Kansas, and Wisconsin locations at age 5 (Clausen 1984). By age 13 this effect had become significant at all sites, including the latter three. However, statistical significance for the family effect was less common than for the provenance effect.

Table 3.--Probabilities of greater F-values in analyses of variance of white ash height and dbh.

	Block		Provenance		Family/provenance	
Plantation	Height	Dbh	Height	Dbh	Height	Dbh
OH	----	----	0.0001	0.0001	0.0003	0.0001
AL	0.0015	0.0015	0.0001	0.0001	0.0001	0.0001
IL	0.0001	0.0001	0.0001	0.0001	0.0016	0.0001
KY	0.0341	0.0154	0.0001	0.0001	0.0472	0.0069
WV	0.0675	0.2821	0.0001	0.0001	0.1143	0.0664
KS	0.0160	0.0581	0.0001	0.0001	0.0001	0.0001
LA	0.6123	0.9030	0.0001	0.0001	0.0066	0.0007
IN	0.3288	----	0.0002	----	0.3273	----
AR	0.0001	0.0001	0.0001	0.0008	0.9708	0.4687
WI	0.0002	0.0002	0.0001	0.0001	0.8768	0.9363
MI	0.0001	0.0001	0.0001	0.0001	----	----
NE	0.0001	0.0002	0.0001	0.0057	----	----

Provenance variance components for height (table 4) appear to be increasing; the overall mean provenance component averaged over all locations increased from 28.6% at age 3 to 38.5% at age 13, although this trend was not consistent at all sites. For example, at the Kentucky site the provenance component decreased from 30% at age 3 to 14% at ages 5 and 13. In Kansas, this component increased from 4% at age 3 to 18% at age 5 and dropped to 10% by age 13.

At the latest measurement the provenance component was greater than the family component at all but two locations for height and at all but one location for dbh. For both height and dbh the mean provenance component was more than three times greater than the family component at age 13. In contrast to the trend for increasing provenance components, family

variance components for height appear to be declining in magnitude; the mean family component decreased from 11.9% of total variance at age 3 to 7.5% at age 13 (table 4).

Table 4.--Provenance and family-within-provenance variance components as a percent of total variation and heritabilities for age 13 height and dbh[1]

	Height						Dbh		Heritability			
	Provenance			Family			Prov.	Fam.				
	Age (yrs)			Age (yrs)			Age (yrs)		Height		DBH	
Plantation	3	5	13	3	5	13	13	13	Prov.	Fam.	Prov.	Fam.
	- - - - % - - - -			- - - - % - - - -			- - - % - - -					
OH	24	43	17	5	1	5	22	4	0.82	0.56	0.85	0.60
AL	51	65	68	12	9	0	46	9	0.96	0.75	0.91	0.77
IL	64	60	46	6	12	4	68	3	0.91	0.54	0.96	0.61
KY	30	14	14	6	2	16	15	20	0.77	0.38	0.80	0.51
WV	17	28	47	17	4	0	40	5	0.90	0.29	0.88	0.34
KS	4	18	10	17	26	31	10	37	0.79	0.74	0.80	0.81
LA	57	67	75	8	7	3	64	8	0.97	0.48	0.96	0.57
IN	0	0	28	30	10	16	--	--	0.87	0.12	--	--
AR	30	21	25	18	20	0	27	0	0.73	0	0.63	0
WI	9	6	57	0	13	0	47	0	0.87	0	0.80	0
mean	28.6	32.2	38.7	11.9	10.4	7.5	37.6	10.8	0.86	0.39	0.84	0.47

[1] Variance components for ages 3 and 5 previously published by Clausen (1984).

Heritabilities for height and dbh (table 4) indicate that a great deal of variation in these plantations is heritable. The mean provenance heritability of 0.81 to 0.85 is the same order of magnitude observed for loblolly pine (Pinus taeda) of this age and indicates that most of the variation among provenances can be utilized for growth improvement (Kung 1989). Similarly, the mean family-within-provenance heritability of 0.39 to 0.47 is consistent with heritability values for height in black walnut (Rink 1984, Rink and Clausen 1989).

Combined location analyses of variance across all planting sites indicated significant provenance x plantation location interactions for both height and diameter. These interactions imply that provenance selection for optimum growth at different geographic localities and perhaps for specific sites within localities may be important for artificial regeneration of white ash. Because these combined location ANOVA's were so highly imbalanced, variance component extraction from them would produce variance components less precise than would be possible from a completely balanced design. To aid in interpreting the interaction, we used an individual location response surface model with linear and quadratic provenance latitude and longitude and their crossproducts as independent variables; response surface regressions are commonly used to model genotypic response to environment. Results of these

analyses indicated that latitude contribution to the model was statistically significant at 10 of 12 outplanting locations, while longitude had a significant contribution at only 4 sites (table 5). Although the patterns were not clearcut, the most frequent response surface solutions indicated that seed sources south of planting sites resulted in maximizing growth. Similarly, in a more recent analysis of 5-year white ash tree height using growth response functions, Roberds et al. (in press) found that trees from southern provenances tended to be broadly adapted and grew well considerably north of their origin. The only definite exception to this pattern was at the West Virginia site where a seed source from northern New York or southern Ontario was projected to maximize growth; this may be the result of a combination of northerly latitude and high elevation (330 m) of this planting location.

Table 5.--F-values and coefficients of determination response surface model for white ash tree height[1]

Plantation	F-value[2]		Model
	Latitude	Longitude	R-square
OH	19.94**	3.70*	0.88
AL	10.98**	0.09	0.82
IL	6.77**	1.67	0.67
KY	2.04	1.93	0.64
WV	2.43	2.17	0.42
KS	7.46**	3.07*	0.59
LA	19.33**	1.66	0.90
IN	9.34**	9.50	0.84
AR	10.81**	0.97	0.79
WI	6.10**	5.22**	0.66
MI	6.82**	1.25	0.47
NE	4.17*	1.83	0.45

[1] Equation for model: $y = a + b_1 (\text{prov. lat.}) + b_2 (\text{prov. lat.})^2 + b_3 (\text{prov. long}) + b_4 (\text{prov. long.})^2 + b_5 (\text{prov. lat. x prov. long.})$

where: a = y intercept and
b_1 through b_5 = coefficients

[2] Statistical significance of F-values: ** significant at $P < 0.01$
* significant at $P < 0.05$

Pearson correlation coefficients between mean tree height at age 13 and provenance latitude, longitude, and elevation are listed in table 6. The most apparent result of this analysis is the trend for statistically significant negative correlations between tree height and provenance latitude in the southernmost outplantings. Correlations between height and provenance

latitude are positive for the northernmost sites. Similarly, there are negative correlations between tree height and provenance elevation at the southernmost sites, but several of these correlations are not statistically significant. There was no readily apparent trend between provenance longitude and tree height. Similarly, at age 5 latitude of seed origin also had a greater effect on height than either longitude or elevation, especially at the northern and southern fringes of the species range (Clausen 1984).

Table 6.--Correlation coefficients of average provenance tree height with provenance latitude, longitude, and elevation[1,2]

Plantation	Latitude	Longitude	Elevation
OH	0.56	-0.24 ns	0.43
AL	-0.88	0.47 ns	-0.75
IL	-0.64	0.57	-0.17 ns
KY	-0.50	0.43	0.07 ns
WV	0.16 ns	-0.17 ns	0.41 ns
KS	-0.21 ns	0.39	-0.05 ns
LA	-0.91	0.58	-0.62
IN	-0.69	0.61	-0.23 ns
AR	-0.45	0.21 ns	-0.49
WI	0.39	0.37 ns	0.29
MI	0.43	-0.20 ns	0.27 ns
NE	0.00 ns	0.19 ns	0.32

[1] Based on family/provenance means at each location, except in Michigan and Nebraska where only provenance means were available.
[2] Unless noted with "ns" all correlations are statistically significant at least at the 95% level of probability.

Such variation patterns may be influenced by susceptibility to frost injury. In an analysis of the distribution of frost injury among white ash provenances in a related Ontario, Canada, seed source test, autumn frost injury was highly correlated with provenance latitude (Clausen 1982). Similarly, when white ash stem sections from ten geographic origins from a southern Michigan provenance test were exposed to controlled freezing, trees of northern origin were found to be more cold hardy than southern trees in early and midwinter (Alexander et al. 1984). Furthermore, a great deal of individual tree variation in cold hardiness within each provenance was observed.

CONCLUSIONS

Clausen (1984) pointed out the beneficial effects of plantation maintenance during the plantation establishment phase of this study. Present results confirm those observations. Perhaps fewer test plantings would have been abandoned if more plantation maintenance had been available.

Present 13-year data indicate that height growth improvements of 25 to 30% on sites with good growth and more than 50% on sites with poor growth may be obtained through proper provenance selection. Seed source recommendations made by Clausen (1984) are still applicable. This is further emphasized by significant provenance x site interactions.

The predominance of statistical significance for provenance effects for height and diameter and the magnitude of provenance variance components indicate the importance of proper provenance selection in artificial regeneration programs for white ash. High heritabilities, based on open-pollinated half-sib family variance components, indicate that individual tree selection is also effective in white ash. However, the latter variance components are relatively low and seem to be declining in magnitude with age. Because variance components follow fluctuating patterns that are probably species specific, we will have to track these patterns to determine how effective individual tree selection is at different ages.

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STOMATAL CONDUCTANCE OF SEEDLINGS OF THREE OAK SPECIES SUBJECTED TO NITROGEN FERTILIZATION AND DROUGHT TREATMENTS

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Abstract: Both nitrogen-fertilized and unfertilized white oak, bur oak, and red oak seedlings were subjected to progressive drought in a greenhouse study. Stomatal conductance was measured before and during drought treatment. When water was not limiting to seedling growth and function, N-fertilized white oak showed greater maximum stomatal conductance (200 mmol m^{-2} s^{-1}) compared to N-deficient white oak (74 mmol m^{-2} s^{-1}). Neither bur oak nor red oak showed any discernible differences in stomatal conductance between fertilization treatments before imposition of drought. During drought, N-limited red oak maintained greater stomatal conductance at a lower soil relative water content compared to N-fertilized red oak. N-fertilized bur oak decreased stomatal conductance partially during moderate drought and ceased conductance completely during extreme drought, whereas N-deficient bur oak maintained high levels of conductance during moderate drought and halted conductance precipitously during severe drought. No discernible difference between N-fertilization treatments was found for white oak stomatal conductance during drought. Red oak and white oak seedlings exhibited lower stomatal conductance values less readily and under drier soil conditions than did bur oak, suggesting superior drought adaptability of bur oak.

INTRODUCTION

Stomatal conductance represents a compromise between carbon assimilation and excessive water loss by transpiration (Ludlow 1980). Mineral nutrient status may directly affect rates of photosynthesis by altering the content and function of key metabolites and enzymes and may also have indirect effects by altering stomatal respones. Nutrient deficiency may increase or decrease stomatal sensitivity to soil moisture availability (Radin *et al.* 1982; Lahiri 1980; Wang *et al.* 1988). Thus, the stomatal and photosynthetic response to drought for a given species may be altered by nutrient status.

White oak (*Quercus alba* L.), red oak (*Q. rubra* L.), and bur oak (*Q. macrocarpa* Michx.) are oaks of the central hardwood region. Bur oak traditionally has been characterized as drought-tolerant and the most xeric of the three species, though it is bimodal in distribution

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occuring on both mesic and xeric sites (Abrams 1986), while white and especially red oak are regarded as more exclusively mesic (Fowells 1965).

We examined the effects of two nitrogen regimes on stomatal conductance of bur, red, and white oak seedlings during the progressive soil drying of an artificially imposed drought.

METHODS

Fifty 2-0 bare-root dormant seedlings of each of red oak, white oak, and bur oak were planted in a steam-sterilized 1:1:1 loamy soil:vermiculite:peat moss mix in 60 cm tall by 10 cm wide cylindrical pots. Half of the plants of each species were given 200 ml of N-free 1/4 strength modified Hoagland's solution weekly and the other half were given the same plus 5 ppm N as NH_4NO_3. Plants were watered daily. After sixteen weeks in the greenhouse (26° day, 18° night, photoperiod extended to 16 h by sodium vapor lamps) drought was imposed by withholding water.

The results of a preliminary study indicated that the plants reached their daily maximum level of stomatal conductance between 1000 and 1100 local standard time; therefore all stomatal conductance measurements were made between those hours. Plants were sampled randomly. Stomatal conductance was measured on the abaxial leaf surface with a steady state diffusion porometer (LI-1600 Li-Cor, Lincoln, NE); relative humidity varied between 15 and 30% on the days when measurements were taken. Predawn leaf water potential was measured on a subsample of fully-expanded leaves with a pressure chamber (# 3000 Soil Moisture Corp., Santa Barbara, CA) at 0300-0400 the morning following stomatal conductance measurements. This allowed us to determine the relationship between soil relative water content and soil water potential estimated as predawn leaf water potential (Nobel 1983). Soil relative water content was determined by weighing the pots during the afternoon of each measurement day and comparing the soil mass of each pot with the saturated (12 h after final watering) soil mass and the dry (constant weight at 70°) soil mass. The formula used to calculate relative water content (RWC) was:

$$RWC = (\text{fresh mass} - \text{dry mass}) / (\text{saturated mass} - \text{dry mass}).$$

Leaf relative water content was determined but it was not found to differ by species or treatment.

RESULTS AND DISCUSSION

Stomatal response was interpreted by boundary line analysis (Webb 1972) where a line is drawn at the boundary of the maximum stomatal conductance values and all points below are assumed to be limited by some factor other than that of the independent variable (Hinckley et al. 1978). This technique is useful owing to the fact that stomata respond to the complex

interaction of a number of environmental and endogenous factors that could not be controlled during this experiment (e.g. daily variation in solar radiation). Conductance measurements >10 mmol $m^{-2}s^{-1}$ were considered to signify at least partially opened stomates based on our measurements of leaves with completely closed stomates indicating that cuticular conductance for all species was about 3-8 mmol $m^{-2}s^{-1}$.

Stomatal Response with High Soil Moisture

White oak increased its maximum rate of stomatal conductance from 74 to 200 mmol $m^{-2}s^{-1}$ when supplied with N fertilizer and water was not limiting (Figures 1*a,b*). This is consistent with the results of Minshall (1975) who found that urea or nitrate stimulated transpiration of tomato, Mingeau and Robelin (1972) who found that N-deficiency decreased transpiration of sunflower, and Nagarajah (1981) who found that N-deficiency of tea caused a decrease in stomatal conductance and transpiration. A general correlation between foliar N and net photosynthesis and stomatal conductance has been reported in an extensive survey of native C_3 plants (Field and Mooney 1986). Neither red oak (Figures 1*c,d*) nor bur oak (Figures 1*e,f*) showed any response to N fertilization treatment when soil moisture levels were high.

Stomatal Response during Drought

White oak +N and -N showed similar responses during drought (Figures 1*a,b*): both N-fertilized and N-deficient plants decreased stomatal conductance suddenly at 22% RWC (-1.8 MPa soil water potential). Red oak stomatal conductance ceased at about 22% RWC (-1.8 MPa) when supplied with N (Figure 1*c*), but continued until 19% RWC (-2.5 MPa) during N-deficiency (Figure 1*d*). This resembles the response of N-deficient beans as described by Shimshi (1970). The response of bur oak is the most distinctive. N-fertilized bur oak accomplished a partial decrease of stomatal conductance at about 33% RWC (-0.5 MPa) and maintained moderately low stomatal conductance to below 20% RWC (-2.1 MPa) (Figure 1*e*). The response of N-deficient bur oak differs; its stomates halted conductance suddenly at about 23% RWC (-1.5 MPa) (Figure 1*f*).

These data suggest a drought adaptation of bur oak seedlings. Under conditions of soil nitrogen availability, bur oak seems to employ a drought avoidance tactic (Jones 1980); the seedlings avoid excessive plant water loss and rapid depletion of limited soil water reserves by closing stomates partially as soil water potential decreases below -0.5 MPa, allowing only a limited level of gas exchange and water loss. These results are similar to those obtained with bur oak under drought conditions in Kansas forests (Abrams and Knapp 1986). This apparent anticipation of extreme drought reflects the ecological performance of bur oak which occurs on droughty sites and soils as well as on more mesic sites which support red and white oak (Fowells 1965).

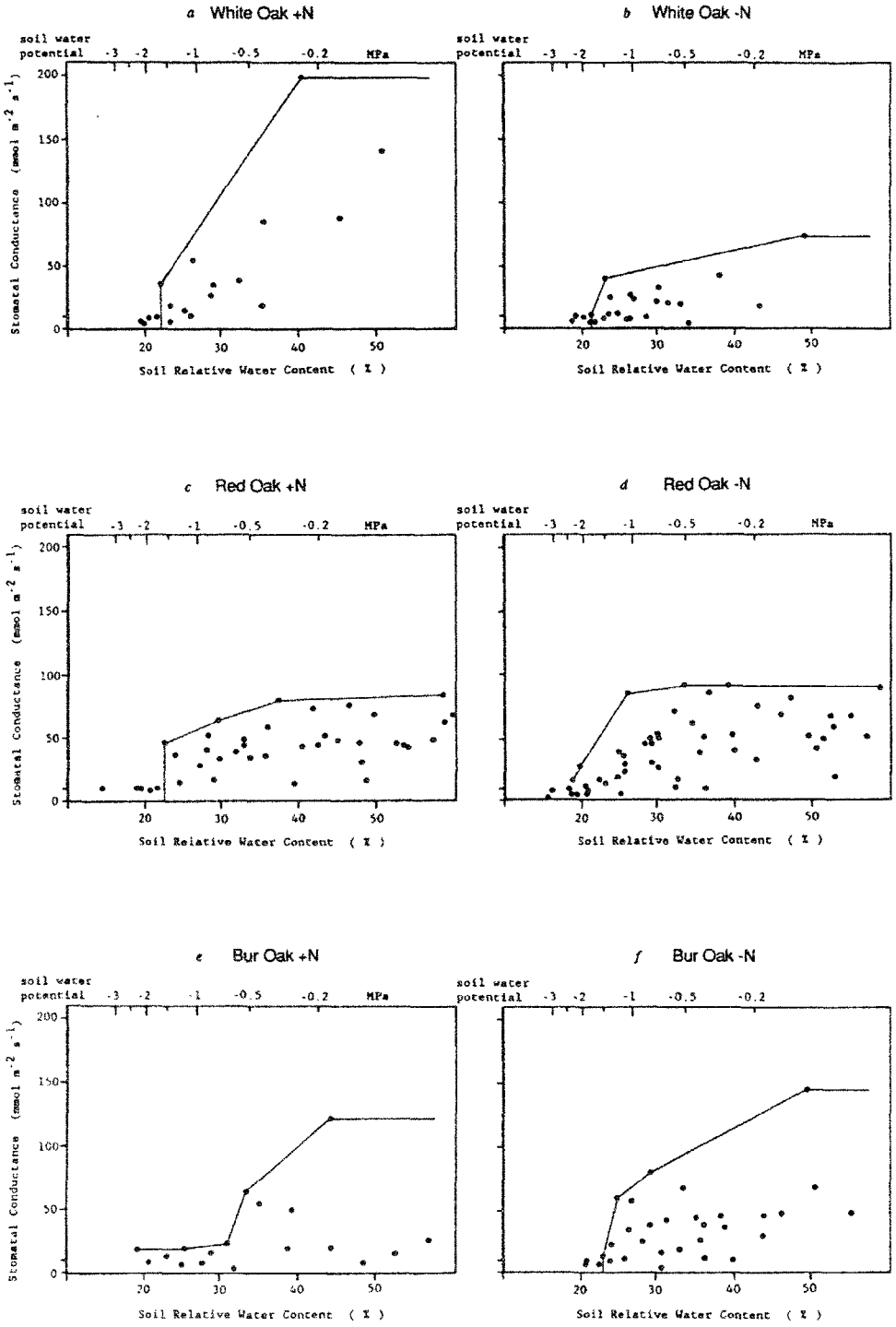

Figure 1. Stomatal conductance of N-fertilized and unfertilized white oak (*a,b*), red oak (*c,d*), and bur oak (*e,f*) seedlings during a progressive drought.

The stomatal conductance data may reflect the fact that white and red oak thrive naturally on more mesic sites than bur oak; on mesic sites stomatal sensitivity to increasing drought is less critical for survival. Bur oak on a mesic site would incur all the disadvantages of an anticipatory response to moderate drought (less capability for photosynthetic gas exchange, slower growth) in exchange for only marginal benefits (water conservation during relatively rare extreme droughts). The tendency of N-deficient red oak to maintain stomatal conductance during extreme drought conditions may indicate that red oak requires N to conserve water. The absence of the drought-adaptive stomatal response in N-deficient bur oak may reflect a nitrogen requirement for the expression of the drought-adaptive response. This suggests a mechanism to explain the seemingly anomolous findings of Abrams (1985) that the growth rate of bur oak trees in Kansas stands was greatest when available soil NH_4 and NO_3 were lowest. Perhaps anticipatory stomatal closing of bur oak with the onset of drought was sufficiently enhanced on soils of greater N fertility in Kansas' dry climate to reduce net photosynthesis and growth of the trees.

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STAND DENSITY, STAND STRUCTURE, AND SPECIES COMPOSITION IN TRANSITION OAK STANDS OF NORTHWESTERN PENNSYLVANIA

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ABSTRACT: Transition stands, those containing species associated with both the northern hardwood and oak-hickory forest types, are important to forest diversity in northwestern Pennsylvania. These stands have high value for a variety of forest uses, including timber production, wildlife habitat, and aesthetics. Diameter distributions are characteristically stratified by species, with the most valuable oak species among the largest trees in the stand. Understories typically consist of a mixture of northern hardwood species with those often found in the understory of true oak-hickory stands, such as dogwood, blackgum, and cucumbertree. In this paper, I characterize diameter distributions for transition stands in northwestern Pennsylvania, and discuss their silvicultural implications. Traditional measures of density tend to overestimate the density of such stands. Three alternatives, one based on tree-area ratio and two based on Reineke's stand-density index, are reported.

INTRODUCTION

The forests of the Allegheny Plateau region of northwestern Pennsylvania are dominated by Allegheny hardwood and northern hardwood forest types. Thus stands of the oak- hickory or oak transition forest types are important for diversity to the wood-using industry, to many wildlife species, and to recreationists and conservationists. Stands of the oak transition forest type represent a challenge to managers because they contain a mix of species somewhat different from the classic central hardwood stand. Often, the oak species are among the largest trees in the stand, dominating one or more subordinate canopy layers composed of a mix of traditional oak associates, such as red maple (*Acer rubrum* L.), dogwood (*Cornus florida* L.), blackgum (*Nyssa sylvatica* L.), and hemlock (*Tsuga canadensis* (L.) Carr), and species less often associated with the oaks, such as sugar maple (*Acer saccharum* Marsh.) and American beech (*Fagus grandifolia* Ehrh.). These species cover a wide range of growth rates and tolerance to shade, and, in mixture with the oaks, achieve levels of density (numbers of trees or basal area per acre) not usually associated with the oaks. Because these stands are highly stratified by species and the oak species are difficult to regenerate, the consequences of management actions in these stands are quite important.

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The United States Forest Service estimates that 20 percent of the land area of the Allegheny National Forest, or about 100,000 acres, is covered by stands in which oak is an important component (Allegheny National Forest 1986). When stands that had experienced severe mortality as a result of the combination of gypsy moth defoliation and drought were sampled in the late summer and early fall of 1988, approximately one-third of the area sampled was typed as oak transition, while the remainder was typed as oak-hickory (Allegheny National Forest 1989). These determinations were made by analyzing the sample data with the SILVAH computer program.[2] In SILVAH, oak-hickory stands are defined as those having at least 50 percent of their basal area in oak and hickory species and at least 65 percent of their basal area in oak, hickory, or commonly associated species. Transition hardwoods are those in which at least 25 percent of the basal area is in each of oak and northern hardwood species, and at least 65 percent of the basal area is in these species plus common associates of either. In these stands, it is not uncommon for northern red oak (*Quercus rubra* L.) to be the sole oak species.

The origin of stands of the oak-hickory and oak transition types on the Allegheny Plateau is not as well documented as is the origin of stands of the Allegheny hardwood forest type. The northwestern Pennsylvania Allegheny Plateau region was virtually completely harvested during turn-of-the century logging, resulting in an even-aged forest. Records from logging companies active during the railroad logging era from 1890 through about 1930 show that most of the stands included in this paper probably originated from a sequence of cuttings. The first was for hemlock and desirable hardwood sawtimber during the period from 1894-1912, and the second for smaller and poorer quality trees between 1913-1930 (Casler 1976). This combination of cuttings was usually quite complete, and similar to a shelterwood sequence. Thus these stands are essentially even-aged and about 70 years old.

In the Allegheny Plateau region, oak-hickory and oak transition stands tend to occur near the river basins, where humans have been in residence, and using fire, for many hundreds of years. The influence of humans and fire is believed to have favored the establishment of oak along waterways, due to the tolerance of oak seedlings for fire. Many of these stands still contain old chestnut (*Castanea dentata* (Marsh.) Borkh.) stumps, suggesting that the chestnut blight may have played a role in releasing oak to greater dominance. Transition stands often are on high-quality sites, where the regeneration of oak species suffers from the competition of fast-growing associates like red maple and black cherry (*Prunus serotina* Ehrh.).

In this paper, I report on the diameter distribution and species composition of 21 research plots representative of the mixed oak-northern hardwood stands of northwestern Pennsylvania, and on the changes that occur as a result of various silvicultural strategies. I also report on efforts to assess relative stand density in these stands.

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[2] Marquis, David A., and Richard L. Ernst. in preparation. User's guide to SILVAH: A stand analysis, prescription, and management simulator program for hardwood stands of the Alleghenies.

METHODS

Twenty-one research plots currently under study by staff of the Northeastern Forest Experiment Station's Forestry Sciences Laboratory at Warren in northwestern Pennsylvania were selected for this study on the basis of species composition. These plots were used in a variety of studies focusing on the management of developing stands for timber and aesthetic objectives, but the data reported in this paper are from pretreatment tallies. Plot size ranged from 0.6 to 4.9 acres. Data collected in each stand included a complete tally of all trees 1.0 inches d.b.h. and larger on each plot by species and 1-inch diameter class. All plots had been free of human disturbance but many showed evidence of natural disturbance, especially chestnut stumps. Northern red oak is the principal oak species on these plots; white oak (*Quercus alba* L.) is the other major oak species. All stands met the criteria for stands at average maximum density (Ernst and Knapp 1985), as they showed no evidence of past cutting, little understory development, and mortality was readily observed among the smallest trees.

Data from each plot were summarized into per acre values of numbers of trees, basal area, and sum of diameters and diameters squared. For each plot, both the quadratic mean diameter (QMD, or diameter of the tree of average basal area) and the medial diameter (MD, or diameter of the tree at the mid-point of the basal area distribution), were also calculated. MD is calculated as a weighted average diameter. Each 1-inch diameter is multiplied by the basal area in that diameter class, and the sum divided by the stand basal area. Composite diameter distributions were calculated by averaging per acre values of numbers of trees per diameter class. Statistical analyses were conducted with SYSTAT statistical analysis software (Wilkinson 1988), and a 5% significance level was accepted in all tests.

DIAMETER DISTRIBUTIONS

The characteristics of the individual stands are summarized in Table 1. MD in these stands ranged from 10.3 to 17.0 inches, and the percent of basal area in oak species ranged from 25 to 75.

The frequency distribution of diameters for all of these stands has a roughly inverse J shape. Figure 1 shows the averaged frequency distributions of diameter for each of three groups of these stands, using medial diameter as the grouping variable. Figure 1d is the frequency distribution of diameter from Schnur's (1937) representative stand table for an age 60 oak stand on a site index 60 site, shown here for contrast. Frequently, the inverse J-shaped diameter distribution is associated with uneven-aged stands, but in the even-aged forests of the Allegheny plateau region, many stands have inverse J-shaped diameter distributions because of the persistence of a dense lower canopy layer of shade-tolerant species. In species composition and diameter distribution, the sapling class in these transition oak stands is similar to the shade tolerant understory layer in even-aged Allegheny and northern hardwood stands.

Table 1. Selected characteristics of sample Pennsylvania oak transition stands.

	Minimum	Maximum	Mean +/- Std. Dev.
No. trees/acre	265	920	449 +/- 163
Basal area/acre ($ft.^2$)	122.3	200.4	154.0 +/- 18.7
Medial Diameter	10.3	17.0	13.5 +/- 1.8
Quadratic Mean Diameter	5.4	11.0	8.2 +/- 1.4
% northern red oak (in basal area)	0	75	40 +/- 18
% oaks (in basal area)	25	75	48 +/- 14

In the smallest diameter stands (Fig. 1a), 46 percent of the sapling (one-inch through five-inch diameter classes) basal area consists of American beech trees, 40 percent of red maple trees, and the remainder consists of birch (*Betula* L.), cucumbertrees (*Magnolia acuminata* L.), sugar maple, and noncommercial species. Average sapling basal area is 17 square feet. The smallest oaks in these stands are 7 inches in diameter, but the pole class (6-inch through 11-inch) is dominated by red maple, which averages 48 percent of the 53 square feet of poletimber. No other species represents more than 11 percent of the poletimber basal area. Among the sawtimber classes (those 12 inches and larger), the oaks dominate, with northern red oak representing 64 percent of the sawtimber basal area.

The pattern for the other two groups is similar. In the medium-diameter stands (Fig. 1b), beech and red maple dominate the sapling class, red maple dominates the pole-size class, and northern red oak dominates the sawtimber-size classes. In the largest diameter stands (Fig. 1c), eastern hemlock dominates the sapling class. Red maple and eastern hemlock are important in the pole-size classes, and northern red oak, red maple, and white oak dominate the sawtimber sizes.

If we look closely at these inverse J curves, we can see them as the curves of three species groups superimposed. The tail of the curve is formed by the inverse J shape of the diameter distribution of shade-tolerant species, while the red maple/intermediate-tolerance species and oak groups each have bellshaped distributions with different means.

If we contrast these patterns with the diameter distribution of Schnur's classic oak stand (Fig. 1d), we see that the overall form as well as the distribution by species is different. This frequency distribution of diameters has a bell shape rather than an inverse J shape, and the distribution for each species group is bellshaped as well. In particular, the shade-tolerant understory species are not as numerous as in northwestern Pennsylvania oak stands, nor does their distribution in the small size classes have an inverse J shape.

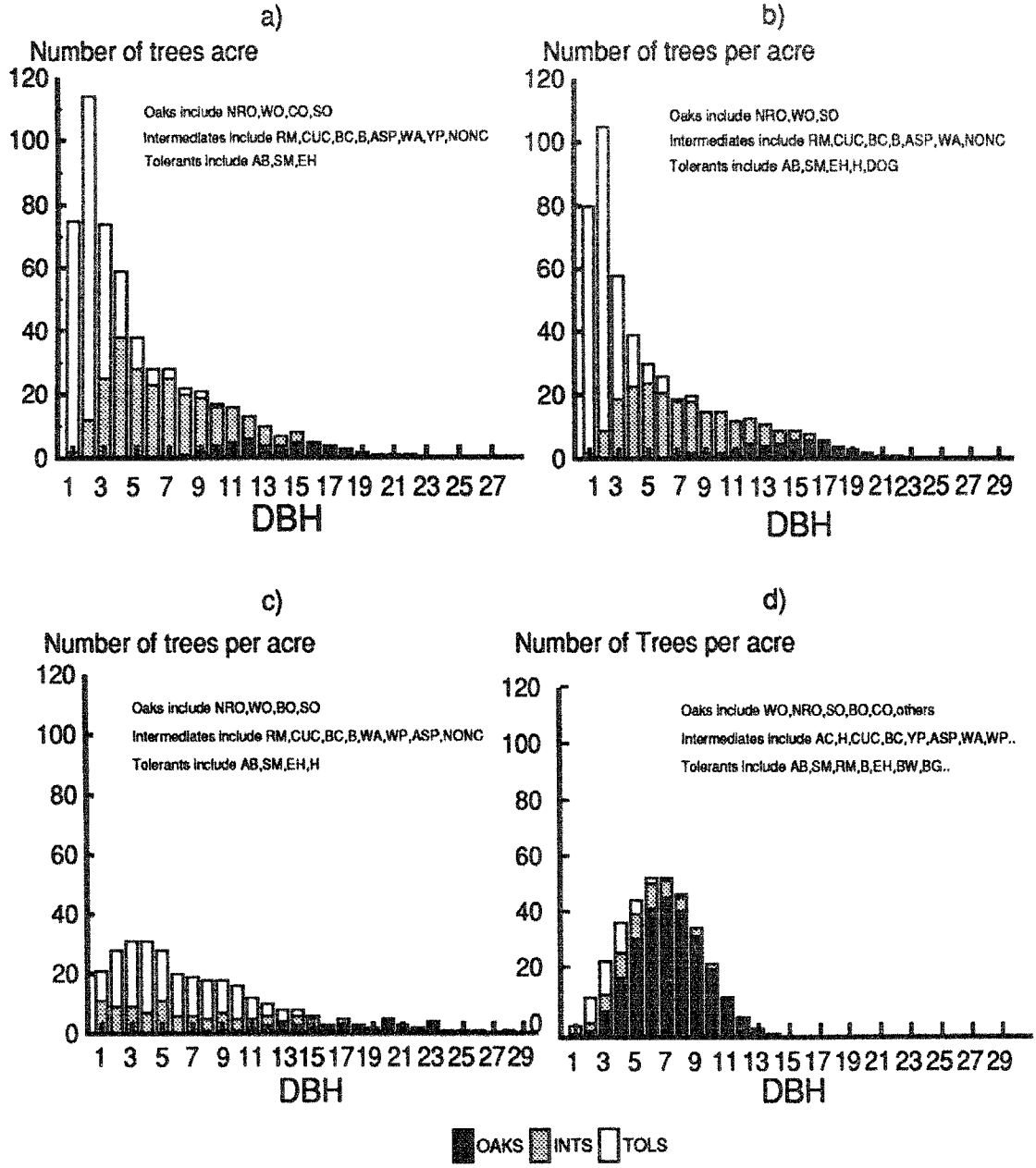

Figure 1. Diameter distributions of composites of the study plots, grouped by medial diameter, and showing species composition. a) Medial diameters from 10. - 12.5 inches. b) Medial diameters from 12.5 - 14.5 inches. c) Medial diameters from 14.5 - 17.0 inches. d) Schnur's (1937) SI 60, age 60 oak stand.

SILVICULTURAL IMPLICATIONS

In the face of serious difficulties in obtaining natural regeneration of oak species, the stratification by species described represents a serious challenge to forest managers who wish to preserve oak. Partial cuttings are desirable to increase the rate of growth of the best trees for the management objective. For wood products, thinnings provide faster diameter growth of the residual trees, capture some potential mortality, and shorten rotation lengths. For wildlife-habitat management, partial cuttings stimulate the growth of tree crowns and increase mast production. But to achieve multiresource objectives in these stands, managers must remain sensitive to a variety of special concerns. Guidelines to minimize gypsy moth impacts (Gansner and others 1987) are important, as is an understanding of the likely impact of common silvicultural practices on species composition. Figure 2 shows residual diameter frequency distributions of the composite, medium diameter class stand shown in Figure 1b after 2 common partial cuts.

Uneven-age management practices like single-tree selection have been shown to favor regeneration of species more shade tolerant than the oaks (Schlesinger 1976). In northwestern Pennsylvania oak stands, however, application of uneven-age practices may reduce the proportion of oak by the cutting alone. The theory of uneven-age silvicultural systems is the creation and preservation of a balanced inverse J diameter distribution in which the largest diameter trees are the oldest and the smaller diameter trees are the youngest. The inverse J shape of diameter distributions in northwestern Pennsylvania oak stands and the shade tolerance of the northern hardwood species in the smaller age classes will ease the transition to uneven-age management in these even-aged stands. At each cutting cycle, the oldest or largest trees are removed, the younger or smaller trees are thinned, and space is created for regeneration. If density is reduced to the levels recommended to obtain a good growth response in the residual trees (Marquis and others 1984, Roach and Gingrich 1968),[3] and no cutting is done in the sapling class, the effect will be to reduce the proportion of oak. The higher the minimum cutting diameter employed, the more pronounced this effect will be. But even if cutting is uniform throughout the retained diameter classes, removing trees from the large end of the diameter distribution, above the selected maximum diameter, will reduce the proportion of oaks over time. Figure 2a shows the species composition of the residual stand after hypothetical selection cutting of the stand in Figure 1b to a Q of 1.5 and a residual density 65 percent that of the original stand, with a maximum retained tree size of 23 inches. No trees smaller than 5.5 inches d.b.h. were cut. The cutting removed 55 square feet of basal area in 73 trees per acre. In this stand, with an original maximum tree diameter of 23 inches, the proportion of oak was unchanged at 47 percent. Little or no replacement of the oaks can be expected to occur under this silvicultural system.

Management guidelines for even-age silviculture in many eastern hardwood stands recommend intermediate thinnings that concentrate removals in the smaller merchantable

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[3] Stout, Susan L. in preparation. Uneven-age management. In: Quantitative silviculture for hardwood stands of the Alleghenies. Available from the author.

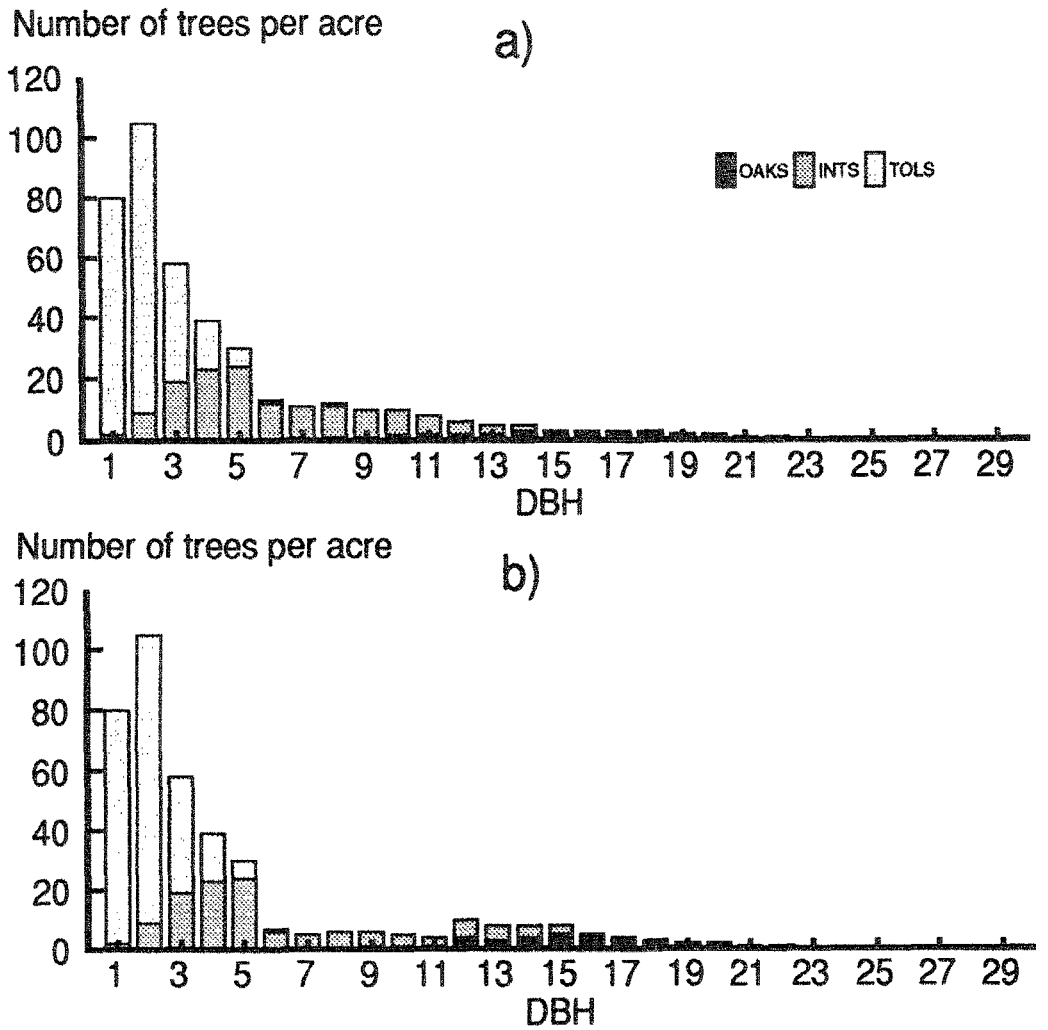

Figure 2. Changes in diameter distribution in the composite stand from Figure 1b. a) after a selection system partial cut. b) after an even-age commercial thinning.

stems, with only enough removals in the largest diameter and tallest trees to free some room in the main canopy (Marquis and others 1984, Roach and Gingrich 1968). Because such treatments concentrate removals in the size classes dominated by non-oak species, they tend to increase the proportion of oak (Figure 2b). In the composite stand shown in Figure 2, the commercial thinning to 65 percent of the original density, primarily from below, increased the proportion of oak from 47 percent to 54 percent of the basal area. This cutting removed 51 square feet in 92 trees per acre. Control of density in these treatments may be difficult,

however, as none of the currently available measures of relative density gives desirable results in northwestern Pennsylvania transition oak stands.

ASSESSING RELATIVE DENSITY

Measures of relative stand density allow foresters to assess the crowding in forest stands as a function of average tree size and, in some cases, species composition. Relative density is expressed as a percent of the average maximum density observed in undisturbed stands of similar average tree size and species composition (Ernst and Knapp 1985). In theory, most undisturbed stands should have relative density values close to 100 percent; in years of optimum growing conditions, tree growth and survival may be high, and relative-density estimates may exceed 100 percent by small amounts, while episodes of poor growing conditions will result in mortality and lower relative-density estimates.

Correct assessment of relative density is key to understanding and managing mixed-species stands. In stands of the same average tree size, but different species composition, absolute measures of density, such as numbers of trees or basal area per acre, vary with species composition, sometimes by as much as 50 percent. Basal-area values that are unrealistically high in one species mix may be average in another. Managers who underestimate the relative density of these complex stands may miss opportunities to increase individual tree growth and crown development, while managers who overestimate relative density risk loss of productivity or encouragement of undesirable plants. Yet assessment of relative density can be particularly difficult in stratified mixed stands. The stands included in this study were specifically chosen to represent the conditions of average maximum density. Thus, one criteria for choosing a density measure for use in these stands is the nearness of the mean estimate of density to 100 percent, as well as the proportion of these stands whose density is estimated as close to 100 percent. Table 2 shows the density of these northwestern Pennsylvania oak stands as assessed by five different measures.

The oak stocking chart in Roach and Gingrich (1968) expressed average maximum density as a curve that showed the average maximum basal area and numbers of trees per acre in upland central hardwood stands as their QMD increased. This chart was extended and used to determine percent oak stocking shown in the first row of Table 2. The oak stocking chart was developed partly with the stand tables in Schnur (1937), and was intended for use in these typical, white oak dominated stands with bellshaped diameter distributions. When applied to northwestern Pennsylvania stands such as those studied here, the charts yield estimates of density well above 100 percent. The mean value is 140 percent, and the estimates range from 111 to 169 percent. Densities this high suggest stagnation and severe mortality among the smallest trees in these stands, which is inconsistent with observation in these stands.

Table 2.--Relative density of study plots as calculated by five density measures.

	Minimum	Maximum	Mean +/- Std. Dev.
Oak Stocking Chart[1]	111	169	140 +/- 14
SILVAH Relative Density[2]	85	143	105 +/- 14
NE-TWIGS Generalized Stocking Percent[3]	60	97	83 +/- 8
PA Oak tree-area ratio[4]	79	125	105 +/- 11
PA Oak Stand Density Index[4]	74	121	96 +/- 11

[1] Roach and Gingrich (1968)
[2] Marquis, David A., and Richard L. Ernst. in preparation. User's guide to SILVAH: a stand analysis, prescription, and management simulator program for hardwood stands of the Alleghenies. Available from the author.
[3] Gribko and others (in press).
[4] Determined using measures developed for this study.

The SILVAH computer programs calculate the density of forest stands using a variant of the measure developed by Roach (1977) and Stout and Nyland (1987). With this procedure, the density contribution of individual trees is estimated as a function of their species and diameter. Species are assigned to one of three groups, based predominantly on their growth rates and tolerance to shade. These include a fast-growing, shade-intolerant group consisting of black cherry, white ash (*Fraxinus americana* L.), and yellow-poplar (*Liriodendron tulipifera* L.); a slow-growing, shade-tolerant group consisting of sugar maple, American beech, and striped maple (*Acer pennsylvanicum* L.); and an intermediate group whose main constituent was red maple, but to which most species were assigned for application purposes. Northwestern Pennsylvania transition hardwood stands were not in the data base used to develop the tree-area coefficients for Allegheny hardwoods. In the SILVAH programs, the density coefficients for the intermediate group are used for northern red oak. The coefficients for the slow-growing shade-tolerant group were so similar to those reported by Gingrich (1968) for the white oaks and hickory that these species were assigned to that group. The densities reported in the second row of Table 2 are the result of calculations made with the SILVAH computer programs. The mean value of relative density calculated by SILVAH is 105 percent, only slightly higher than the value we would prefer in unmanaged stands. But the range of values observed in this small group of stands, from 79 to 125 percent, suggests that this measure does not discriminate well between understocked, fully stocked, and overstocked stands.

A different approach to estimating density in mixed stands was taken by the developers of NE-TWIGS, the northeastern regional variant of the TWIGS forest growth projection system (Teck 1990). NE-TWIGS calculates a generalized stocking percent (GSP) for all stands. This measure is a weighted average relative stand density, calculated using Stand Density Index (Reineke 1933) values for seven different forest types. GSP is influenced by the species composition of the stand, and is a summation of weighted relative stand densities, where each species can only represent a single forest type (personal communication, Richard

Teck). The NE-TWIGS GSP values for these stands are reported in the fourth row of Table 2. The mean value of relative density calculated by NE-TWIGS is 83%, quite low for undisturbed stands. But the range of estimates is the narrowest of any of the measures reported, from 60 to 97 percent.

The values from the 21 undisturbed stands studied here were used to estimate the coefficients for two new measures of relative density for undisturbed stands. The fifth and sixth rows of Table 2 show the density of these stands by two measures developed during this study. Column 5 shows the results of applying a tree-area ratio measure developed from these data. The mean value is close to 105 percent. The range of values calculated for these stands is from 79 percent to 125 percent.

The tree-area ratio equation calculated for these transition stands is:

$$Tree\ area = -0.0068718 * N + 0.0167869 * \sum_{i=1}^{N} D_i + 0.0019797 * \sum_{i=1}^{N} D_i^2 \qquad (1)$$

where N is number of trees per acre and D_i is the diameter of the *i*th tree.

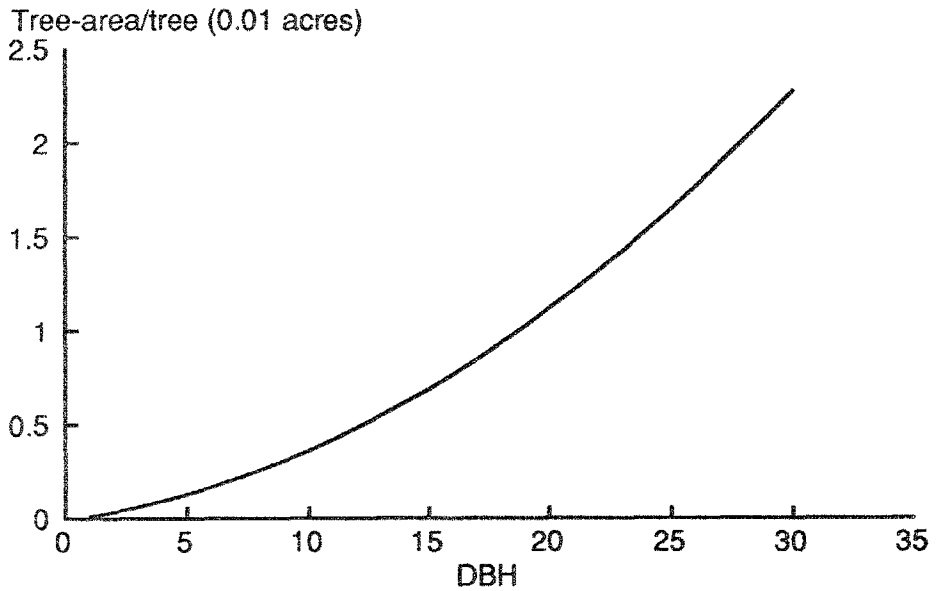

Figure 3. Tree area per tree (in centacres) as estimated by the tree-area ratio equation developed for this data set.

This tree-area curve is shown in Figure 3 as it would be used to estimate the density contribution of an individual tree. With 21 stands in the data used to estimate the coefficients for this equation, separation into species groups did not significantly improve the fit of the equation.

Row 6 of Table 2 contains an estimate of stand density based on the relationship between the number of trees and the quadratic stand diameter, as suggested by Reineke (1933). For the 21 undisturbed stands studied here:

$$\log_{10} N = 4.393 - 1.962 * \log_{10} QMD \quad (2)$$

where N is number of trees per acre and QMD is the quadratic mean diameter.

This equation has an r^2 of .88. The values in row 6 are ratios of the number of trees per acre in each of these stands to the number predicted by equation (2), expressed as a percent. This measure has a mean value of 96 percent in these stands, with a range from 74 percent to 121 percent.

DISCUSSION

The research reported here is part of a larger effort to develop regional tools to assess relative density in mixed hardwood stands. Managers must be able to discriminate between stands whose density is close to the average maximum for a type and those whose density is well below the average maximum, regardless of their management objective. Such discrimination is key to identifying opportunities and projecting changes (Stout and Larson 1987). The work reported here highlights the difficulties of assessing density in complex, stratified mixtures. The structure of these stands, with bellshaped oak distributions in the larger diameters and inverse J distributions of shade-tolerant northern hardwoods in the smaller diameters, contributes to their consistently overstocked ratings by traditional measures.

As our understanding of the interactions of these structures with site, management, and stand development improves, we will develop new and more efficient methods of assessing density in such stands. Differences among density measures reported here may help managers choose which of the existing measures of density they prefer, as well as point directions for future research. The new measures developed using this data provide the mean relative-density estimates closest to 100 percent for these 21 undisturbed stands, but their ranges are quite large, and they are untested outside this data set. The NE-TWIGS measure has the narrowest range, but underestimates the density of these stands, heightening the risk of missed treatment opportunities. Estimates made using the oak stocking guide or SILVAH tend to be high and have wide ranges, but may be acceptable as they minimize the risk of missed treatment opportunities.

CONCLUSIONS

Oak stands in northwestern Pennsylvania are usually stratified mixtures of central and northern hardwood species. In many such stands, northern red oaks are the largest trees in the stand, with red maple, the other oak species, cucumbertree, eastern hemlock, birch, and others in the middle of the diameter distribution, and American beech, sugar maple, and eastern hemlock forming a dense, sapling understory. Managers of such stands must be sensitive to the effects of silvicultural treatments on species composition by cutting alone; uneven-age cuts will tend to decrease the proportion of oak species or leave it unchanged, and even-age cuts will tend to increase it. Traditional measures of relative density are often poor at discriminating among these stratified oak stands with respect to stocking for any management objective. Both tree-area ratio and stand density index procedures offer some promise for assessing density in these stands.

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COMPOSITION AND STRUCTURE OF AN OLD-GROWTH VERSUS A SECOND-GROWTH WHITE OAK FOREST IN SOUTHWESTERN PENNSYLVANIA

Julie A. Downs and Marc D. Abrams[1]

Abstract: A relatively undisturbed, old-growth *Quercus alba* remnant and a second-growth example of the forest type were surveyed in 1988-89 to investigate the successional status of *Q. alba* in the region. Oaks (*Q. alba*, *Q. rubra*, and *Q. velutina*) totalled 18% importance in the old-growth stand and 30% importance in the second-growth stand. The overstory of the old-growth stand was mainly comprised of *L. tulipifera*, *F. grandifolia*, *Q. alba* and *Nyssa sylvatica*, whereas the overstory of the second-growth stand was mainly *Q. alba* with a relatively minor component of *F. grandifolia*, *A. saccharum*, and *L. tulipifera*. *Acer rubrum*, *A. saccharum*, and *Prunus serotina* were the dominant seedlings in both stands. The younger stand had greater sapling density. Both stands had few *Quercus* individuals in the understory. The oldest and largest trees in both stands were *Q. alba* with ages of 310 years and 148 years in the old-growth and second-growth stand, respectively. However, over 90% of all trees in the old-growth stand were < 120 years-old. Logging of several trees in the 1930's and 40's appears to have accelerated the dominance of the mixed-mesophytic species in the old-growth forest. The radial growth patterns of trees varied with species and canopy position. However, the oldest oak trees had average growth rates of < 0.75 mm/yr and > 1.5-2.0 mm/yr in the old-growth and second-growth stands, respectively. Many of the understory trees had average growth rates of > 1.5-2.0 mm/yr in both stands. We believe these stands represent an early versus late stage of oak replacement by mixed-mesophytic species, a process that seems inevitable in many eastern oak forests.

INTRODUCTION

Oak (*Quercus*) forests dominate much of the eastern deciduous forest biome and have been considered a climax type by early ecologists (Braun 1950, Clements 1936). Indeed, oak presence and dominance was recorded in presettlement forests of the northeast and mid-Atlantic regions (Bromley 1935, Loeb 1987, Russell 1980, Secor 1975, Spurr 1951). Oak dominance prior to European settlement in these regions may be explained, in part, by periodic fire set by early Native Americans and by lightning (Buell et al. 1954, Lorimer 1985). Following European settlement, cutting and slash fires further perpetuated or even

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caused an increase in oaks in many areas (Crow 1988, Lutz 1928, Nowacki et al. 1990, Whitney 1987). However, there now exists substantial documentation that oaks are failing to regenerate under their own canopy, especially on mesic sites, suggesting oak replacement by more shade tolerant species (Abrams 1986, Lorimer 1984, Nigh et al. 1985, Parker et al. 1985). Much of this evidence, however, comes from studies of relatively young forests of generally less than 120-years-old with shade tolerant species confined to regeneration layers. Many eastern oak species can, in fact, live well over 300 years (Fowells 1965). Thus, examples of actual oak replacement with later successional species dominating the canopy of old-growth stands are lacking.

In southwestern Pennsylvania we found a relatively undisturbed old-growth stand with white oak (*Q. alba* (L.)) trees up to 310 years in age. In the same area there also existed an undisturbed second-growth forest on a similar site with white oak trees up to 148 years in age. This paper compares the composition, age and diameter structure, radial growth patterns and regeneration trends in the old-growth stand with that of the second-growth stand to provide evidence that mesic white oak forests in this region are not a true climax type and, thus, are replaced by later successional species. Moreover, the results of this study may indicate whether successional trends apparent in the younger stand actually occurred in the old-growth stand.

METHODS

Study Area

The 3 ha old-growth forest, known as Sophia's Woods, is located within the 270 ha Friendship Hill National Historic Site in Fayette County, in southwestern Pennsylvania. Friendship Hill preserves the country estate of Albert Gallitin, the United States Secretary of Treasury under Presidents Jefferson and Madison. Gallitin purchased this land in 1786 when it was virgin timber. At that time, Gallitin girdled and removed some of the forest for agricultural purposes. By 1880, after Gallitin had sold the estate, 90 ha were cleared for pasture and food crops, while 180 ha were left in mature timber. By 1895, only 80 ha remained wooded.

A 1923 timber cruise of Friendship Hill reported that mature forests on the property were predominantly oaks "of the various species" with ages up to 260 years, and that some trees were of "unusual size" (e.g., the diameter of one white oak was 152 cm). It was also noted that *Carya* (hickory) and *Quercus coccinea* (Muench.) (scarlet oak) were "dying". This report recommended harvesting, but major timber operations were held off until the 1940's and lasted intermittently through the 1950's. Between the 1930's and 1950's the amount of non-forest area within the property had more than doubled.

Physical evidence within Sophia's Woods and growth patterns of the existing trees indicated that this area was selectively cut in the 1930's and 1940's. Several large oak stumps (dbh >

1 m) of low density (about 2 stumps/ha) were irregularly distributed throughout the stand. Fire scarring on trees was lacking and only one uprooted tree was observed. Sophia's Woods is located on an upland bluff over the east bank of the Monongahela River. The stand is gently sloping (3-8%) and is bisected by two small streams. The Monongahela silt loam soil present is deep (1.5-5.0 m) and moderately well-drained. The permeability of this soil is moderately slow due to the presence of a fragipan, normally starting at a depth of 48 cm. The available moisture capacity is high (Kopas 1973).

The 4 ha second-growth stand is located within the 1600 ha Bear Run Nature Reserve, also in Fayette County in southwestern Pennsylvania. This second-growth stand originated after clearcutting and is protected by the Western Pennsylvania Conservancy. No physical evidence of logging or fire since stand initiation was observed. The Bear Run site is located on an upland bluff over the east bank of the Youghiogheny River. The stand is gently sloping to the northwest and traversed by 3 small intermittent streams. The Dekalb soil present is a very stony, sandy loam and is moderately deep (0.6 -1.0 m). The permeability of the soil is rapid and the available moisture capacity can be low (Kopas 1973).

The climate of Fayette County is humid continental. Annual precipitation averages 101 cm per year and is evenly distributed. The mean annual temperature is 12° C (monthly range = -18 to 35° C). The growing season averages about 169 days (Kopas 1973).

Field Methods

Trees (individuals > 10 cm at 1.37 m; dbh) of Sophia's Woods and Bear Run were surveyed during July 1988 and July 1989, respectively, using the point-quarter method (Cottam and Curtis 1956). Twenty sample points located at 20 m intervals along transects were used. Transects were oriented to best include the entire study area and avoid edges. Species name, dbh and distance to the point center of the tree in each of four quadrants closest to the sample point were recorded. These data were used to calculate importance values for each tree species as the sum of relative dominance, frequency and density. The canopy class of each sample tree was rated as dominant, codominant, intermediate, or overtopped (cf. Smith 1986). Sample trees were also cored at 1.37 m for age determination. In Sophia's Woods every sample tree was cored because of the wide range of tree ages. In contrast, only two sample trees from each plot were cored in the younger Bear Run stand. A total of 61 suitable cores from Sophia's Woods were sanded, stained and measured for annual radial growth to the nearest 0.1 mm with a dissecting scope and an ocular micrometer. A total of 37 suitable cores from Bear Run were analyzed using the same technique.

Using the 20 sample points in the tree survey as centers, fixed area plots were established in both stands for regeneration data. Saplings (tree species < 10 cm dbh and taller than 1.37 m) and seedlings (tree species < 1.37 m tall) were counted by species in 10 m^2 and 5 m^2 plots, respectively.

RESULTS

In Sophia's Woods, the old-growth stand, *Fagus grandifolia* (Ehrh.) (beech), *Acer rubrum* (L.) (red maple) and *Liriodendron tulipifera* (L.) (tulip poplar) represented 63% of the importance value total (Table 1). White oak, *Quercus rubra* (L.) (northern red oak), and *Q. velutina* (Lam.) (black oak) totalled only 18% importance. The importance of white oak in Sophia's Woods was mainly due to its high basal area from a few large diameter individuals. Bear Run, the second-growth stand, was dominated by white oak, *Acer saccharum* (Marsh.) (sugar maple), red maple and tulip poplar which represented 76% of the importance value.

Table 1.--Relative importance values for trees (> 10 cm dbh) surveyed during 1988 and 1989 in an old-growth (Sophia's Woods) and a second-growth (Bear Run) stand on mesic sites in southwest Pennsylvania. Relative importance value is the sum of the relative dominance, frequency, and density divided by three for each species.

Species	Importance Value	
	Sophia's Woods	Bear Run
Quercus alba	11	27
Quercus velutina	3	1
Quercus rubra	4	1
Acer rubrum	20	12
Acer saccharum	5	25
Liriodendron tulipifera	18	11
Fagus grandifolia	25	7
Betula lenta	4	4
Nyssa sylvatica	4	1
Prunus serotina	2	1
Tilia americana	2	--
Cornus florida	1	4
Carya spp.	1	2
Ulmus spp.	--	4

Prunus serotina (Ehrh.) (black cherry), red maple and sugar maple were the dominant seedlings surveyed in Sophia's Woods and Bear Run, despite the low importance of black cherry trees on both sites (Table 2). Sugar maple and red maple had similar seedling densities at Bear Run, while the density of red maple seedlings was 400% greater than that of sugar maple in Sophia's Woods. Sophia's Woods had greater total seedling density than

Table 2.--Seedling and sapling data (no./ha ± se) from the 1988 and 1989 survey of an old-growth forest (Sophia's Woods, SW) and a second-growth forest (Bear Run, BR) on mesic sites in southwest Pennsylvania.

Species	Seedlings		Saplings	
	SW	BR	SW	BR
Acer rubrum	23400±300	7600±153	50±2	900±3
Acer saccharum	5100±61	7100±119	100±3	50±2
Prunus serotina	11000±138	14300±123	50±2	500±15
Nyssa sylvatica	4900±160	600±18	50±2	450±10
Quercus alba	3000±82	500±10	0±0	300±8
Quercus rubra	2500±58	800±22	0±0	0±0
Quercus velutina	100±5	0±0	0±0	0±0
Fraxinus spp.	1500±27	700±17	100±3	150±5
Fagus grandifolia	1100±15	300±8	100±5	700±14
Carya spp.	500±18	900±25	0±0	100±3
Cornus florida	100±5	900±25	0±0	100±3
Hamamelis virginiana	0±0	4900±159	0±0	600±16
Crataegus spp.	0±0	700±3	0±0	50±2
Sassafras albidum	0±0	600±15	0±0	0±0
Ulmus spp.	0±0	500±25	0±0	50±2
Asimina triloba	0±0	400±12	0±0	100±3
Betula lenta	0±0	100±5	0±0	50±2
Liriodendron tulipifera	0±0	100±5	0±0	50±2
Total	53300±874	41000±744	450±17	4150±90

Bear Run and twice the number of species with seedling density > 1000/ha. However, these species (which included *Nyssa sylvatica* (Marsh.) (blackgum), northern red oak, white oak, *Fraxinus* spp. (ash) and beech) had few if any saplings (from 0-100/ha) in Sophia's Woods. At Bear Run these same species had saplings with densities in the range of 150-900/ha (with the exception of northern red oak). Seedlings and saplings of tulip poplar were absent in the sample plots at both sites, but were observed under canopy gaps.

Diameter class distribution in both stands approximated a reverse-J curve typical of an uneven-aged condition (Figure 1) (cf. Smith 1986). In Sophia's Woods the large diameter classes (> 60 cm) were dominated by white oak and beech, whereas the medium classes (35-60 cm) were dominated by tulip poplar and beech with some blackgum. The small diameter classes (< 35 cm) at Sophia's Woods were dominated by red maple, with some sugar maple, beech and tulip poplar also present. White oak and beech dominated the larger and medium diameter classes and sugar maple followed by red maple dominated the smaller diameter classes at Bear Run. Relatively few oak trees were surveyed in the smaller diameter classes at either site. Diameter distribution and tree size was similar in both stands despite the great difference in stand ages.

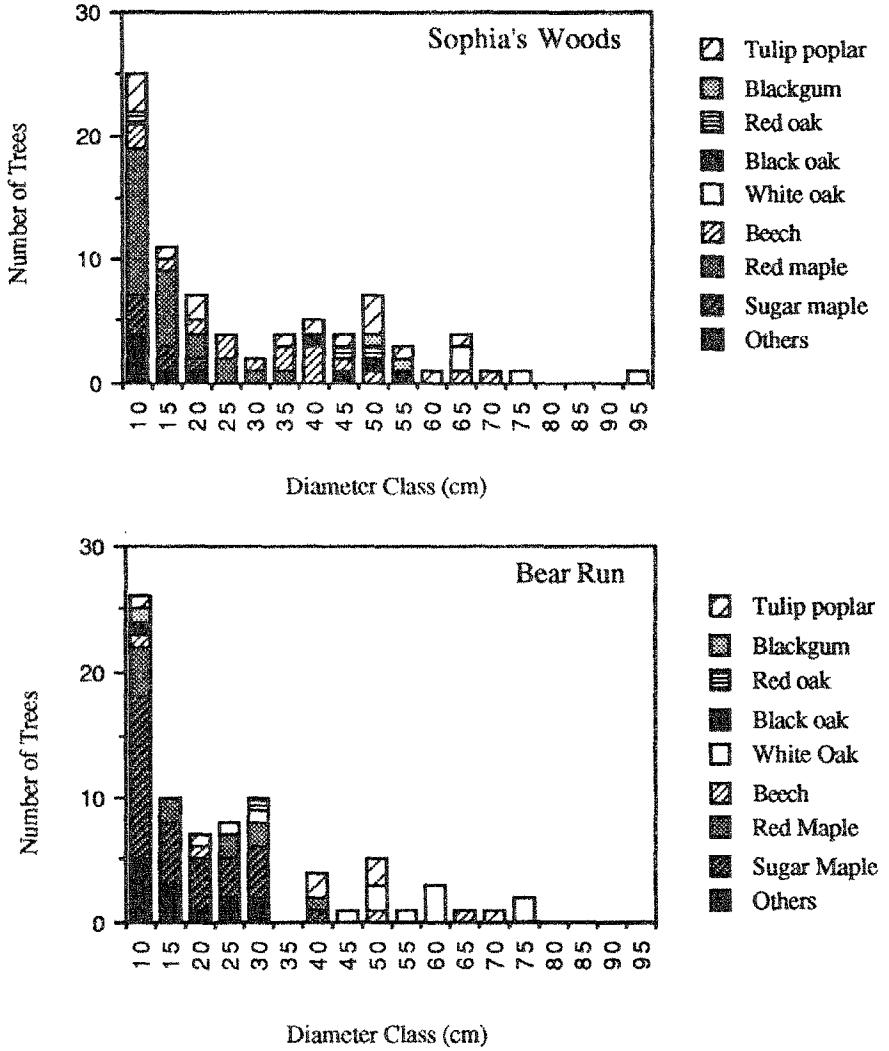

Figure 1. Diameter distribution of tree species in an old-growth oak forest (Sophia's Woods) and a second-growth oak forest (Bear Run) in southwestern Pennsylvania. Other species include *Betula lenta, Prunus serotina, Tilia americana, Cornus florida* and *Aesculus* spp. in Sophia's Woods and *Betula lenta, Prunus serotina, Cornus florida, Carya* sp. and *Ulmus* spp. in Bear Run. The Bear Run distribution excludes a white oak tree surveyed in the 125 cm class.

Table 3.--Canopy and diameter class distributions among the surveyed trees at Sophia's Woods (SW) and Bear Run (BR), old-growth and second-growth stands, respectively, in southwest Pennsylvania, surveyed in 1988 and 1989. N=number of individuals. Large, medium and small diameter classes are dbh >60, 35-60 and <35 cm, respectively.

Canopy Class	Species	N		Diameter Class	
		SW	BR	SW	BR
Dominant:	*Liriodendron tulipifera*	5	1	Medium	Large
	Fagus grandifolia	4	1	Large	Large
	Quercus alba	3	3	Large	Large
	Quercus velutina	1	0	Medium	-----
	Nyssa sylvatica	1	0	Large	-----
	Tilia americana	1	0	Medium	-----
Codominant:	*Liriodendron tulipifera*	2	3	Medium	Medium
	Fagus grandifolia	2	1	Medium	Medium
	Nyssa sylvatica	1	0	Medium	------
	Betula lenta	1	0	Medium	------
	Quercus alba	0	8	------	Medium
	Acer saccharum	0	2	------	Medium
	Acer rubrum	0	1	------	Medium
Intermediate:	*Fagus grandifola*	6	0	Medium	------
	Liriodendron tulipifera	4	1	Small	Medium
	Acer rubrum	2	3	Small	Small
	Acer saccharum	0	9	-----	Small
	Quercus rubra	2	0	Medium	-----
	Quercus velutina	1	0	Medium	-----
	Carya spp.	0	2	------	Small
	Ulmus spp.	0	2	------	Small
	Prunus serotina	0	1	------	Small
Overtopped:	*Acer rubrum*	22	8	Small	Small
	Acer saccharum	6	18	Small	Small
	Fagus grandifolia	7	2	Small	Small
	Liriodendron tulipifera	2	2	Small	Small
	Betula lenta	2	3	Small	Small
	Carya spp.	1	0	Small	-----
	Prunus serotina	2	0	Small	-----
	Quercus rubra	1	1	Small	Small
	Quercus alba	0	1	-----	Small
	Quercus velutina	0	1	-----	Small
	Cornus florida	1	4	Small	Small
	Ulmus spp.	0	1	-----	Small
	Nyssa sylvatica	0	1	-----	Small

Canopy position of trees in Sophia's Woods and Bear Run was closely related to their respective diameter class (Table 3). However, species composition within canopy classes differed between the old-growth and second growth stands. More dominant beech and tulip poplar were surveyed at Sophia's Woods versus Bear Run. Eight codominant white oaks were surveyed at Bear Run compared to none at Sophia's Woods. Sugar maple and red maple were overstory codominants at Bear Run but not at Sophia's Woods. Sophia's Woods had a greater number of dominant overstory species, which included blackgum, black oak, and *Betula lenta* (L.) (black birch), not present at Bear Run. Overtopped trees in Sophia's Woods were primarily red maple, beech and sugar maple, while at Bear Run more overtopped sugar maple and less beech and red maple were present.

Two white oaks were estimated to be > 300 years-old at Sophia's Woods (Figure 2). However, greater than 90% of all sampled trees were less than 120 years-old, including many beech, tulip poplar and red maple, but few oaks. Several beech and tulip poplar were in the canopy despite their relatively young ages (Table 3). At Bear Run, white oak, with a maximum age of 148 years, and to a lesser extent beech, dominated the higher age classes. A greater number of 90-148 year-old white oaks were surveyed at Bear Run compared to Sophia's Woods. Sugar maple was much more dominant in the younger age classes at Bear Run compared to Sophia's Woods. Relatively few individuals in the 20-year class were observed at either site.

Radial growth patterns of the surveyed trees varied with species and canopy position in both stands (Figures 3 and 4). Several cores of Sophia's Woods showed release in the 1930's and 40's which coincided with reported logging activities (Figure 3D, E, F, G, and H). Many trees in Bear Run also exhibited periodic release, such as intermediate white oak, red maple and sugar maple, presumably in response to natural gaps (Figure 4B, D, G). A codominant sugar maple in Bear Run had high but decreasing growth with age, suggesting it had originated in a gap and had no accelerated growth after reaching the canopy (Figure 4C) (cf. Lorimer et al. 1988). A dominant white oak in Sophia's Woods exhibited this same pattern (Figure 3C). An understory northern red oak at Bear Run had early growth of 5.0 mm/yr and a decrease to < 1.0 mm/yr probably as a result of gap closure (Figure 4H). A codominant beech at Bear Run (Figure 4E) displayed moderate, low, then high radial growth, suggesting that it grew during the opening and closing of a gap and then was released upon reaching the canopy. Tulip poplar exhibited the highest average growth rate of any species in both stands (3.0 mm/yr), with no extended periods of suppression.

Differences in radial growth between stands were apparent when comparing the oldest oaks. At Sophia's Woods a 310 year-old white oak and a 240 year old black oak averaged < 0.60-0.75 mm/yr radial growth (Figure 3A, B). In contrast, the oldest white oaks of Bear Run averaged > 1.5-2.0 mm/yr radial growth (Figure 4A, B). Younger trees of all species at both sites, in general, had average growth rates exceeding 1.5-2.0 mm/yr.

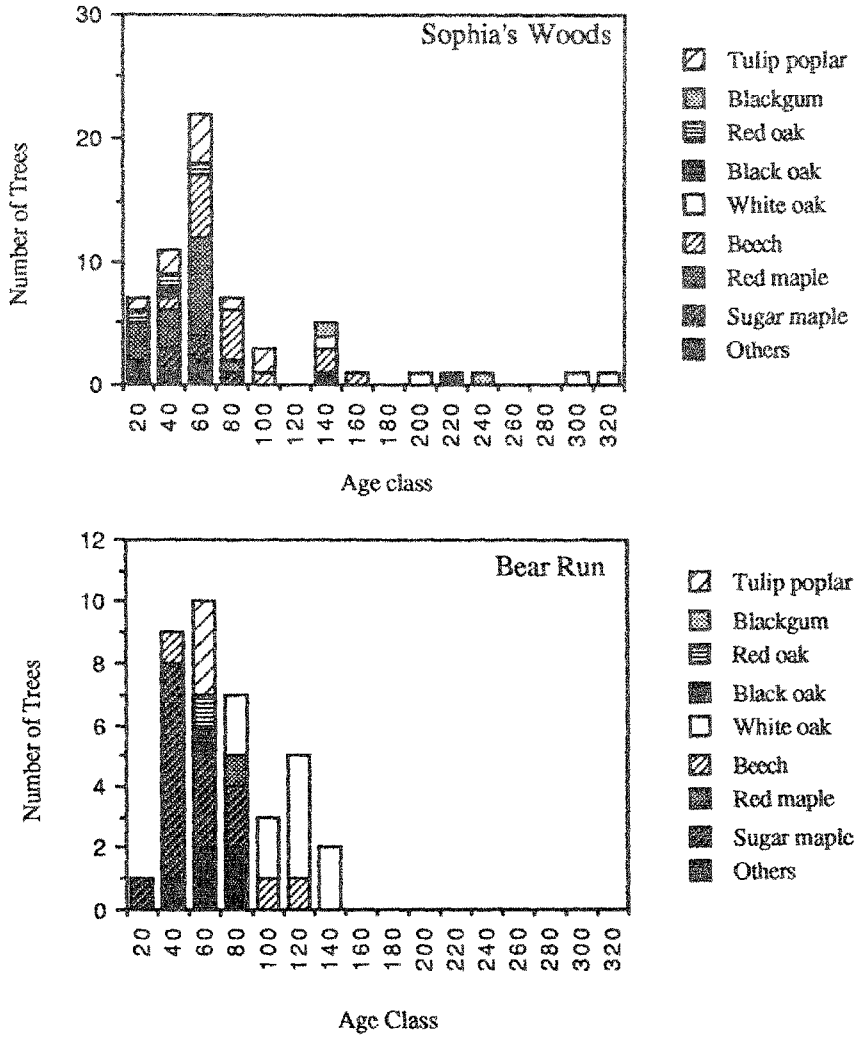

Figure 2. Age distribution of tree species in an old-growth oak forest (Sophia's Woods) and a second-growth oak forest (Bear Run) in southwestern Pennsylvania. Other species include *Betula lenta, Prunus serotina, Tilia americana, Cornus florida* and *Aesculus* spp. in Sophia's Woods and *Prunus serotina, Carya* spp. and *Ulmus* spp. in Bear Run.

DISCUSSION

Presettlement forests of southwestern Pennsylvania were dominated by white oak (Braun 1950, Jenning 1927). Beech may have been a codominant with white oak in the original forests (Braun 1950), and at Friendship Hill one beech and two white oak were among five trees present in a 1787 survey of the property corners. The age of beech trees relative to white oak in the original forests is unknown, but they were distinctly younger than the white oaks in Sophia's Woods, despite that beech can live over 300 years. Periodic fire by Native Americans and lightning seems to be responsible, at least in part, for the predominance of oak

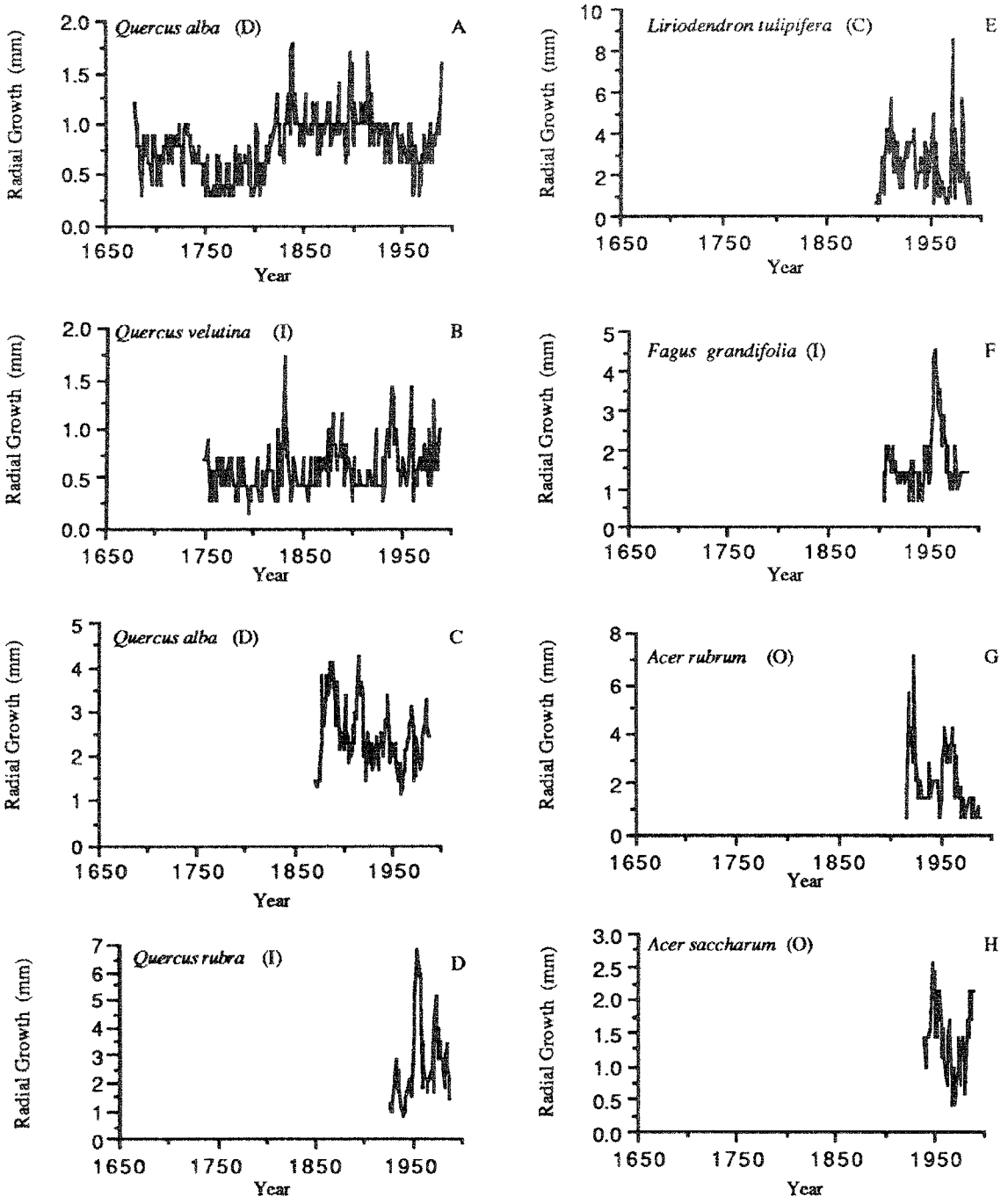

Figure 3. Radial growth of representative trees in an old-growth white oak forest (Sophia's Woods) located in southwestern Pennsylvania. Letters in parentheses indicate canopy class as follows: D = dominant, C = codominant, I = intermediate, O = overtopped (cf. Smith 1986).

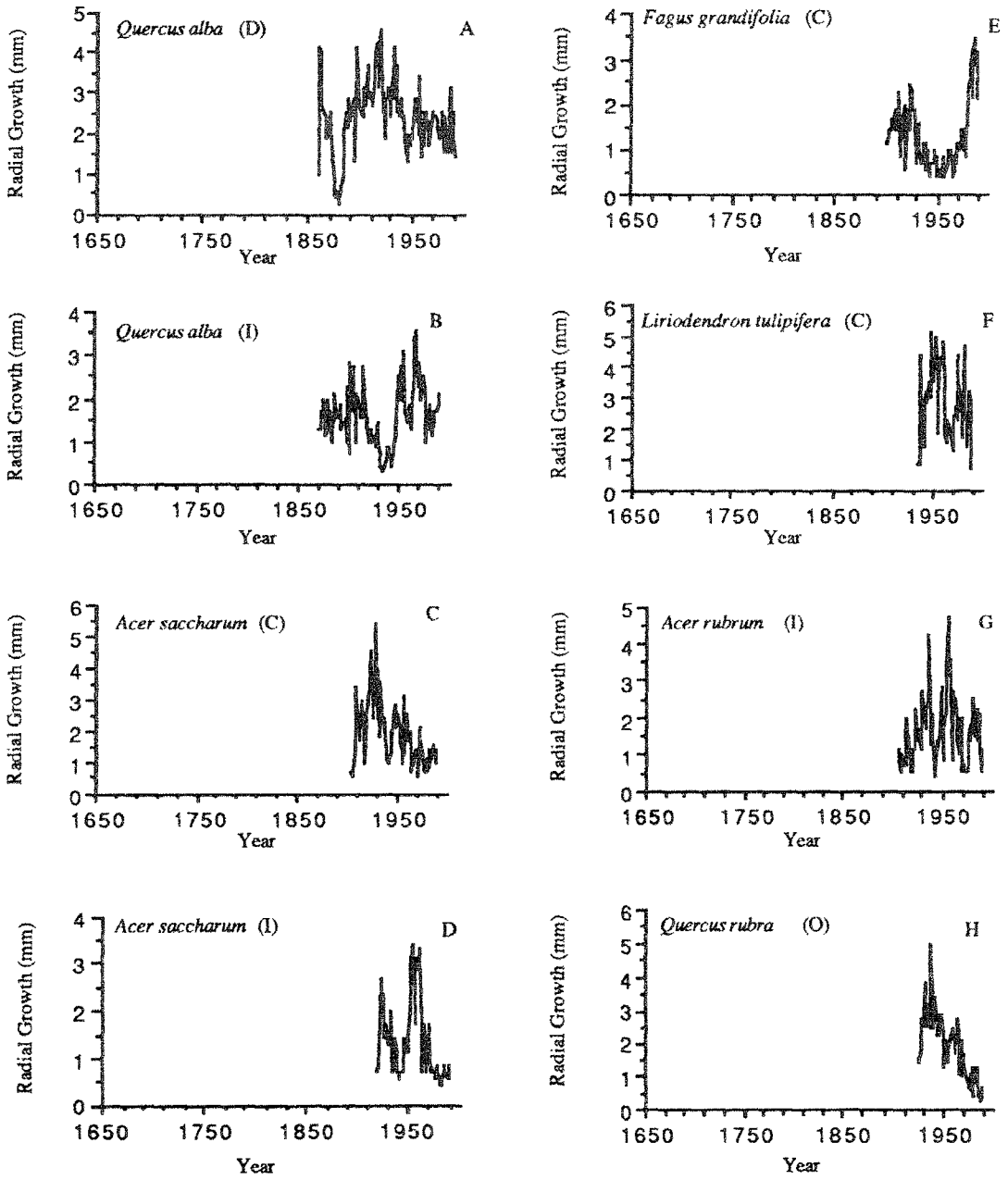

Figure 4. Radial growth of representative trees in a young-mature white oak forest (Bear Run) located in southwestern Pennsylvania. Letters in parentheses indicate canopy class as follows: D = dominant, C = codominant, I = intermediate, O = overtopped (cf. Smith 1986).

in the region prior to European settlement (Buell et al. 1954, Lorimer 1984). Not surprisingly, however, fire scarring on trees was not observed at Sophia's Woods, which has been a country estate for the last 200 years. Sophia's Woods was probably dominated by white oak in the 1600-1700's. Five trees (four oak and one blackgum) in the stand were over 195 years and the two oldest trees were white oak of over 300 years.

All of the older trees surveyed at Sophia's Woods exhibited slow radial growth of approximately 0.60-0.75 mm/yr. The specific reason for slow growth of the oldest white oak is unknown, but may be related to growing up in small gaps of an uneven-aged forest, or to the differential survival of slow growing individuals in an even-aged oak cohort. In contrast, the white oak of Bear Run originated directly after logging and exhibited high growth rates (> 1.5-2.0 mm/yr) probably in response to growing in high light. Likewise, many present-day northeastern, Lake States and Central Plains oak forests have an even-aged cohort of oak that originated either directly after large-scale disturbances, such as logging and fire, or the cessation of prairie fires and exhibited relatively high growth rates (Abrams 1986, Knox 1984, Lorimer 1981, Nowacki et al. 1990, Oliver and Stephens 1977). The younger northern red oaks in Sophia's Woods had much higher radial growth than the older white oaks and black oaks, suggesting that these individuals benefited from greater understory light conditions created by periodic logging or other gap-creating events. Relatively high growth rates with little or no periods of prolonged suppression were also exhibited by younger trees of beech, tulip poplar, red maple and sugar maple at Sophia's Woods, which matched the growth rates of those species at Bear Run. The general scarcity of trees > 195 years and the consistently high growth rates of younger individuals in Sophia's Woods suggest the occurrence of selective logging not reported in the historical record.

Oaks at both study sites were represented almost exclusively in the older age and middle to larger diameter classes, with the slight exception of northern red oak. Northern red oaks were also present in the smaller diameter classes of two virgin hemlock-pine forests in northwestern Pennsylvania (Morey 1936a), and were able to maintain a minor place in the forest canopy by infrequent gap capture in a southern Appalachian hardwood forest (Barden 1981). A scarcity of young oak trees is typical of many forests in eastern North America, and this has been used as evidence for predicting oak replacement by more shade tolerant species (Abrams 1986, Adams and Anderson 1980, Fralish 1988, Host et al. 1987, Lorimer 1984, Nowacki et al. 1990, Parker et al. 1985).

In both Sophia's Woods and Bear Run, beech, tulip poplar, red maple and sugar maple dominated the smaller and middle tree classes. In addition, many beech and tulip poplar and some blackgum, *Tilia americana* (L.) (basswood) and black birch also dominated the upper canopy at Sophia's Woods. This contrasted with the predominance of white oak at Bear Run and suggests that Sophia's Woods is in a later stage of oak replacement. Red maple and sugar maple trees at Sophia's Woods were generally smaller in diameter and height than the other mesophytic hardwoods, but showed every indication of becoming a codominant in the canopy in the near future. Red maple and sugar maple were present as codominants and dominated as understory trees at Bear Run. Thus, a pattern of decreasing oak and increasing sugar and red maple importance was also apparent in this stand. The more advanced status of maples at Bear Run versus Sophia's Woods may be due to the more extensive or complete

logging of that stand. We were somewhat surprised at the higher importance of sugar maple at Bear Run which has soil with lower moisture holding capacity than that at Sophia's Woods. Other studies reported higher red maple than sugar maple in drier oak forests (Host et al. 1987, Nowacki et al. 1990).

A pattern of gradual decreasing oak and increasing tulip poplar, beech and some red maple trees in Sophia's Woods was apparent before the selective logging in the 1930-40's. However, peak recruitment of these species and sugar maple occurred during and shortly after logging. Thus, this stand seems to have experienced accelerated succession of mixed-mesophytic hardwoods following logging (cf. Abrams and Scott 1989, Lorimer 1985). Similarly, gaps created by oak wilt or gypsy moth in eastern and Lake States forests became dominated by sugar maple or red maple (Collins 1961, Menges and Loucks 1984, Tryon et al. 1983). Beech has been reported to grow slowly as saplings beneath overstory conifers or hardwoods and then extend to the canopy following subsequent disturbance (Foster 1988, Spurr 1956). The small number of younger trees (in the 20-year age class) and saplings in both stands may be due to monopolization of resources (e.g. from canopy closure) by older, shade tolerant or gap-specialist trees.

Red maple was a dominant seedling at Sophia's woods and Bear Run, which was consistent with its importance as an understory tree at both sites. Red maple is the dominant seedling in many eastern and Lake States oak forests (Christensen 1977, Host et al. 1987, Lorimer 1984, Nowacki et al. 1990). Beech was poorly represented as seedlings at both sites which contrasts with its reputation of forming a dense seedling layer even in heavily shaded understories (Curtis and Rushmore 1958, Fowells 1965). However, beech seedlings were also scarce in many southeastern Pennsylvania hardwood forests, where reproduction of this species occurs mainly from root suckers (Keever 1973). Regardless, beech was present in most age classes in both stands. Tulip poplar also dominated the overstory but was not surveyed in the seedling layer at either site. Tulip poplar is intolerant of shade, but is a component of old-growth forests because it is an aggressive gap-phase species that often dominates its own gaps, and because trees of this species obtain great size and age (Buckner and McCracken 1978). Northern red oak and white oak were well represented as seedlings at Sophia's Woods, but they were poorly represented at Bear Run. Northern red oak has had some recruitment into the tree size class over the last 80 years in Sophia's Woods whereas white oak has not. Oak recruitment in closed stands may be limited to whether or not a substantial number of oak seedlings are present (Abrams 1986, Nowacki et al. 1990).

Black cherry seedlings dominated at Bear Run and were second in abundance to red maple at Sophia's Woods, despite the presence of only a few black cherry trees in both stands. The adults in Sophia's Woods were only about 20-years-old, which suggests that black cherry invaded the stand relatively recently. Black cherry recruitment in response to canopy gaps has been reported for oak woods in Wisconsin (Auclair and Cottam 1971, McCune and Cottam 1985), and has been observed in mesic white oak stands in central Pennsylvania (Nowacki and Abrams, unpublished data). We anticipate a gradual increase of black cherry into the canopy of Sophia's Woods and Bear Run.

In conclusion, Sophia's Woods is a remnant white oak forest in a late stage of oak replacement. Presettlement white oak forests in the region were probably maintained by periodic fire. Younger mixed-oak forests in the region are most likely a direct response to wide-spread cutting and subsequent fire in the mid-to late-1800's (Powell and Considine 1982). Sophia's Woods has been a part of a country estate since the late 1700's, during which time fire frequency was most likely reduced and a succession from white oak to mixed-mesophytic species has occurred. No white oaks under 130-years-old were surveyed, whereas numerous beech, tulip poplar, red maple, and sugar maple trees less than 120 years-old were present. A succession toward these mixed-mesophytic species was also apparent at Bear Run, but because of the relatively young stand age white oak still dominated. Replacement of oaks on undisturbed sites is relatively slow due to their longevity, but the results of this and previous studies of second growth oak forests indicate the inevitability of this process in many eastern forests.

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CHANGES IN THE RELATIONSHIP BETWEEN ANNUAL TREE GROWTH AND CLIMATIC VARIABLES FOR FOUR HARDWOOD SPECIES

Elizabeth R. Smith and John C. Rennie[1]

Abstract: A study was conducted to characterize temporal and spatial variability in the growth response of four major hardwood species (white oak, chestnut oak, northern red oak, and yellow-poplar) to climatic fluctuations, and to evaluate the role of environmental factors associated with differences in response among individuals. The study incorporated tree-ring data collected by the Tennessee Valley Authority from a system of permanent forest inventory plots. Results of the dendroclimatic modelling indicated that there is a great deal of temporal variability in the climate/growth relationship for the species and sites included in this study. Statistically significant trends in growth showed a decrease in sensitivity to climate occurring in the tree-ring series. Changes in tree sensitivity did not appear to coincide with changes in climate. Environmental factors were effective in explaining groupings of tree core series as long as interactions between variables were considered. These factors indicate that differences in growth response to climate may be a function of changes in stand structure, competitive interactions and soil moisture holding capacity.

INTRODUCTION

Climate is often considered one of the most prominent and consistent factors affecting year to year variability in tree growth and, depending on the existence of other growth limiting factors, may be one of the most difficult to understand (Fritts 1976). In areas such as the arid southwest United States where moisture is the limiting growth factor, response to rainfall fluctuations is strong and predictable, especially at the forest - desert interface where conditions are marginal for tree survival (Fritts et al. 1965, Stahle 1987). However, moving towards more mesic sites, where moisture is less limiting, response to climate becomes less predictable due to the effects of factors such as nutrient availability and stand competition and their interactions with climate. The dynamic nature of these factors along with their inherent variability further obscures direct climatic effects resulting in a great deal of temporal and spatial variability in tree growth response. As these relationships increase in complexity from the moisture limited "sensitive" trees of the arid southwest to the "complacent" trees growing on more mesic sites, the level of detail of investigation of other factors and the sophistication of analytical techniques must also increase if tree growth response to climate is to be understood.

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As moisture becomes less limiting, other growth-limiting factors increase in relative importance, particularly in that stress due to some other factor may predispose a tree to injury attributable to climate. Site quality changes over time as a result of the natural aging processes of ecosystems, as well as stochastic events that cause significant disturbances. These changes bring about both abrupt and gradual changes in soil properties and species composition before a constant vegetation composition associated with a mature soil is reached (Pritchett and Fisher 1987). Over the life of a forest stand, changes occur in 1) soil physical and chemical properties as well as soil biota (Carmean et al. 1976, Whittaker and Woodwell 1972); 2) the physiology of individual trees and their sensitivity to stresses (Boyce 1961, Daubenmire 1974, Kim and Siccama 1987, Kozlowski 1979, Waring and Cleary 1967); and 3) stand structure and competition among trees (Haines and Cleveland 1981, Hornbeck et al. 1986, Van Deusen 1987, 1988). In addition, microsite differences within a stand modify individual tree response to various stresses.

Variability in tree growth response to climate across geographical gradients can be anticipated due to: 1) varying site requirements for different species (Fowells 1965); 2) differences in soils reflected in moisture availability and nutrient content (Bassett 1964, Kim and Siccama 1986, Pritchett and Fisher 1987); 3) local fluctuations in climate not accounted for in available data (Daubenmire 1974, Haines and Cleveland 1981); 4) intraspecific genetic variability as a result of species adaptation to a particular site; and 5) interactions with other trees (Doyle 1983). Spatial variability is, of course, a function of scale. However, variability in forest ecosystems can be extreme, as conditions influencing tree growth can change substantially over a small area.

The objective of this study was to characterize temporal and spatial variability in tree growth response to climate for four major hardwood species that occur within the Tennessee Valley region: white oak (*Quercus alba*), chestnut oak (*Q. prinus*), northern red oak (*Q. rubra*), and yellow-poplar (*Liriodendron tulipifera*). Temporal variability was examined using a time-variant response function, the Kalman filter (Kalman 1960), to model the relationship between climatic variables and annual increment. The hypothesis that environmental factors could explain differences in growth response in terms of spatial variability was tested using corollary site information and multivariate statistics.

METHODS

In 1986 the Tennessee Valley Authority (TVA) initiated a study to assess factors contributing to forest condition with regard to the possible impact of atmospheric deposition. The research described here utilizes data collected in that study. The study was designed to determine growth trends in uneven-aged, mixed species, second-growth natural hardwood stands occurring in the Tennessee Valley region and was built on an existing framework of permanent forest inventory plots. Since the objectives of the study were to determine the effects of natural factors on growth, plots were selected to represent a variety of sites and stocking levels. Three study sites (figure 1) were selected based on geographic distribution, spatial distribution of plots, and number of remeasurements: 1) the Emory River Land

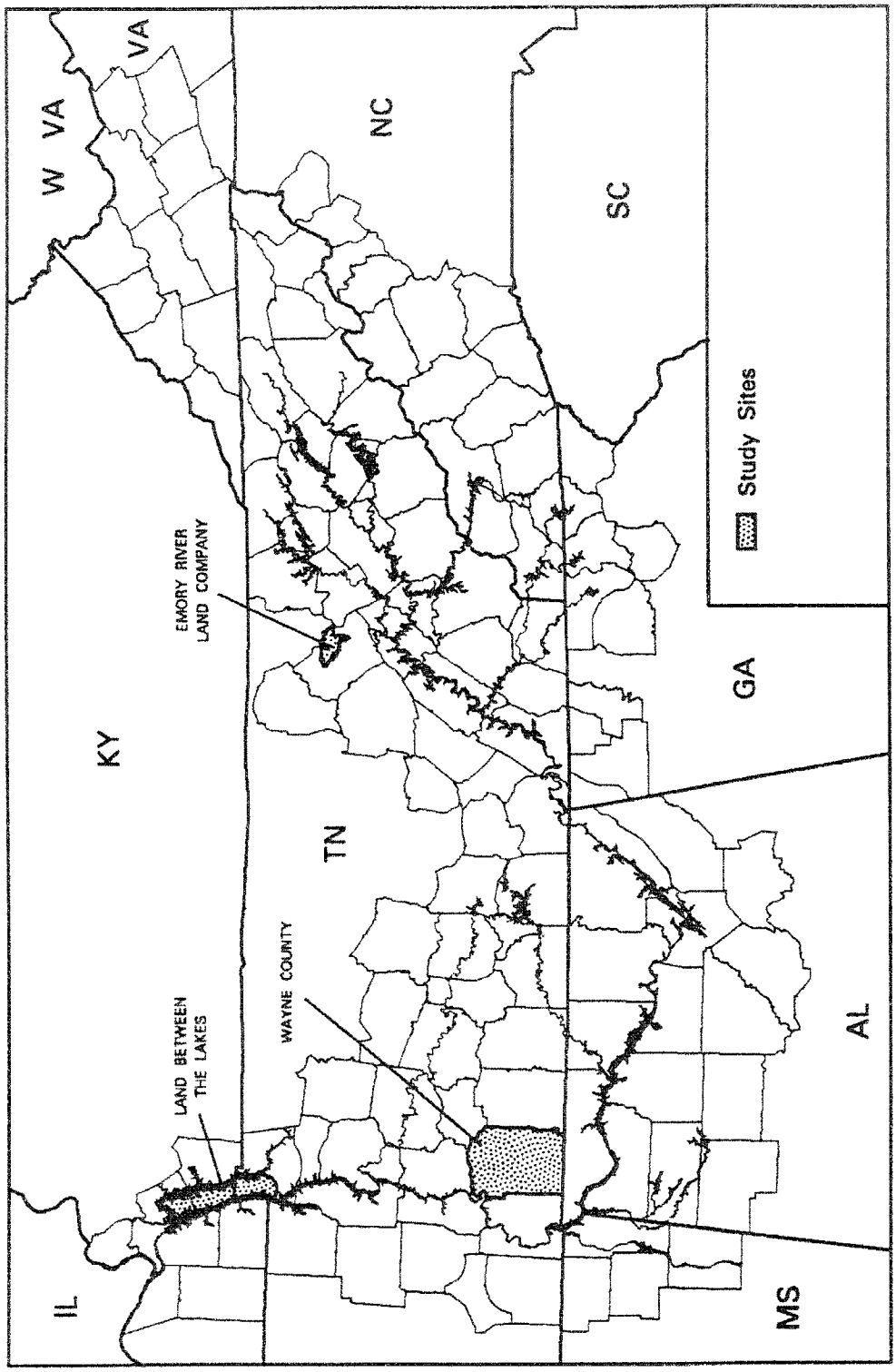

Figure 1. Map showing location of study sites.

Company, a 14,770 ha private land ownership located in Morgan County in northeast Tennessee; 2) "Land Between The Lakes" (LBL), a 68,797 ha national demonstration area managed by TVA and located in northwest Tennessee and southwest Kentucky; and, 3) Wayne County, located in southwest Tennessee, encompassing a total area of 191,903 ha. Together, these sites are considered representative of the forests of the Tennessee Valley region. Plots included in the study were selected from the total inventory based on forest type (white oak--black oak--northern red oak forest cover type and variants, Eyre 1980), size of trees (predominantly large sawtimber size trees -- greater than or equal to 28 cm dbh), and lack of substantial recent disturbance. A total of 267 0.08 ha plots were actually remeasured in the spring and summer of 1987 after preliminary screening.

Increment cores were collected from every living dominant and codominant tree on the plot (regardless of health). Core trees were not selected to represent site condition strata as the intention was to assess growth for a population and the relative importance of each of the many candidate site descriptors was unknown. Additional cores were collected from trees off the plot but in the immediate vicinity to increase core tree sample size. Ideally, five samples per species were collected but because of time constraints the total number of cored trees did not exceed 15 (unless more than 15 dominant and codominant trees occurred on the plot). Diameter at breast height (dbh) was recorded for all core trees to facilitate later age estimation. A prism count was made around every cored tree as a measure of individual competitive pressure. Notes regarding injury or other conditions affecting growth were also recorded for each core tree.

Tree cores were mounted according to the procedures described by Phipps (1985) and sorted by species. Crossdating was done by standard dendrochronological technique and was verified by a computer program COFECHA (Holmes 1985). Measurement of annual radial increment from individual trees was done using a Bannister incremental measuring device linked to an IBM-XT microcomputer. Tree-ring series from a total of 1843 trees were analyzed in this study (table 1). A wide range of ages was represented in each species sample with the youngest tree being a yellow-poplar at LBL with an estimated age of 34 years up to a total estimated age of 319 years for an individual chestnut oak at Emory River.

In complacent species growing in closed-canopy forests, the natural growth trend is often confounded with stand dynamics such as competition. This can complicate standardization of tree-ring series as it is difficult to determine what portion of the year-to-year variation in growth is due to climate and what portion is due to other factors. Therefore, in this study tree-ring series were standardized using first differences of natural logarithms, resulting in values that represent relative annual growth rates (Van Deusen 1990a). This technique avoids subjective decisions about what type of growth curve to use to remove the natural growth trend, or how stiff a spline is necessary to remove the low frequency variation due to endogenous disturbances while maintaining the high frequency variance associated with exogenous disturbances or climate.

Next, series from each species-site combination were scanned to identify a period for which there were measurements in common (table 2). A cluster analysis was run on standardized data for this common period to identify trees that had similar growth patterns. The

Table 1.--Number of trees and range of ages by site and species.

	White oaks	Chestnut oaks	Northern red oaks	Yellow-poplar
Emory River	229 trees (48-206 yrs.)	276 trees (49-319 yrs.)	143 trees (48-185 yrs.)	237 trees (34-161 yrs.)
LBL	384 trees (39-214 yrs.)	123 trees (51-267 yrs.)	15 trees (65-136 yrs.)	26 trees (34-130 yrs.)
Wayne County	193 trees (47-256 yrs.)	106 trees (42-157 yrs.)	62 trees (60-151 yrs.)	49 trees (42-127 yrs.)
Total trees:	806	505	220	312

Table 2.--Common measurement period used for clustering tree-ring data.

Site and Species	measurement period	number of years
Emory River white oak	1949 - 1983	35
LBL white oak	1952 - 1986	35
Wayne Co. white oak	1956 - 1986	31
Emory River chestnut oak	1951 - 1986	36
LBL chestnut oak	1947 - 1986	40
Wayne Co. chestnut oak	1955 - 1986	32
Emory River northern red oak	1956 - 1986	31
LBL northern red oak	1942 - 1986	45
Wayne Co. northern red oak	1948 - 1986	39
Emory River yellow-poplar	1968 - 1986	19
LBL yellow-poplar	1968 - 1986	19
Wayne County yellow-poplar	1960 - 1986	27

FASTCLUS procedure in SAS was run iteratively to group tree-ring series in clusters with high within-cluster correlation. FASTCLUS performs a disjoint cluster analysis on the basis

of Euclidean distances computed from one or more variables, which in this case were individual measures of annual increment for the common measurement period. FASTCLUS utilizes *nearest centroid sorting* (SAS 1985). In this procedure, *n* clusters are specified and a set of *n* points known as *cluster seeds* are selected as a first guess of means of the clusters. Each observation is then assigned to the nearest cluster and the cluster seeds are updated according to these temporary cluster groupings. The process is repeated until no further changes occur in the clusters.

Initial sizes of clusters were determined based on the computer memory limitations of the software used in the following analyses; each cluster could have a maximum of 87 series with 91 years of data per series (to be used with climate data available from 1895-1986 minus one year for the differencing). After working with the white oak data, a criterion was established of cluster sizes having a maximum distance from seed to observation equal to or less than approximately 2.5. The initialization method used by FASTCLUS makes it sensitive to outliers; clusters that contained four or less series were discarded as outliers. The resulting number of clusters and associated statistics are given in table 3.

Table 3.--Cluster statistics for each species at the three study sites.

Species/ Site		Percent of Plots with Species	Number of Resulting Clusters	Mean Cluster Size (trees)	Coefficient of Variation for Cluster Size
White oaks					
	ER[1]	68	9	24.3	96%
	LBL	63	9	42.7	48%
	WC	75	6	32.2	67%
Chestnut oaks					
	ER	75	7	39.4	64%
	LBL	17	4	30.8	55%
	WC	42	3	35.3	71%
Northern red oaks					
	ER	58	2	71.5	13%
	LBL	6	2	7.5	47%
	WC	35	3	20.7	44%
Yellow-poplars					
	ER	48	4	59.3	41%
	LBL	6	1	23.0	-
	WC	28	4	12.3	52%

[1] ER = Emory River, LBL = Land Between the Lakes, and WC = Wayne County.

Climate data, consisting of monthly averages of temperature and monthly totals for precipitation, for the period 1895 through 1986 were made available from Oak Ridge National

Laboratory (ORNL) for state climatic divisions in which the study sites occurred. These data were also standardized using the first differences of the natural logarithm so that subsequent analyses would assess the relationship between rates of change in tree growth and rates of change in the climate data. Due to the large amount of data processed in this study, climate variables were selected for each cluster using multiple regression techniques rather than fitting a Kalman filter model one parameter at a time because the latter is a very time-intensive technique.

A stepwise regression was performed using annual values from a cluster mean chronology as the dependent variable with climatic variables for the current year through the end of the growing season and variables lagged one year as independent variables. To enter the model, variables had to be significant at the 0.15 level, and to remain in the model the parameter had to be significant at the 0.05 level. Coincident with fitting the regression, tolerance values were calculated for the variables used in each of the models to determine if there was a potential problem with collinearity. Tolerance values are defined as $1\text{-}R^2$ for a variable with respect to all other regressor variables in the model (SAS 1985). Collinearity did not appear to be a problem with the selected variables.

Once climate variables were selected from the stepwise regression, dendroclimatic modelling using the Kalman filter proceeded using the software package DYNACLIM (Van Deusen and Koretz 1988). The Kalman filter has been proposed to address problems in tree-ring analysis arising from temporal nonstationarity in the relationship between annual increment and climate (Van Deusen 1987, 1988; Visser 1986; Visser and Molenaar 1987, 1988). The formulation used here, described by Van Deusen and Koretz (1988), is a generalization of an ordinary regression equation that allows for dynamic parameters which are estimated using maximum likelihood. Models were specified using a non-varying intercept while regression coefficients for all climate variables were allowed to vary through time. DYNACLIM software produced smoothed parameter estimates for each of the climate variables for every year and their associated variances.

Verification of dendroclimatic models traditionally involves demonstration of time stability by comparing a model developed from data from one time period (known as the calibration period) with data from another (known as the verification period). By using the Kalman filter to develop dendroclimatic models we are allowing the relationship between climatic variables and tree growth to be non-stable through time because of the dynamic nature of the trees' growing environment. Therefore, other means of verification must be used. Van Deusen (1990b) suggests a number of statistical tests to assess the possibility of model misspecification or the absence of a systematic component in the resulting model. These include observation of the cumulative sum of the prediction errors and their confidence intervals according to Brown et al. (1975), assessment of recursive residuals using the modified Von Neumann ratio (Harvey 1981), and use of the C^* statistic calculated from the cumulative sum of prediction errors for time t (Harvey 1981). Each of these tests were applied to the models produced using DYNACLIM and no evidence was found of either model misspecification or missing components. Additionally, each tree-ring data set was tested for remaining autocorrelation up to a five-year lag. Although there was evidence of some autocorrelation, it occurred in amounts small enough (generally less than 0.10) to be

considered unimportant. Verification was also provided through replication of results. Models developed for clusters within a species generally consisted of the same climatic parameters, although coefficient values differed. Once model testing was completed, a normal distribution for the variance among individual trees was assumed and ninety-five percent confidence intervals were calculated for each of the climate parameters to assess if these values were significantly different from zero.

Observed trends in parameter coefficients were tested using a *runs* test (Draper and Smith 1981) to determine if changes in coefficient values followed a pattern that might be associated with a change in sensitivity to climate or if they occurred randomly and therefore did not reflect true changes in sensitivity. The runs test was performed for individual clusters by calculating a mean coefficient over time for specific climate parameters that were common to a large proportion of the clusters over each site. Deviations from the mean were calculated on a year by year basis and assigned a value of "+" if they were greater than zero and "-" if less than zero. Changes in sign within a sequence of pluses and minuses denote the beginning of a new run. The Z statistic described in Draper and Smith (1981) was used to determine if the number of runs is an "extreme" arrangement as opposed to one which would occur randomly. A small number of runs (the minimum would be 2) indicates a trend in coefficient value, while a large number of runs indicates lack of a trend or a random pattern similar to white noise. The climate data, standardized and non-standardized, were also tested for trends using the runs test.

The last part of the analysis was to determine which environmental factors could be associated with different clusterings and might therefore affect differences in response to climatic fluctuations. This was accomplished using a discriminant analysis on a set of environmental factors that was associated with each individual increment core tree. Each tree was identified with a cluster number and the environmental factors (quantitative variables) were used to discriminate the trees into cluster groupings (classification variables).

Environmental factors consisted of variables associated with individual trees and site variables determined for each plot. Individual tree data consisted of the dbh of the core tree, an estimated age based on average annual increment and tree radius, and the prism count collected for each tree. Site information included descriptive variables such as elevation, slope percent, topographic classification, aspect, and fire and grazing codes. Information calculated from the inventory data included: 1) a productivity index calculated as average annual basal area increment for the plot; 2) relative frequency of each of the four core tree species; 3) an importance value for each of the core tree species calculated as that species' basal area per acre divided by total basal area per acre; 4) mean age of all cored trees; 5) basal area of mortality trees; 6) basal area of cut trees; and 7) percent of trees in the stand affected by the different injury classifications. Soils data consisted of horizon depth and texture for each plot. Horizons were aggregated into an A and E horizon and a B horizon -- deeper horizon data were not included. Soil textures were assigned a categorical name in the field. These data were ranked according to a gradient reflecting change in texture from fine to coarse and assigned a numerical value representative of this gradient. Presence of an argillic zone (Bt horizon) or a fragipan (Bx horizon) was indicated with a presence code of 1 or an absence code of 0 for a variable representing each type of horizon.

Canonical discriminant analysis was applied to the data using the SAS procedure CANDISC. This procedure is a dimension-reduction technique related to PCA and canonical correlation. CANDISC calculates linear combinations of the quantitative variables (known as *canonical variables*) that summarize between-class variations and that have the highest possible multiple correlation with the groups, then tests the hypothesis that resulting canonical correlations are zero in the population. A variable's importance in determining groupings can be evaluated by observing the value of the standardized canonical coefficients associated with it. In conjunction with CANDISC, univariate statistics in the form of one-way analyses of variance were calculated for each environmental variable.

A classificatory discriminant analysis was also performed on the data using the SAS procedure DISCRIM. This procedure generates a linear discriminant function for each group of data as well as probabilities of misclassification (error rates). This provided an evaluation of how well the environmental factors explained the cluster groupings of tree growth.

RESULTS

Clustering of tree-ring series by species and sites resulted in a total of 54 groups. All clusters incorporated trees of different ages and sizes. Series from trees in close proximity to one another sometimes grouped in the same cluster but often did not. Cluster groupings were observed on a plot-by-plot basis to determine the degree of spatial heterogeneity that occurred for each species-site combination. A count was made of the number of plots with more than one sample tree on which all of the trees of a species were grouped into a single cluster. This revealed a great deal of spatial variability with a range of values showing plot homogeneity on only 2% of the plots with chestnut oak at Emory River, up to a high of 39% for northern red oak at Emory River (table 4). Plots with many cluster groupings were compared to those with a single cluster grouping to see if any differences were apparent to explain the degree of heterogeneity. Examination of soils diagrams made in the field showed that the number of cluster groupings could not be explained by differences in soils. Disturbance history accounts were also compared. Plots that were very homogeneous in tree growth response included histories that indicated no apparent disturbance, disturbance by Timber Stand Improvement (TSI), insects, disease, fire and widespread adjacent mortality. Spatial homogeneity did appear to relate to the percent of the stand that was occupied by the individual species. Plots that consisted of only one species generally had core trees that clustered together, while plots with a number of species often exhibited heterogeneity in growth response for each species.

For white oaks, June temperature was overall the most important variable selected in the stepwise regression, exhibiting a negative relationship with growth. Later variables that entered the climate models differed somewhat by site -- at Emory River, generally past August rainfall (a positive relationship) was the next most important variable, while at LBL past December rain (a positive relationship) usually entered the model second, and at Wayne County, each cluster had a different variable entering in the second place position.

Table 4.--Percent of plots in which all trees of one species clustered into the same group.

	White oaks	Chestnut oaks	Northern red oaks	Yellow-poplar
Emory River	5%	2%	39%	24%
LBL	29%	29%	14%	-
Wayne County	24%	16%	33%	18%

June temperature was also the most important variable for chestnut oak, although at Emory River, May rain was a close competitor for first place. June rain was also important, especially at LBL. Northern red oaks behaved similarly, with June temperature the unanimous choice for first entry. Past August rain was important at Emory River, showing similar associations as the white oaks. Summer rains were important to Emory River yellow-poplar, especially June rain. No other clear relationships were apparent for a species or site.

Kalman filter estimates of parameter values for each of the 54 tree-ring clusters indicated some interesting differences and similarities between species and overall time trends in the climate/growth relationship. Changes in parameter coefficients over time were compared with graphs of monthly climatic data over time to determine if changes were coincident with trends in climate. No associations were determined. Additionally, the runs test indicated that the number of runs was not significantly different than random (i.e. no trends) for both standardized and non-standardized climate data. For the most part, each cluster model revealed that through time, these trees become less sensitive (i.e. coefficient values for these parameters approached zero over time) to climate variables such as summer temperature and rainfall.

Trends in coefficient values for June temperature and past August rain were assessed for all clusters which incorporated these parameters in the dendroclimatic model. These variables were not always the most significant for each cluster, however, they were the most prevalent overall and therefore were used to gain insight into the general relationship between climate and tree growth. Figures 2-7 show the percentage of clusters that had a coefficient that was significantly different from zero by year. This graphical display provides an overview of what appears to be a general trend towards decreasing sensitivity to climate. In each graph except for past August rain in Wayne County (figure 7), there is first a trend towards increasing significance in coefficient values, followed by a drop in the percent of clusters which included values that were significantly different from zero. The early low values reflect relatively wide confidence intervals for each coefficient value resulting from a large amount of variation between individuals and small sample sizes for older trees. Later decreases in the percentages of significant values are associated with coefficient values that approach zero over time, reflecting a decreasing sensitivity to these climate variables for most trees.

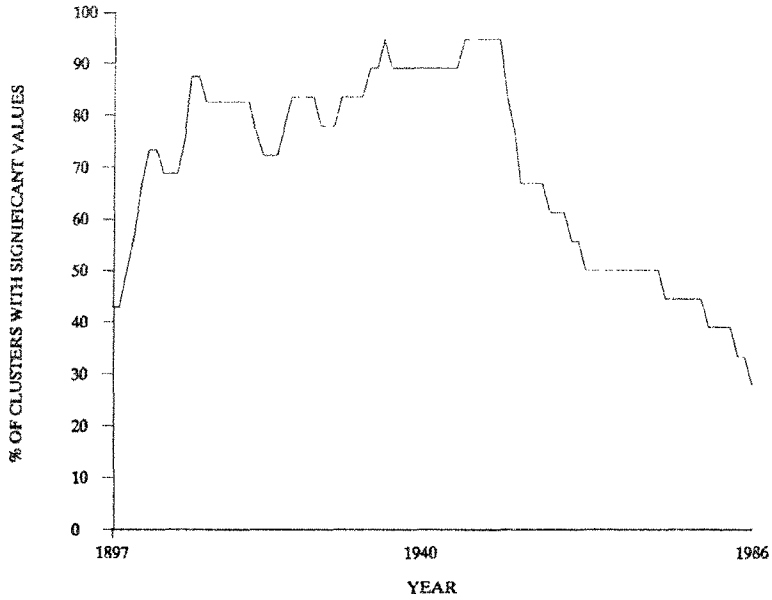

Figure 2. Percent of Emory River clusters with June temperature coefficients that are significantly different than zero by year.

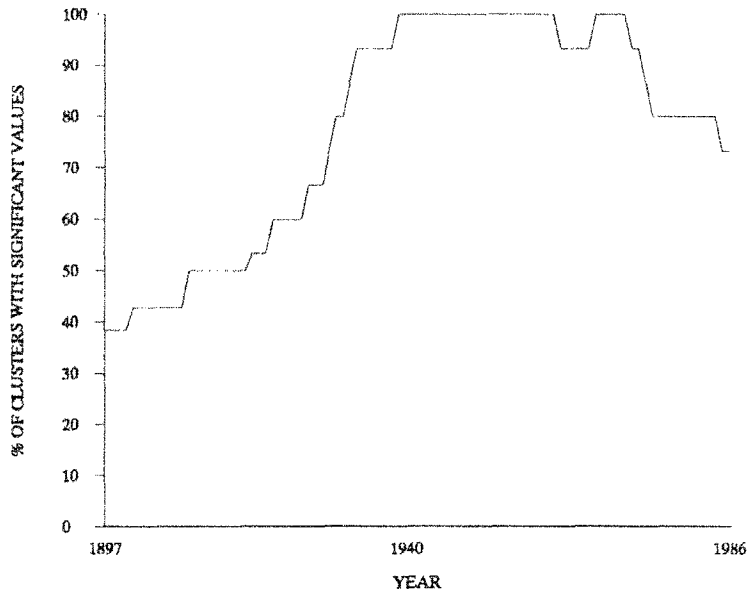

Figure 3. Percent of Emory River clusters with past August rain coefficients that are significantly different than zero by year.

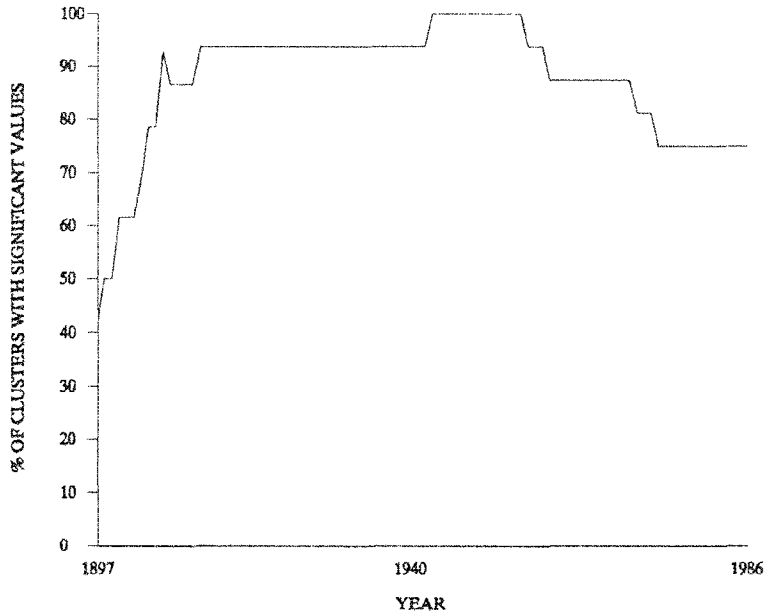

Figure 4. Percent of Land Between the Lakes clusters with June temperature coefficients that are significantly different than zero by year.

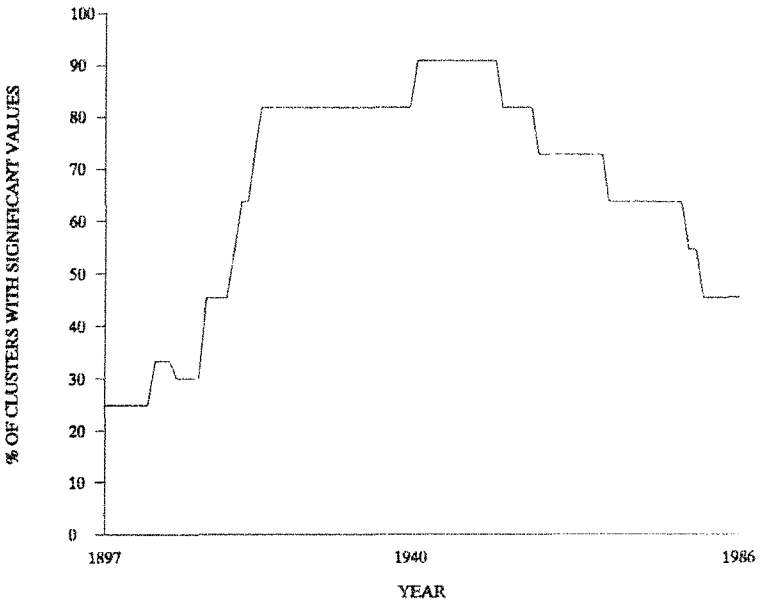

Figure 5. Percent of Land Between the Lakes clusters with past August rain coefficients that are significantly different than zero by year.

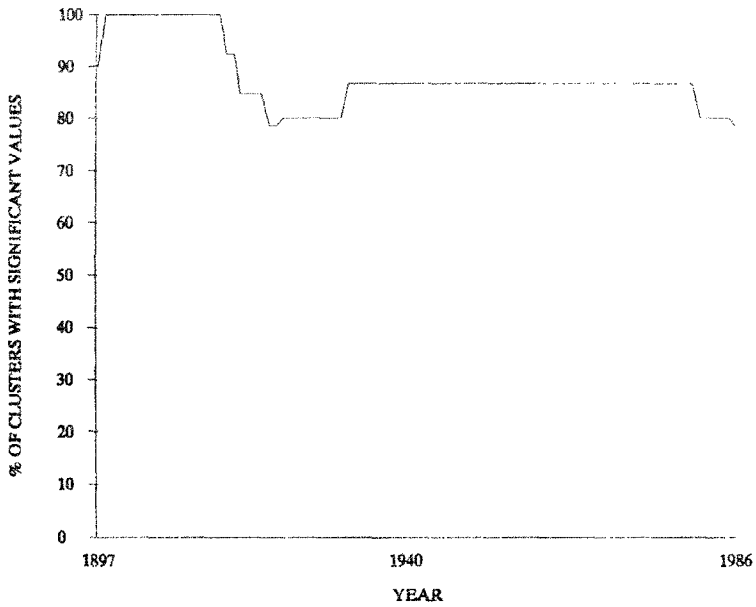

Figure 6. Percent of Wayne County clusters with June temperature coefficients that are significantly different than zero by year.

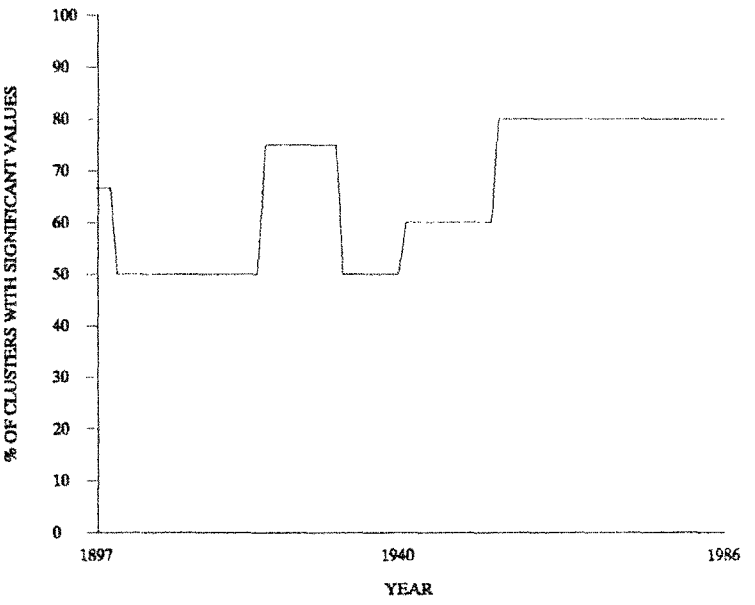

Figure 7. Percent of Wayne County clusters with past August rain coefficients that are significantly different than zero by year.

A runs test was done on June temperature and past August rain for those clusters in which these variables contributed to the explanation of variation in growth. Decreased sensitivity to June temperature is indicated by a change towards less negative coefficients (denoted by a plus sign), while a change towards more negative coefficients (denoted by a minus sign) indicates increased sensitivity. At Emory River, all clusters that exhibit temporal variation in coefficient value showed a trend towards decreasing sensitivity to June temperature that was significantly different than random changes in the relationship (figure 8). One yellow-poplar cluster (number 1) showed a reversal in this trend, towards increased sensitivity. Similar trends were observed for all species at LBL, except where there was no temporal variability in June temperature coefficients. At Wayne County, the pattern was more confused. All white oaks again showed a trend towards decreased sensitivity. Two clusters, chestnut oak number 1 and northern red oak number 1, showed a reversed trend, towards increased sensitivity.

Changes in sensitivity to past August rainfall were not as apparent, although general patterns did exist (figure 9). Decreased sensitivity to past August rain was signified by a less positive coefficient (denoted by a minus). A more positive coefficient (denoted by a plus sign) indicated increased sensitivity. No temporal variation was represented by zeros. Of the 16 clusters at Emory River, four showed no temporal variation, five showed a significant trend towards decreased sensitivity, and seven showed a trend towards increased sensitivity. At LBL, all clusters except white oak number 9 showed a significant trend towards decreased sensitivity. In white oak number 5 there was a recent change towards increased sensitivity. Of the five clusters incorporating past August rain at Wayne County, two showed no temporal variability, and the remaining three showed increased sensitivity to this variable.

Analyses of variance provided little insight into which environmental factors were important in differentiating growth responses to climatic variables. Although a number of environmental variables were significant ($P<0.01$) in explaining differences among groupings, the amount of variation explained by individual factors was very low (table 5). This result was expected because of the nature of the data and its collection. The data base consisting of tree-ring series from 1843 individual trees selected from 267 sites located over a large geographic area was created to represent the forests of the Tennessee Valley and therefore incorporates a wide variety of site conditions and potential stresses. Trees were not selected to represent a specific suite of environmental variables, but rather to represent the population of each of these species within the region.

Discriminant analysis based on environmental variables collected in the study was generally successful in reclassifying tree-ring clusters. Total error count estimates ranged from 0% for northern red oaks at LBL, up to 75% for chestnut oaks at Emory River (table 6). Overall, site statistics outperformed individual tree statistics in discriminatory power, and when analyzed as multivariate data, presence and predominance of competing species was the most important factor influencing tree-ring groupings (table 7). Other factors that commonly had high canonical coefficient values included variables related to soil moisture conditions such as soil depths and textures, topographic position, and aspect; and variables related to changes in stand density, including current basal area, and basal areas of cut and mortality trees.

Figure 8. Runs in the time sequence of deviations from the mean for June temperature coefficients.

Figure 9. Runs in the time sequence of deviations from the mean for past August rain coefficients.

Table 5.--Results of one-way analyses of variance - average R^2s weighted by variance for environmental variables, by site and species.

Site/Species	R^2
ERWO[1]	0.10
LBLWO	0.16
WCWO	0.16
ERCO	0.01
LBLCO	0.08
WCCO	0.12
ERNRO	0.15
LBLNRO	0.01
WCNRO	0.11
ERYP	0.07
LBLYP[2]	-
WCYP	0.04

[1]Site/Species identification consists of a combination of letters designating site: ER = Emory River, LBL = Land Between the Lakes, WC = Wayne County; followed by letters designating species: WO = white oak, CO = chestnut oak, NRO = northern red oak, and YP = yellow-poplar.
[2]LBL had only one grouping of yellow-poplar series.

Individual tree age was only important for Wayne County yellow-poplar, indicating that variability in growth response was not strongly influenced by changes in tree physiology.

DISCUSSION AND CONCLUSIONS

The results of this study indicate that, for the 4 hardwood species studied within the Tennessee Valley region, relationships between climatic variables and tree growth change over time. Maximum sensitivity to monthly values of temperature and precipitation did not coincide with extreme values of these variables. Instead, maximum sensitivity generally occurred at the beginning of the time series and decreased over time. Patterns of change in sensitivity (parameter coefficient values) were significantly different ($P<0.001$) from random indicating a trend in the relationship. However, statistical tests indicated only random variation in the climatic data. This implies that tree growth sensitivity to climate is not merely a function of climate, or that other factors work to modify the influence of climate. In natural, mixed-species hardwood stands in the Tennessee Valley, these factors are apparently dynamic.

Table 6.--Error count estimates (percent) for linear discriminant functions on non-transformed data.

Species/Site	Cluster # 1	2	3	4	5	6	7	8	9	Total
White oaks										
ER[1]	50	25	29	41	60	50	0	26	33	42
LBL	15	56	11	44	33	35	53	32	28	36
WC	23	26	30	26	40	24				27
Chestnut oaks										
ER	54	63	60	52	63	53	75			57
LBL	50	47	11	23						28
WC	7	27	22							14
Northern red oaks										
ER	21	20								21
LBL	0	0								0
WC	6	8	22							10
Yellow-poplars										
ER	25	32	37	32						30
LBL	-									-
WC	0	11	43	27						20

[1]ER = Emory River; LBL = Land Between the Lakes; WC = Wayne County.

Table 7.--Environmental factors determined important in producing differences in tree growth response to climate from canonical discriminant analysis, by site and species.

Site/Species	Important Environmental Factors
ERWO[1]	Relative frequency and importance values for core tree species, presence of a fragipan
LBLWO	Relative frequency and importance values for core tree species, soil texture
WCWO	Relative frequency and importance values for core tree species, current basal area, elevation
ERCO	Relative frequency and importance values for core tree species, topographic position, presence of an argillic horizon
LBLCO	Relative frequency and importance values for core tree species, aspect
WCCO	Relative frequency and importance values for core tree species, aspect, topographic position, presence of insect damage
ERNRO	Relative frequency and importance values for core tree species, elevation, soil depth and texture
LBLNRO	Current basal area, size distribution of trees, basal area of mortality trees, slope, topographic position, aspect
WCNRO	Relative frequency and importance values for core tree species, grazing damage, aspect
ERYP	Relative frequency and importance values for core tree species, aspect, basal area of mortality trees, soil depth and texture
WCYP	Relative frequency and importance values for core tree species, slope, current basal area, basal area of cut trees, basal area of mortality trees, individual tree age

[1]Site/Species identification consists of a combination of letters designating site: ER = Emory River, LBL = Land Between the Lakes, WC = Wayne County; followed by letters designating species: WO = white oak, CO = chestnut oak, NRO = northern red oak, and YP = yellow-poplar.

Factors that could modify climatic effects include those related to changes that occur within the individual or within the forest stand. Individual or physiological changes occurring within a single tree should be highly correlated with age or size. However, except for yellow-poplar at Wayne County, both of these variables lacked statistical significance in differentiating growth response patterns when analyzed as either univariate or multivariate data. However, factors representing changes in stand density were important for some clusters. Changes that occur within the forest stand may affect attributes associated with climate such as moisture availability which would appear as a change in sensitivity to climate in this analysis. It is well known that climatic extremes are buffered within a fully-developed forest stand through shading and the wind-breaking effect of stand structure (Daubenmire 1974, Haines and Cleveland 1981). Site conditions have also been shown to improve over time with stand development (Whittaker and Woodwell 1972, Carmean et al. 1976). The trend towards decreased growth sensitivity to climatic variables over time is synchronous with a period of increased forest protection and improved forest management within the Tennessee Valley. In general, this has resulted in a transition from poorly-stocked, cutover stands to more productive forests with increased stocking levels. Thus, it appears that decreases in individual tree sensitivity to climate are associated with stand development as the changes in stand structure and site quality buffer climatic variation.

Spatial variation in tree growth response to climate is more difficult to characterize. Univariate statistical analyses (one-way analyses of variance) were ineffective in identifying environmental factors important in producing the different patterns of growth response identified through cluster analysis. However, multivariate analyses of environmental factors were, in most cases, very effective in discriminating differences in patterns of annual increment. Unfortunately, these results are more difficult to interpret, as they indicate that interactions between environmental factors can significantly alter a tree's growth response.

Standardized coefficient values for canonical components indicate the relative importance of each environmental factor as it impacts the relationship between climate and growth. Overall, the most important factors were relative frequency and importance values for the predominant species. This indicates that differences in size and species composition of neighboring trees is associated with differences in pattern of growth response. This could reflect competitive interactions, signifying that trees behave differently according to the company they are in, or it may denote a difference in site quality or some type of ecological gradient. Ermich et al. (1976) suggested that homogeneity of tree growth patterns was related to site quality. Their premise was that low site quality results in increased susceptibility to additional stresses that increase the variability in annual increment among individuals. The results of the current study indicate that spatial heterogeneity increases as the predominance of a species on a site decreases, a fact that may be due to site quality, competitive interactions, or both.

Factors typically associated with soil moisture conditions were also identified as relatively important in producing differences in growth. As expected, there were identifiable differences in growth pattern between mesic and xeric sites. Trees on drier sites generally appeared more sensitive to climate (i.e. coefficient values were of greater magnitude). However, interactions with other, often more subtle, environmental factors exhibited the potential to alter characteristic growth patterns. For example, insect infestation on a mesic site was observed

to increase tree sensitivity to climate producing a response more typical of a tree located at a drier site.

The literature on forest tree growth indicates that there is a great deal of both temporal and spatial variability in tree growth response to climate, and that reasons for the variability are not obvious. The results of this study were similar to those reported in the literature. Temporal variability in growth response to climate can be characterized as a trend towards decreased sensitivity to climate that apparently occurs primarily as a result of stand development rather than as a function of changes in individual trees. Spatial variability was profound, occurring in part as a result of changes in site conditions and potentially as a function of competitive interactions among individual trees of different species. Environmental factors were generally useful in explaining similarities in growth response to climate among individual trees, as long as interactions between factors were incorporated into the analysis. Use of additional site variables, information specific to individual trees, and more detailed climate data might provide a better understanding of what response to climate might be expected under various combinations of environmental factors.

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COMMUNITY AND EDAPHIC ANALYSIS OF MIXED OAK FORESTS IN THE RIDGE AND VALLEY PROVINCE OF CENTRAL PENNSYLVANIA

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Abstract: Forty-two relatively undisturbed mixed oak stands on nine different physiographic units in the Ridge and Valley Province of central Pennsylvania were surveyed to investigate the ecological status of oak species in the region. *Quercus* species were primarily restricted to the canopy, with the exception of *Quercus ilicifolia* Wangenh. (a shrub). The most species rich forest stands were located along an indented stream and on fine-textured, valley floor sites where *Quercus alba* L., *Quercus velutina* Lam. and/or *Quercus rubra* L. dominated the overstories and *Acer rubrum* L. and *Prunus serotina* Ehrh. dominated the understories. The importance of *Quercus prinus* L. was positively correlated with percent sand and elevation, and this species dominated steep inclines and xeric ridgetop communities. *Quercus velutina, Carya* spp. and *Q. rubra* occurred on all topographic sites, however the latter was most abundant on cool, north-facing slopes.

Most present-day stands were initiated following heavy cutting and fire around the 1900's, and the oak component tended to be even-aged. Regeneration data suggest that succession to more shade tolerant species, primarily *A. rubrum*, is occurring in all but the most xeric oak stands. Frequent understory associates with *A. rubrum* included *P. serotina, Acer saccharum* Marsh. and *Fraxinus americana* L. on mesic toe slopes, indented stream bank and valley floor sites and *Betula lenta* L. and *Acer pensylvanicum* L. on and near ridgetops. Although *Quercus* species were well represented as seedlings in most stands, recruitment into larger classes was infrequent, except on the driest sites.

INTRODUCTION

The topography of Ridge and Valley Province of central Pennsylvania leads to an diverse floristic pattern across the landscape, in which *Quercus* species predominate. Typical of most eastern forests, large-scale logging and subsequent fires following European settlement drastically altered the original vegetation in central Pennsylvania (Hough and Forbes 1943, Whitney 1987, Crow 1988, Nowacki et al. 1990). Braun (1950) had classified this area as oak-chestnut (*Castanea dentata* [Marsh.] Borkh.) forest type, though most ecologists now consider it an oak-hickory (*Carya* spp.) or mixed-oak association (Keever 1953, McCormick and Platt 1980, Johnson and Ware 1982). Braun also suggested that the mixed mesophytic

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forest is the potential climax in the region, but that topographic diversity would lead to physiographic or edaphic climaxes, including mixed oak communities on mountain slopes, hemlock-dominated (*Tsuga canadensis* [L.] Carr.) communities within mountain coves, white oak (*Q. alba*) forests on valley floors and mixed mesophytic communities on ravine slopes along indented streams. Whether the oak communities are actually true or edaphic climaxes in this or other regions of eastern North America is uncertain. Recent studies indicate a transition from oak to more shade tolerant species in many forests (Christensen 1977, Lorimer 1984, Parker et al. 1985, Abrams 1986, McGee 1986, Nowacki et al. 1990). Successional trends in oak forests of central Pennsylvania have not been well established, although regional surveys indicate poor oak development under shaded conditions (Lorimer 1984, Russell and Schuyler 1988, Abrams and Downs 1990).

In this study, mixed oak stands on nine different physiographic units in the Ridge and Valley Province in central Pennsylvania were surveyed to investigate the effect of edaphic factors on stand composition and structure. From these data we attempt to predict the successional status of mixed oak forests in the region and how successional pathways may vary with physiographic changes.

METHODS

During the summers of 1988-1989, 42 relatively undisturbed mixed oak forests in central Pennsylvania were surveyed. Stands selected for sampling were 1) relatively homogeneous vegetative units located on uniform topography and restricted to a single soil type and 2) showed little or no evidence of recent disturbance by fire, cutting, etc. Trees ($\geq$ 10 cm dbh) were sampled using the point-quarter method (Cottam and Curtis 1956) at 20 points within each stand. Points were systematically located along transects at intervals of 20 to 30 m depending on stand size. Transects were positioned to avoid forest edges. Tree information included distance from the sample point, dbh, species name and canopy position (dominant, codominant, intermediate, or overtopped). Crown class definitions followed those of Smith (1986).

Saplings and seedlings were recorded by species at each sampling point within nested circular plots of 10 and 5 m^2, respectively. Saplings were classified as tree species < 10 cm at dbh but $\geq$ 1.5 m in height, whereas seedlings were < 1.5 m in height. Average slope and aspect were estimated for each stand using a clinometer, compass and topographic maps.

Soils were described at a centrally-located pit within each stand. Horizons comprising the upper 50 cm solum were identified and their depth recorded. Soil samples were collected form the mineral surface (A or E horizon) for particle-size analysis using the Hydrometer Method (Bouyoucos 1962). Soil pH was also recorded by use of a pH meter (calibrated at pH 4.0) and a prepared soil slurry consisting of 5 g soil and 10 ml distilled water.

Species importance percentages were calculated from the tree data for each stand (importance percentage = [relative density + relative dominance + relative frequency]/3; Cottam and Curtis

1956). Statistical analyses were accomplished using simple correlation, ANOVA and Scheffe's mean separation procedure at $p < 0.05$.

Table 1.--Edaphic features of the nine physiographic units studied in the Ridge and Valley Province of central Pennsylvania.

Physio. Unit	% sand	% silt	% clay	pH	Predominant texture	Representative soil type	% slope[1]	Elev.[1] (m)
Stream	46^{ab}	41^{ab}	14^{a}	6.1^{b}	loam	Ultic Hapludalfs	19±6	306±6
Fine-Valley	26^{a}	59^{a}	15^{a}	4.9^{a}	silt loam	Typic Hapludalfs	7±1	344±6
Cove	65^{ab}	27^{b}	8^{a}	3.5^{c}	sandy loam	Typic Fragidults	7±3	547±21
North-Lower	52^{ab}	34^{b}	14^{a}	4.3^{ac}	loam	Typic Fragidults	28±3	464±4
South-Lower	53^{ab}	34^{ab}	14^{a}	4.4^{ac}	loam	Typic Fragidults	30±0	472±1
North-Upper	60^{ab}	30^{ab}	10^{a}	3.9^{ac}	loam	Typic Dystrochrepts	35±6	501±21
South-Upper	67^{b}	26^{b}	7^{a}	3.7^{c}	sandy loam	Typic Dystrochrepts	28±7	568±16
Coarse-Valley	70^{b}	21^{b}	9^{a}	4.1^{ac}	sandy loam	Ultic Hapludalfs	6±1	407±9
Crest	75^{b}	19^{b}	6^{a}	4.1^{ac}	sandy loam	Typic Dystrochrepts	4±0	598±22

[1] Mean±S.E.
Values in a column with the same letter are not significantly different at $p < 0.05$.

RESULTS

Stand Classification Based On Edaphic Factors

Forty-two forest stands were grouped into nine physiographic units based on topographic position and soil characteristics (Table 1). The physiographic groups were indented stream bank, fine textured-valley floor, coarse textured-valley floor, cove, northern-lower slope, northern-upper slope, crest, southern-upper slope, and southern-lower slope (Fig. 1). Soil factors were correlated with changes in elevation. In particular, percent sand increased and percent silt, clay and pH decreased with elevation ($p < 0.05$, $r = .58$, $-.57$, $-.49$ and $-.77$, respectively). Fine textured-valley sites contained significantly less sand and more silt than coarse textured-valley, crest, and southern-upper sites (Table 1). Average soil pH was highest

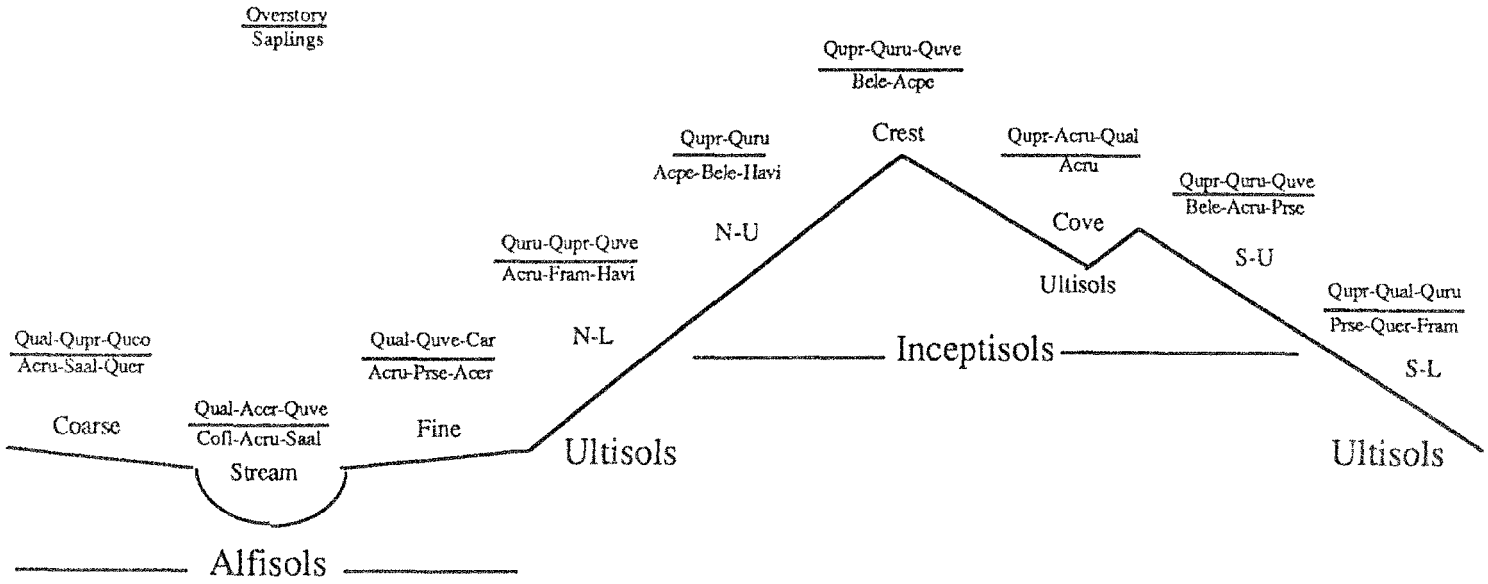

Figure 1. Dominant overstory and regenerating species on nine physiographic areas in the Ridge and Valley Province of central Pennsylvania arranged along a topographic gradient.
Acer=*Acer saccharum/platanoides*, Acpe=*Acer pensylvanicum*, Acru=*Acer rubrum*, Bele=*Betula lenta*, Car=*Carya* spp., Cofl=*Cornus florida*, Fram=*Fraxinus americana*, Havi=*Hamamelis virginiana*, Prse=*Prunus serotina*, Qual=*Quercus alba*, Quco=*Quercus coccinea*, Quer=*Quercus* spp., Qupr=*Quercus prinus*, Quru=*Quercus rubra*, Quve=*Quercus velutina*, Saal=*Sassafras albidum*.

along streams, intermediate on valley sites and lower slopes and lowest on upper slopes and coves. A general shift in soil type occurred with elevation, with Alfisols dominating valley floor and stream bank sites, Ultisols along lower slopes and coves and Inceptisols located on upper slopes and ridgetops (Fig. 1).

Stand Composition and Structure

The overstory of all groups was dominated by *Quercus* (Fig. 1 and 2), however significant differences in species importance occurred among groups (Table 2). The three most abundant oaks, *Q. alba*, *Q. rubra*, and *Q. prinus*, varied with elevation. *Quercus alba* was most important on gently sloping, valley and indented stream locations, although it was also important in mesic cove forests. *Quercus alba* importance was negatively correlated with slope ($r = -.38$), elevation ($r = -.50$) and the importance of *Q. rubra* and *Q. prinus* ($r = -.66$ and $-.67$, respectively). *Quercus rubra* and *Q. prinus* were most abundant on lower slopes and crest sites, respectively. *Quercus prinus* importance was correlated with percent sand, silt, clay, elevation, and pH ($r = .56, -.54, -.49, .79$ and $-.58$, respectively). Similar to *Q. alba*, *Quercus coccinea* Muenchh. was most frequent on valley sites, although it was associated with coarser soils. *Quercus velutina* was fairly common on all sites, but its highest importance occurred at lower elevations. Overstory trees other than *Quercus* were primarily *A. rubrum*, *A. saccharum*, *Pinus strobus* L., *P. serotina*, and *Carya* spp. Most of these species were infrequent, intermediate in crown size, and restricted to stream bank, valley floor and/or cove sites.

A larger number of species were present as understory trees, including *Quercus*, *Carya*, *Acer*, *Prunus* and *P. strobus* (Fig. 2). In general, understory trees of *Quercus* were most abundant on xeric areas (i.e. coarse textured-valley, crest, and upper slope sites) and in younger stands regardless of physiographic location. *Carya*, *Acer*, *Prunus* and *P. strobus* were most abundant in the understory on stream banks and fine textured-valley sites. *Acer rubrum* was a common understory tree in most stands.

Regeneration Trends Across An Environmental Gradient

Total seedling number tended to be greatest on the coarse textured-valley sites and least on the upper slopes (Table 3). Seedling number was negatively correlated with stand basal area and percent slope ($p < 0.05$, $r = -.43$ and $-.41$). *Quercus* species were well represented as seedlings in all physiographic units and seedling density closely followed importance values of the overstory species. Seedlings of *Q. alba* were most abundant on stream bank and valley sites, *Q. rubra* on slopes and *Q. prinus* on slopes, ridges and coarse textured-valley sites. *Quercus prinus* seedlings were significantly correlated with percent sand, silt and clay ($p < 0.05$, $r = .50, -.47$ and $-.42$, respectively), as exhibited with its overstory importance. *Acer rubrum* and *P. serotina* were common seedlings on all sites, however the latter were most

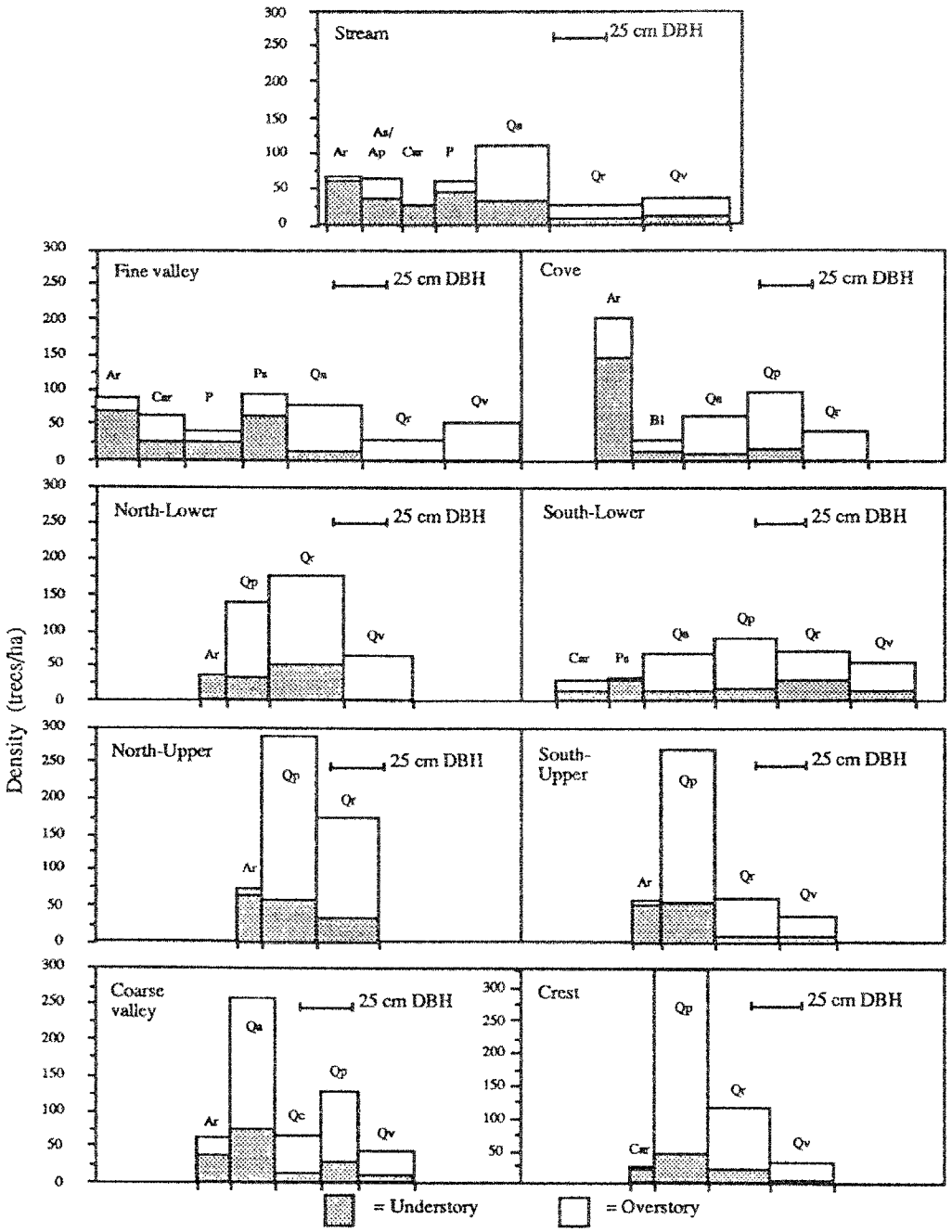

Figure 2. Stand structure on nine physiographic areas in the Ridge and Valley Province of central Pennsylvania based on mean density of overstory and understory trees and mean diameter of principal species (mean importance percentages of 5 or greater). Ar=*Acer rubrum*, As/Ap=*Acer saccharum/platanoides*, Bl=*Betula lenta*, Car=*Carya* spp., P=*Pinus strobus*, Ps=*Prunus serotina*, Qa=*Quercus alba*, Qc=*Quercus coccinea*, Qp=*Quercus prinus*, Qr=*Quercus rubra*, Qv=*Quercus velutina*.

Table 2.--Mean importance percentages[1] (±S.E.) of principal species and mean stand density (trees/ha) and basal area (m^2/ha) of 42 mixed oak forest stands organized by physiographic unit.

	Fine Stream Valley	Fine Cove	North Lower	South Lower	North Upper	South Upper	Coarse Valley	Crest
Acru	10±3^{ab}	15±2^{ab}	30±5^{b}	6±2^{a}	1±0^{a}	9±7^{ab}	10±4^{ab}	10±2^{a}	2±1^{a}
As/Ap	8±6^{a}	2±1^{a}	0±0^{a}	0±0^{a}	1±1^{a}	0±0^{a}	0±0^{a}	0±0^{a}	0±0^{a}
Bele	0±0^{ab}	0±0^{a}	6±4^{b}	2±1^{ab}	0±0^{ab}	1±1^{ab}	1±1^{ab}	0±0^{a}	2±1^{ab}
Carya*	5±1^{a}	11±3^{a}	3±3^{a}	1±1^{a}	9±5^{a}	1±1^{a}	3±3^{a}	2±1^{a}	5±1^{a}
Pist*	9±4^{a}	8±3^{a}	0±0^{a}	1±1^{a}	1±1^{a}	4±2^{a}	2±2^{a}	1±1^{a}	0±0^{a}
Prav	1±1^{a}	3±2^{a}	0±0^{a}	0±0^{a}	1±0^{a}	0±0^{a}	0±0^{a}	0±0^{a}	0±0^{a}
Prse	4±2^{b}	15±2^{a}	1±1^{b}	1±1^{b}	7±2^{ab}	0±0^{b}	0±0^{b}	1±1^{b}	1±1^{b}
Qual	27±9^{ab}	20±5^{ab}	15±9^{ab}	1±1^{b}	18±3^{ab}	0±0^{ab}	1±1^{b}	38±9^{a}	1±1^{ab}
Quco	4±2^{ab}	1±1^{a}	2±2^{ab}	0±0^{a}	1±0^{ab}	0±0^{a}	1±0^{a}	14±3^{b}	0±0^{a}
Qupr	0±0^{ab}	0±0^{a}	22±1^{abc}	32±6^{abc}	22±5^{abc}	47±1^{bc}	52±8^{c}	17±9^{abc}	54±4^{c}
Quru	9±3^{ac}	8±4^{a}	11±4^{ac}	39±4^{b}	19±3^{ab}	34±6^{bc}	17±5^{ab}	3±2^{a}	27±1^{ab}
Quve	11±4^{a}	15±5^{a}	5±3^{a}	13±5^{a}	14±5^{a}	1±1^{a}	10±4^{a}	10±3^{a}	8±2^{a}
# of Stands	4	7	3	5	3	3	5	9	3
Density	507^{a}	498^{a}	501^{a}	478^{a}	390^{a}	575^{a}	472^{a}	617^{a}	530^{a}
Basal Area	34^{ab}	35^{a}	24^{ab}	37^{a}	30^{ab}	31^{ab}	24^{ab}	20^{b}	31^{ab}

[1] Importance percentage = (relative density + relative dominance + relative frequency)/3. Values in a row with the same letter are not significantly different at $p < 0.05$.
* Significant differences based on ANOVA, but not detected by Scheffe's mean separation procedure.
Acru=*Acer rubrum*, As/Ap=*Acer saccharum/platanoides*, Bele=*Betula lenta*, Carya=*Carya* species, Pist=*Pinus strobus*, Prav=*Prunus avium*, Prse=*Prunus serotina*, Qual=*Quercus alba*, Quco=*Quercus coccinea*, Qupr=*Quercus prinus*, Quru=*Quercus rubra*, Quve=*Quercus velutina*.

abundant on southern lower slopes and fine textured-valley sites. *Acer saccharum*, *Acer platanoides* L. and *Prunus avium* L. seedlings were restricted primarily to mesic sites, specifically fine textured-valley and stream bank sites. In contrast, *A. pensylvanicum* and *B. lenta* seedlings occurred primarily on more severe, ridge sites.

Sapling density was not consistent among species, although higher density was skewed towards shade tolerant species (Table 4). The most prevalent sapling was *A. rubrum*, which commonly occurred on all physiographic sites. *Prunus serotina* saplings were similar in number to *A. rubrum* on all sites except for coarse textured-valley and cove sites. *Acer saccharum*, *A. platanoides* and *Cornus florida* L. were frequent saplings in mesic, fine

Table 3.--Mean seedling number (stems/ha) of principal species of 42 mixed oak forest stands organized by physiographic unit.

	Stream	Fine Valley	Cove	North Lower	South Lower	North Upper	South Upper	Coarse Valley	Crest
Acpe	0[a]	0[a]	900[a]	380[a]	0[a]	6733[ab]	1180[a]	11[a]	13600[b]
Acru	20200[a]	6329[a]	57033[a]	15440[a]	4100[a]	7767[a]	10980[a]	36322[a]	9200[a]
As/Ap	3225[a]	3886[a]	0[a]	20[a]	33[a]	0[a]	0[a]	0[a]	0[a]
Bele*	0[a]	0[a]	1567[a]	420[a]	0[a]	433[a]	480[a]	11[a]	4333[a]
Carya*	1125[a]	857[a]	0[a]	1560[a]	1733[a]	467[a]	200[a]	633[a]	367[a]
Cade*	0[a]	0[a]	0[a]	60[a]	0[a]	33[a]	20[a]	244[a]	0[a]
Cofl	925[a]	386[a]	33[a]	100[a]	67[a]	0[a]	0[a]	89[a]	267[a]
Fram	3025[ab]	1171[ab]	33[ab]	10700[b]	11067[ab]	467[ab]	500[ab]	222[a]	0[ab]
Havi*	600[a]	43[a]	633[a]	1520[a]	0[a]	1067[a]	500[a]	33[a]	500[a]
Nysy	0[a]	0[a]	300[a]	100[a]	0[a]	0[a]	340[a]	0[a]	0[a]
Osvi*	1650[a]	43[a]	0[a]	200[a]	0[a]	0[a]	0[a]	44[a]	0[a]
Pist	425[a]	0[a]	200[a]	0[a]	0[a]	33[a]	0[a]	67[a]	0[a]
Prav*	325[a]	6629[a]	0[a]	20[a]	67[a]	0[a]	20[a]	56[a]	0[a]
Prse	5075[ab]	14457[ab]	2933[ab]	2660[a]	27333[ab]	2333[ab]	5420[b]	6100[ab]	3067[ab]
Prvi	0[ab]	8686[a]	0[ab]	60[ab]	67[ab]	0[ab]	80[ab]	11[b]	0[ab]
Qual*	3575[a]	3557[a]	3800[a]	200[a]	4233[a]	0[a]	20[a]	29589[a]	0[a]
Quco	325[a]	29[a]	0[a]	0[a]	0[a]	0[a]	0[a]	2200[b]	0[a]
Quil	0[ab]	0[a]	0[ab]	0[ab]	0[ab]	0[ab]	0[ab]	2933[b]	0[ab]
Qupr	0[a]	43[a]	3700[a]	6560[a]	26267[a]	19333[a]	14640[a]	28756[a]	10207[a]
Quru*	400[a]	271[a]	533[a]	2200[a]	1333[a]	1600[a]	1880[a]	756[a]	1100[a]
Quve*	1050[a]	314[a]	233[a]	780[a]	2133[a]	333[a]	1020[a]	2178[a]	1533[a]
Saal*	4450[a]	0[a]	200[a]	20[a]	133[a]	267[a]	720[a]	6444[a]	67[a]
Total	51675[ab]	48786[a]	96000[ab]	44280[a]	82667[a]	42467[ab]	39060[ab]	124744[b]	44700[ab]

Values in a row with the same letter are not significantly different at $p < 0.05$.
* Significant differences based on ANOVA, but not detected by Scheffe's mean separation procedure.
Acpe=*Acer pensylvanicum*, Acru=*Acer rubrum*, As/Ap=*Acer saccharum/platanoides*, Bele=*Betula lenta*, Carya=*Carya* spp., Cade=*Castanea dentata*, Cofl=*Cornus florida*, Fram=*Fraxinus americana*, Havi=*Hamamelis virginiana*, Nysy=*Nyssa sylvatica*, Osvi=*Ostrya virginiana*, Pist=*Pinus strobus*, Prav=*Prunus avium*, Prse=*Prunus serotina*, Prvi=*Prunus virginiana*, Qual=*Quercus alba*, Quco=*Quercus coccinea*, Quil=*Quercus ilicifolia*, Qupr=*Quercus prinus*, Quru=*Quercus rubra*, Quve=*Quercus velutina*, Saal=*Sassafras albidum*.

textured-valley and stream bank communities, whereas *Hamamelis virginiana* L., *A. pensylvanicum*, and *B. lenta* saplings were common on slopes and ridgetops. The latter two species were positively correlated with elevation ($p < 0.05$, $r = .36$ and .37, respectively). *Sassafras albidum* (Nutt.) Nees saplings frequently occurred on coarse textured-valley sites.

Table 4.--Mean sapling number (stems/ha) of principal species of 42 mixed oak forest stands organized by physiographic unit.

	Fine Stream Valley		Cove	North Lower	South Lower	North Upper	South Upper	Coarse Valley	Crest
Acpe*	0[a]	0[a]	0[a]	170[a]	0[a]	1467[a]	50[a]	0[a]	1017[a]
Acru	187[a]	1136[a]	2250[a]	420[a]	100[a]	67[a]	440[a]	1333[a]	50[a]
As/Ap	62[a]	321[a]	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]
Bele	0[a]	0[a]	87[a]	146[a]	29[a]	987[a]	442[a]	17[a]	2330[a]
Carya	25[a]	50[a]	0[a]	110[a]	133[a]	0[a]	20[a]	33[a]	0[a]
Cade	0[a]	0[a]	0[a]	10[a]	10[a]	0[a]	0[a]	89[a]	0[a]
Cofl	475[b]	129[ab]	0[a]	40[a]	50[a]	17[a]	0[a]	28[a]	0[a]
Fram	25[a]	250[a]	0[a]	280[a]	150[a]	33[a]	0[a]	6[a]	0[a]
Havi	0[ab]	0[a]	17[ab]	270[b]	0[ab]	100[ab]	20[ab]	0[a]	67[ab]
Nysy	0[a]	0[a]	33[a]	10[a]	20[a]	0[a]	0[a]	0[a]	0[a]
Osvi	87[a]	14[a]	0[a]	40[a]	0[a]	0[a]	0[a]	22[a]	0[a]
Pist	13[a]	7[a]	0[a]	0[a]	30[a]	0[a]	0[a]	44[a]	0[a]
Prav	0[a]	71[a]	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]
Prse	62[a]	729[a]	33[a]	80[a]	1850[b]	67[a]	190[a]	128[a]	17[a]
Prvi*	0[a]	129[a]	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]
Qual	13[a]	0[a]	0[a]	0[a]	50[a]	0[a]	0[a]	83[a]	0[a]
Quco	13[a]	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]	83[a]	0[a]
Quil	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]	0[a]	94[a]	0[a]
Qupr	0[a]	0[a]	0[a]	10[a]	50[a]	0[a]	10[a]	78[a]	0[a]
Quru	13[a]	14[a]	0[a]	30[a]	33[a]	17[a]	10[a]	6[a]	0[a]
Saal	187[ab]	7[a]	0[ab]	0[a]	10[a]	0[ab]	0[ab]	456[b]	0[ab]
Total	1350[a]	3000[a]	2400[a]	1580[a]	2917[a]	2450[a]	1050[a]	2583[a]	2667[a]

Values in a row with the same letter are not significantly different at $p < 0.05$.
* Significant differences based on ANOVA, but not detected by Scheffe's mean separation procedure.
Acpe=*Acer pensylvanicum*, Acru=*Acer rubrum*, As/Ap=*Acer saccharum/platanoides*, Bele=*Betula lenta*, Carya=*Carya* spp., Cade=*Castanea dentata*, Cofl=*Cornus florida*, Fram=*Fraxinus americana*, Havi=*Hamamelis virginiana*, Nysy=*Nyssa sylvatica*, Osvi=*Ostrya virginiana*, Pist=*Pinus strobus*, Prav=*Prunus avium*, Prse=*Prunus serotina*, Prvi=*Prunus virginiana*, Qual=*Quercus alba*, Quco=*Quercus coccinea*, Quil=*Quercus ilicifolia*, Qupr=*Quercus prinus*, Quru=*Quercus rubra*, Quve=*Quercus velutina*, Saal=*Sassafras albidum*.

DISCUSSION

Mixed oak forests of the Ridge and Valley Province of central Pennsylvania differ appreciably in composition and structure due to differences in edaphic factors. General

decreases in soil moisture with increasing elevation from mesic indented stream sites to xeric ridgetops occurred due to increases in percent sand and slope, decreases in soil thickness and percent silt and clay, and changes in substrate (limestone to sandstone) and soil type (Alfisols to Inceptisols)(cf. Whittaker 1956). This gradient is rather uniform across the landscape except for two physiographic outliers, the coarse textured-valley floor and cove units. These units encompass xerophytic and mesophytic communities, respectively, which contrast sharply with surrounding forests. Otherwise, changes in forest composition were rather subtle between adjoining physiographic units, representing a continuum of community organization (Gleason 1926). Although changes in forest composition seemed to be closely linked with moisture availability, changes in fertility and pH may also play important roles (Peet and Loucks 1977, Balter and Loeb 1983, Campbell 1987).

Quercus species were consistently the largest and presumably oldest individuals on all sites, and dominated the overstories of all physiographic units. These attributes seem to be quite characteristic of *Quercus* in other eastern forests (Cottam 1949, Parker et al. 1985, Abrams 1986, McGee 1986, Nowacki et al. 1990). General shifts in *Quercus* dominance from *Q. alba* through *Q. rubra* to *Q. prinus* occurred from mesic to xeric sites, and is consistent with regional surveys (Niering 1953, Keever 1973, Overlease 1978, Russell and Schuyler 1988). In contrast, both coarse textured-valley and cove sites had overstories dominated by *Q. alba* and *Q. prinus*. This is rather unusual considering that these two physiographic units occur at the opposite extremes of the moisture spectrum and the co-occurrence of these two species on other sites is infrequent.

The mixed oak forests in this study are considered early- to mid-successional on most sites based on regeneration trends. Replacement of the oak component to varying degrees by more shade tolerant species seems likely in the future, though the transition may be rather gradual due to long life span of *Quercus* species (Abrams and Downs 1990). Understory trees and saplings are probably the best predictor of future composition, barring large-scale disturbances to the site (cf. Ohmann and Buell 1968). On mesic sites, *A. rubrum* and *P. serotina* were the most abundant understory species, which is consistent with other forests in the region (Gysel and Arend 1953, Crow and Miller 1983, Lorimer 1984, Russell and Schuyler 1988, Abrams and Downs 1990). The distribution of *A. rubrum* on a wide variety of sites in central Pennsylvania can be explained, in part, by genotypic variation and physiological plasticity (Abrams and Kubiske 1990). Some studies indicate poor performance of *P. serotina* in understory conditions (cf. Mackey and Sivec 1973), however we found this species growing rather vigorously and recruiting well in most cases. *Acer saccharum*, usually a dominant understory species in other *Quercus* forests (Crow and Miller 1983, Parker et al. 1985, Nowacki et al. 1990), was lacking on most mesic areas, probably due to its low overstory importance in the area. On the drier upper slopes, trends towards *A. pensylvanicum, H. virginiana, B. lenta, A. rubrum* were apparent, though only the latter two species have overstory potential. Regeneration on the crest was primarily made up of *B. lenta* and *A. pensylvanicum*. Successful seedling-to-sapling recruitment of *Quercus* species occurred only on coarse textured-valley floor locations, combining with *A. rubrum, P. strobus* and *S. albidum* to form the understory. Abundant *Quercus* regeneration on xeric sites has been documented elsewhere (Gysel and Arend 1953, Overlease 1978, McCune and Cottom 1985,

Abrams 1986), and may be explained by higher light levels at the forest floor and fewer competing seedlings of less drought tolerant species. We conclude from these data that future decreases of *Quercus* will probably occur, with corresponding increases of *A. rubrum* and *P. serotina* on mesic sites and *A. rubrum* and *B. lenta* on drier slopes and ridgetops. In the most xeric communities, *Quercus* seems to be a rather stable component, although slight increases in *A. rubrum, S. albidum* and/or *B. lenta* may occur.

Betula lenta often dominates recently disturbed areas in central Pennsylvania, however it can also occur in shaded forest understories (Fowells 1965). Successional trends in this and other studies of northeastern forests suggest that *B. lenta* has been increasing in importance over the past few decades, possibly in response to canopy gaps (Good 1968, Russell and Schuyler 1988, Loeb 1990). Nonetheless, the distribution of *B. lenta* in this study was restricted to high-elevational or xeric valley-floor forests.

Present-day mixed oak stands seem to be intrinsically linked with intense anthropogenic disturbances. Most stands included in the survey are associated with recurring logging and fire from 1760 to 1900. Even though *Quercus* species were an important component in eastern presettlement forests (Sears 1925, Braun 1950, Spurr 1951, Russell 1981, Abrams and Downs 1990), it seems likely that their dominance has been maintained or even promoted from recurring disturbances due to their resistence to fire and competitiveness in post-disturbance environments (Lorimer 1985, Crow 1988, Lorimer 1989, Nowacki et al. 1990). However, decreased disturbance this century has led to conditions favoring shade tolerant species, with few opportunities for *Quercus* establishment and canopy recruitment. Under today's low-disturbance regime, *Quercus* species will most likely decline on all but the most xeric sites.

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EXTRAPOLATION OF FOREST COMMUNITY TYPES WITH A GEOGRAPHIC INFORMATION SYSTEM

Wayne K. Clatterbuck and John Gregory[1]

Abstract: A geographic information system (GIS) was used to project eight forest community types from a 1,190-acre (482-ha) intensively sampled area to an unsampled 19,887-acre (8,054-ha) adjacent area with similar environments on the Western Highland Rim of Tennessee. Both physiographic and vegetative parameters were used to distinguish, extrapolate, and map communities. Accuracy of the GIS-generated community map was tested by sampling community types from 211 plots and assessing whether the predicted communities actually occurred. Probability statements were formulated to assess map accuracy within a specified confidence level for each community type. The extrapolated composite community map was 85 percent correct at the 90 percent confidence level. Maps of six community types - American beech, northern red oak, black oak-hickory, yellow-poplar, post oak, and scarlet oak - were also 85 percent correct at the 90 percent confidence level. The map was accurate less often, 70 percent and 80 percent correct at the 90 percent confidence level, for American sycamore-sweetgum and chestnut oak communities respectively. These results indicate that when forest communities across a landscape are similar in species composition, structure, and physiography, sampling and inventories of these communities can be reduced or eliminated.

INTRODUCTION

The use of Geographic Information Systems (GIS) by natural resource organizations has expanded greatly beyond just map making capabilities in the last 5 years. Lipscomb and Williams (1989) described some of the more specific uses of a GIS for forest management activities such as fire weather danger simulations and logging transportation costs. The Tennessee Wildlife Resources Agency (TWRA) is using its system as a tool to model wildlife habitat parameters for improved management of wildlife species (Davis 1982). The objective of this paper was to determine if GIS technology could be used to model and predict with an acceptable degree of confidence, forest attributes or community types across the landscape. Can a vegetational and physiographic database obtained from intensively sampled portions of the landscape be used to accurately describe forest communities with similar biotic and physiographic environments? Such a process would conserve substantial sampling and

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inventory costs while generating forest community databases for wildlife habitat management much more quickly than could be obtained through 100 percent inventories.

STUDY AREA

The study was conducted on the 19,887-acre (8,054-ha) Cheatham Wildlife Management Area (CWMA), situated in the Western Highland Rim physiographic region of Tennessee (Fenneman 1938), and managed by the TWRA. The CWMA is located approximately 25 miles (40 km) west of Nashville, TN (36012'N, 8705'W). Braun (1950) described the vegetation of the Western Highland Rim as part of the Western Mesophytic Forest, a transition area between the Mixed Mesophytic Forest Region of the mountains to the east and the Oak-Hickory Region to the west. The CWMA consists of narrow to broad ridges, steep dissected side slopes, and V-shaped upland stream valleys. Elevations range from 480 ft (146 m) in the valleys to 820 ft (250 m) on the ridges. Site index for upland oaks ranges from 55 ft (17 m) at 50 years on the exposed dry south slopes to 85 ft (26 m) on the well-drained footslopes and cooler moist north slopes (Schnur 1937).

According to Smalley's (1980) hierarchical classification of forest sites, the CWMA is within the Highland Rim and Pennyroyal physiographic province, Western Highland Rim region, Highland Rim plateau subregion, and two landtype associations: strongly dissected plateau and moderately dissected plateau. Six landtypes from the two landtype associations are present on the CWMA: narrow ridges and convex upper slopes; broad ridges - north aspect; broad ridges - south aspect; cherty north slopes; cherty south slopes; and footslopes, terraces, streambottoms, and upland depressions with good drainage (Smalley 1980). Agronomical, climatological, and geological characteristics of the region are described by Smalley (1980). Prevalent tree species on the study area include white oak (*Quercus alba* L.), northern red oak (*Q. rubra* L.), black oak (*Q. velutina* Lam.), scarlet oak (*Q. coccinea* Muenchh.), post oak (*Q. stellata* Wangenh.), chestnut oak (*Q. prinus* L.), hickories (*Carya* spp.), yellow- poplar (*Liriodendron tulipifera* L.), American beech (*Fagus grandifolia* Ehrh.), sweetgum (*Liquidambar styraciflua* L.), white ash (*Fraxinus americana* L.), American sycamore (*Platanus occidentalis* L.), dogwood (*Cornus florida* L.), blackgum (*Nyssa sylvatica* Marsh.), sourwood (*Oxydendrum arboreum* L.), and sassafras (*Sassafras albidum* (Nutt.) Nees).

PROCEDURES

In a previous study, eight statistically discrete community types (yellow-poplar, northern red oak, post oak, American beech, chestnut oak, scarlet oak, black oak-hickory, and sycamore-sweetgum) were defined and mapped on an intensively sampled 1,190-acre (482-ha)

compartment within the CWMA.[2] The community classification was expanded to cover the entire 19,887-acre (8,054-ha) CWMA. The process of projecting these community types to unsampled areas will be referred to as extrapolation in this paper. The variation and landscape heterogeneity associated with the community classification system were recognized and accepted as a source of the variation encountered during the extrapolation process.

GIS Extrapolation

The extrapolation procedure involves two steps. We first describe or define each community according to physiographic features, i.e., landtype, topographic slope, aspect, and then integrated these features to produce maps of forest community types. The second step involves evaluating the accuracy of the community map. Thus, the extrapolation procedure is not only a test of differentiating and defining communities by physiographic parameters, but also a test of projecting those parameters or community entities on the landscape.

The projection of the community classification system on the landscape was accomplished with a Geographic Information System (GIS) that assembles, stores, retrieves, and manipulates data in formats to allow information to be mapped and spatially analyzed. The GIS uses different coverages, i.e., layers, of information such as topography, vegetation, soil, hydrology, etc. in a point, line, or polygon form that are referenced to a coordinate system. Roads, easement right-of-ways, waterways, and specific units of the landscape such as fields or ponds can be digitized and geographically referenced. These coverages are superimposed on each other to yield a geographically connected information system which can be used in planning and decision-making analyses.

The GIS database for the CWMA was compiled during previous TWRA inventories. Earth Resource Data Analysis System (ERDAS) software (ERDAS, Inc. 1987) was used to organize data geographically. Grid cell size was 0.67 acre (0.27 ha), and each cell contained information on landtype, topographic slope, and aspect of locations within CWMA. Communities were defined according to these geographic parameters; ERDAS was used to integrate and manipulate these coverages to produce maps of community types. The GIS output was a gray map of eight computer symbols, with each symbol representing one grid cell and its corresponding community type.

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[2]Clatterbuck, W.K. 1988. Classification and analysis of forest plant communities on Cheatham Wildlife Management Area in north-central Tennessee. Unpublished USDA Forest Service Report, RWU-4102, Study No. 1.45. Southern Forest Experiment Station, New Orleans, LA.

Accuracy testing involved selecting sample points from each community type on the map, "ground-truthing" those points, and assessing whether the predicted communities actually occurred. Departures were recorded and evaluated for future refinements in the extrapolation process as well as in the community classification system. A probability statement concerning the accuracy of the projected community types was formulated and used to determine the degree of accuracy within some level of confidence (e.g., a community type on the map is 85 percent accurate at the 95 percent confidence level). The equations and reasoning used in these methodologies are in accordance with those reported by Ginevan (1979) and modified by Aronoff (1982) who used hypothesis testing to determine consumer and producer risks. Consumer's risk, i.e., probability of accepting an inaccurate map is as follows:

$$A \geq \frac{\sum_{X=0}^{X'} N!}{[X!(N-X)!]QL^{(N-X)}(1-QL)^{X}} \qquad (1)$$

To use this equation, a minimum acceptable map accuracy (QL), a sample size (N), and a consumer's risk (A) are selected. The maximum number of allowable misclassifications (X') is found such that the cumulative probability of having X' or fewer misclassifications is less than or equal to A.

Producer's risk (B) is the probability of incorrectly rejecting an acceptable map of some high accuracy (QH) by having more than X' misclassifications. The equation for producer's risk is:

$$B = \frac{\sum_{X=X'+1}^{N} N!}{[X!(N-X)!]QH^{(N-X)}(1-QH)^{X}} \qquad (2)$$

The primary consideration in evaluating extrapolation success is determining the number of samples to take and the maximum number of misclassified samples to allow to attain a prescribed map accuracy.

Approximately 30 samples per community type were adequate to achieve an accuracy of 85 percent with a 90 percent level of precision. Samples for each community type were selected at random from the map where the same community type covered five contiguous grids. Each sample represented at least 3 acres (1.2 ha) of the predicted community type. Map accuracy and confidence levels were altered when community misclassifications were more frequent than desired or if 30 samples for a community type were not represented on the map. A total of 211 sample plots was used for a sampling density of one plot per 94 acres (38 ha).

RESULTS AND DISCUSSION

Community Matrix

To predict community occurrence on CWMA, a matrix of aspect and percent slope that described the eight communities was constructed (Table 1). Six of the community types were adequately defined by aspect and percent slope: northern red oak, black oak-hickory, yellow-poplar, scarlet oak, American beech, and post oak; chestnut oak and sycamore-sweetgum were not. However, both chestnut oak and sycamore-sweetgum communities were delineated by landtype: chestnut oak on broad undulating ridges greater than 250 ft (76 m) wide, and sycamore-sweetgum in the stream valleys. The two landtypes depicting chestnut oak and sycamore-sweetgum communities were superimposed onto the coverage created by the aspect and percent slope matrix to generate a composite map for all eight communities. The overlay of the landtype map effectively replaced communities defined by the matrix (Table 1) in the 0 to 8 percent slope range that occurred on the broad ridge crests and in stream valleys with chestnut oak and sycamore-sweetgum communities respectively. Thus the only communities defined by the matrix at 0 to 8 percent slope were on narrower ridge crests less than 250 ft (76 m) wide. The percentage of land area within CWMA in each community type, as predicted by the aspect-slope percent matrix superimposed with landtype maps, is shown in Table 2.

Table 1.--Community types by aspect and percent slope, as used in the extrapolation analysis.[1]

Aspect	Percent slope		
	0-23	24-35	>35
North	Yellow-poplar	Northern red oak	Northern red oak
Northeast	Yellow-poplar	Northern red oak	Northern red oak
East	Black oak-hickory	Black oak-hickory	American beech
Southeast	Black oak-hickory	Black oak-hickory	American beech
South	Scarlet oak	Scarlet oak	Post oak
Southwest	Scarlet oak	Scarlet oak	Post oak
West	Scarlet oak	Scarlet oak	Post oak
Northwest	Yellow-poplar	Northern red oak	American Beech

[1]The map created by this matrix was overlayed with landtype maps to define the two communities (chestnut oak and sycamore-sweetgum) that could not be defined by aspect and/or percent slope.

Table 2.--Extrapolation analysis: predicted area by community type and mapping accuracy.

Community type	Predicted land area	Sample plots	Correctly identified plots	Map accuracy	Confidence level of map	Allowable plot misclassifications
	--Percent--	----------Number----------		----------Percent----------		-Maximum number-
Yellow-poplar	1.4	12	10	85	90	3
Northern red oak	17.8	31	26	85	90	7
Black oak-hickory	17.4	31	28	85	90	7
Chestnut oak	16.3	25	18	80	90	8
American beech	20.9	30	24	85	90	6
Scarlet oak	8.8	22	17	85	90	5
Post oak	14.0	32	29	85	90	7
Sycamore-sweetgum	3.4	28	19	70	90	10
Total	100.0	211	171	85	90	44

Map Accuracy

Six of the GIS generated communities were within map accuracies of 85 percent at the 90 percent confidence level: yellow-poplar, scarlet oak, post oak, northern red oak, black oak-hickory, and American beech (Table 2). Communities that were misclassified usually appeared as communities that occur adjacent to the predicted communities. The scarlet oak and yellow-poplar communities only contained 22 and 12 samples, respectively, as contiguous map grids for these communities were scarce. Although 30 samples for each community type were initially sought, the scarlet oak and yellow-poplar communities at the smaller sample size were within the prescribed map accuracies.

The map was accurate less often for sycamore-sweetgum and chestnut oak communities. Both these communities were defined by landtype rather than the aspect-percent slope matrix in the extrapolation. Communities were often classified as American beech and northern red oak rather than sycamore-sweetgum, and black oak-hickory rather than chestnut oak (Table 3). The landtype representing sycamore-sweetgum communities extended into narrow, V-shaped, second-order streams on the GIS map, locations where this community does not occur. Generally, sycamore-sweetgum communities appeared more often as stream width increased and as valleys became more U- shaped. Adjustments in the data base could be made so that the stream bottom landtype would not extend into V-shaped, second-order streams.

Chestnut oak communities were defined on ridge crests greater than 250 ft (76 m) wide. Ridge crests in the compartment where the community type classification was developed rarely exceeded 400 ft (122 m) in width and occupied a very small portion of the compartment. Several ridges on the CWMA were wider than 400 ft (122 m), but less than 1,000 ft (305 m), and constituted a much larger percentage of the total land base within CWMA (Table 2) than represented in the sampled compartment. Several oak species (white oak, scarlet oak, black oak, post oak, and chestnut oak) were present on these ridges. Accordingly, many of these wider ridges (>400 but <1,000 ft or >122 but <305 m) contained black oak-hickory communities rather than the predicted chestnut oak community. Alterations in the community classification system will be necessary to accommodate extrapolation of these different communities on these wider ridges.

Approximately 4.3 percent or 867 acres (350 ha) of the GIS generated map contained blocks of 20 or more continuous grids that were composed of three or more communities. Within these blocks, no one community was continuous or connected. Refinements in the database and modeling procedures should allow each unit of the landscape to be mapped and interpreted more clearly. One refinement currently being implemented by TWRA is changing their GIS modeling procedure from a grid to a polygon format so that areas of varying shape and size can be mapped.

Table 3.--Extrapolation: accuracy of community type projections.

Predicted community	Actual community								Sample size
	Sycamore-sweetgum	Scarlet oak	Post oak	Yellow-poplar	American beech	Black oak-hickory	Chestnut oak	Northern red oak	
	Number of plots[1]								--n--
Sycamore-sweetgum	19				5			4	28
Scarlet oak		17	3			2			22
Post oak			29		1	2			32
Yellow-poplar				10				2	12
American beech					24			6	30
Black oak-hickory						28	3		31
Chestnut oak						7	18		25
Northern red oak					1	4		26	31
Total									211

[1]Of the 211 extrapolated classifications, 40 were misclassified.

SUMMARY

The use of the GIS was instrumental in generating a landscape model of forest community types. The composite CWMA community map was 85 percent correct at the 90 percent confidence level. All but two community type projections were within the prescribed limits. The slightly lower map accuracies and confidence levels for the chestnut oak and sycamore-sweetgum communities would not alter forest management or habitat modeling for these communities. Although some variation is present in both the community classification system and the extrapolation, the level of map accuracy achieved was more than adequate to serve as a database in modeling vegetation for wildlife and forest management.

Perhaps the greatest usefulness of GIS generated community classification modeling is the characterization and estimation of vegetational properties across the landscape. Great advances in forest management and habitat planning can be made if a treatment successfully applied to a community at one location can be expected to be successful on the same community type at another location. Currently, the community classification is being used to assess habitat potential. Community classification is also playing a role in the planning and decision-making processes used to appraise the effect of forest management on wildlife habitat. This study provides a broad qualitative extrapolation of communities. Further research should quantify the variation and consistency of forest communities and community properties or values across even broader landscapes of the Western Highland Rim.

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INSECTS AFFECTING ESTABLISHMENT OF NORTHERN RED OAK SEEDLINGS IN CENTRAL PENNSYLVANIA

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Abstract: Studies to evaluate the impact of insects on the establishment of advance oak regeneration in Pennsylvania were initiated in 1989. The populations and species of insects feeding on germinating acorns and new seedlings, their activity periods, and the damage caused by these insects were studied in relation to overstory-density (40, 60, and 100 percent relative density) and understory vegetation control (herbicided and unherbicided) at three sites on the unglaciated Allegheny Plateau in Clearfield County. These experiments showed that overstory-density levels and treatment with herbicide to eliminate the understory had negligible effects on the species of acorn-feeding insects present, their population levels, and their damage to germinating red oak acorns and new seedlings. These experiments also showed that acorn weevils (*Conotrachelus posticatus* (Boheman), nitidulids (*Stelidota octomaculata* (Say), and acorn moths (*Valentinia glandulella* (Riley) are important acorn predators, that they become active during late winter and spring, and that they destroy great numbers of germinating acorns and new seedlings in central Pennsylvania oak stands, thus affecting oak regeneration.

INTRODUCTION

"Although there seems to be a universal problem with regenerating northern red oak, there is not a universal solution. Specific requirements for local conditions will need to be developed from the general requirements for regenerating the species". These comments by Crow (1988) are supported by the large volume of literature on the problem of regenerating oak, yet this problem remains a formidable one.

One problem that is encountered in regenerating mature oak stands on good and excellent growing sites can be traced to a lack of advance oak reproduction. The oak seedlings must be of sufficient size to successfully compete with other faster growing species when the stand is regenerated (Sander 1988; Loftis 1988; Lorimer 1989).

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In 1988, the Northeastern Forest Experiment Station initiated a series of studies to identify and understand the important factors that limit the development of advance red oak reproduction on high-quality growing sites in Pennsylvania, West Virginia, Ohio, and Kentucky[2]. The effects of deer, rodents, insects, light, competition from herbaceous and woody species, site, stand composition, and acorn availability are some of the factors being evaluated.

The first research plots were established in 1988-89 on the Moshannon State Forest in central Pennsylvania. This paper reports early results from studies on the impact of insects on the establishment of northern red oak (*Quercus rubra* L.) seedlings.

DESCRIPTION OF STUDY AREA

The Moshannon State Forest is located in four counties in central Pennsylvania within the unglaciated Allegheny Plateau region. The experiments were conducted in the Clearfield County section of the Forest, where the elevation is about 2200 feet. Precipitation averages 45 inches and is distributed uniformly throughout the year. The area is usually snow covered from December through mid-March. Soil moisture is usually ample during the spring and early summer, though intermittent periods of moisture stress are common during the latter part of the growing season. The frost-free period is about 130 days.

All of the study stands originated after a complete clearcutting shortly after the turn of the century. As a result, they are even-aged and about 80+ years old. The site index for northern red oak is about 70.

Following clearcutting, many factors, including repeated fires, gave rise to the fully stocked, second-growth hardwood stands that are present today. These stands have a major component of northern red oak growing in mixture with black cherry (*Prunus serotina* Ehrh.), sugar maple (*Acer saccharum* Marsh.), red maple (*Acer rubrum* L.), and white ash (*Fraxinus americana* L.). Other species represented include yellow-poplar (*Liriodendron tulipifera* L.), American beech (*Fagus grandifolia* Ehrh.), cucumbertree (*Magnolia acuminata* L.), bigtooth aspen (*Populus grandidentata* Michx.), hickory (*Carya* spp.), white oak (*Quercus alba* L.), black oak (*Quercus velutina* Lam.), and chestnut oak (*Quercus prinus* L.).

The understory on the study areas is limited in abundance and diversity, reflecting long-term browsing from the high deer population that numbers between 31 to 34 per square mile

[2]Study Plan: Factors limiting the establishment of advance oak regeneration in mature oak stands by H. Clay Smith and L. R. Auchmoody (called Limiting Factors Study).

(Powell and Considine 1982; Pennsylvania Game Commission)[3]. Hay-scented fern (*Dennstaedtia punctilobula* L.), New York fern (*Thelypteris noveboracencis* L.), striped maple (*Acer pensylvanicum* L.), and American beech are not preferred by deer and, therefore, are the species found most frequently in the understories. Desirable hardwood regeneration also is sparse, being limited to species that are low in preference as deer browse. Virtually all oak seedling regeneration is less than 15 inches tall due to repeated browsing. The number of advance red oak seedlings ranges from about 60 to 350 per acre.

METHODS

The field design of the Clearfield installation on the Moshannon State Forest consists of six, 4-acre cutting-level plots arranged in three randomized complete blocks (a total of 18 plots). Treatments applied to these plots were: 1) three cutting levels (40, 60, and 100 percent residual relative density); 2) fencing half of the plots to exclude deer; and 3) herbicide (glyphosate) applied to one-half of each of the 18 plots to eliminate the understory vegetation. Each block (replicate) was located in a fully stocked stand in which northern red oak was a principal component, and that also was representative of the oak stands in the area. Herbicide was applied in August 1988, and the overstory treatments were made in the winter and spring of 1989.

Studies to determine the relative populations and species of insects that might be causing damage to red oak acorns were conducted in the spring of 1989 and 1990. Both experiments used pitfall traps to catch the insects. The pitfall traps consisted of pint canning jars with 10-ounce plastic cup inserts containing a paper towel, 20 ml of water, and four or five viable red oak acorns that had been cut into halves (bait). The jar sealing caps were replaced with 1/4-inch hardware cloth circles to allow entry by the insects. The wire discs were glued inside the screw caps with epoxy ribbon adhesive to prevent rodents from pulling out the wire screens. The traps were buried in the soil with the tops flush with the ground. Rain shields for the traps were provided by positioning plastic food container lids (6- to 8-inch diameter), supported on 10-inch nails, about 3 inches above the tops of the traps. The traps were checked at 7- to 10-day periods. At the end of each trapping period, the insects that were caught were identified and counted, and the traps equipped with new plastic cup inserts containing fresh acorn bait.

In 1989, the trapping period was between May 3 to June 13 and a total of five collections were made. That year, 4 pitfall traps (2 in each herbicided and unherbicided section of each cutting level) were placed in each of the 6 plots at replicates 2 and 3 and also in the two uncut (100 percent relative density) plots of replicate 1, a total of 56 traps. The 40 percent and 60 percent relative density plots at replicate 1 were not trapped in 1989 because rain

[3]Unpublished Pennsylvania Game Commission annual estimate of winter deer population estimates by William Palmer.

delayed the completion of the cutting treatments until mid-June. In 1990, the trapping period was between May 15 and June 6 and a total of three collections were made. During 1990, two pitfall traps were placed in each herbicided and unherbicided section of all plots, for a total of 72 traps. Analysis of variance was used to determine if the insect species present or their population levels were affected by the residual stand densities on the plots and by the application of herbicide (i.e. understory removal).

In separate experiments to evaluate insect damage to germinating red oak acorns and young seedlings, direct-seeded acorns were used along with 6-inch-square, open-bottom wire boxes of 0.5- by 1.0-inch hardware cloth to protect sown acorns from chipmunks and larger mammals. The wire boxes were secured to the ground with 12-inch landscaping nails or 8-inch plastic tent stakes. As with the pitfall trap experiments, these studies also were conducted in the herbicided and unherbicided sections of the main cutting-level plots (40, 60, 100 percent relative density).

The first of the experiments began in early May 1989 and was conducted on seven plots where deer were excluded and one unfenced plot. Six wire boxes were placed in herbicided and unherbicided sections of each plot. Under each wire box, two red oak acorns were planted 1-inch deep and two acorns were placed on the soil surface. At a distance of 1 foot from each of 2 sides of the wire box, one acorn was planted 1-inch deep and one placed on the soil surface (eight acorns total per site). All acorns inside and outside the boxes were covered with leaves. The acorns, which had been collected in 1988 and kept in cold storage, were just beginning to germinate so all were viable when sown. Thus, 768 acorns were deployed; half were protected from rodents and half were surface or subsurface sown. The sites were checked in late June to determine the extent of insect and rodent damage. Differences in damage attributed to residual overstory density and to understory removed by herbicide were determined by analysis of variance (ANOVA).

The second experiment began in late October and early November of 1989. Ten wire boxes were placed in each herbicided and unherbicided section of all 18 plots. Under each wire box, five red oak acorns were placed on top of the ground and covered with leaves. The boxes were secured to the ground with 12-inch landscaping nails or 8-inch plastic tent stakes. The acorns used in this study were collected outside of the study plot boundaries and float-tested; any acorns showing signs of insect or other damage were discarded. The boxes were distributed throughout the plots and placed under acorn-bearing trees. Thus, 100 acorns were sown in each cutting-level plot (1,800 acorns total). The wire boxes were lifted and the acorns and seedlings checked for damage in May, June, and July of 1990. The heights of the seedlings were measured in July when the boxes were removed from the plots. Differences in damage between the residual overstory densities and from the removal of the understory with herbicide were evaluated by ANOVA.

The viability of the acorn crop and effects of insects thereon were determined from acorn samples taken in November inside 14- by 42-ft. fenced rodent-exclosure plots inside the fenced 4-acre plots (Auchmoody et al. - unpublished). This eliminated variation due to removal of acorns by rodents prior to sampling. A sample of 10 to 25 acorns was collected in each rodent-exclosure plot. The acorns were packed in moist peat moss in plastic bags and

stored at 45 to 50°C. Several small holes were punched in each bag to allow aeration. About 3 months later the bags were placed at room temperature and a small amount of water was added to each bag. After 2 weeks the acorns were checked for germination. Inviable acorns were cut open and inspected to determine the cause of germination failure.

A final study was conducted to determine when feeding activity by acorn insects begins. A sample of 300 acorns was collected near the plots on February 13, 1990, and a second sample of 235 acorns was collected on March 15, 1990. The acorns were examined in the laboratory and insect activity associated with each of the sampling dates was determined.

RESULTS

Three important species of insects that damage germinating acorns were caught in the pitfall traps in 1989 and 1990: the weevil, *Conotrachelus posticatus* (Boheman); the nitidulid or sap beetle *Stelidota octomaculata* (Say); and the acorn moth, *Valentinia glandulella* (Riley). Table 1 gives the mean number of weevils and sap beetles caught per trap per trapping period for five periods in 1989 and three periods in 1990.

Analysis of variance revealed no significant differences in weevil or sap beetle populations associated with the overstory-density treatments or with the removal of the understory with herbicide in either years. Thus the data from all plots within a replicate were pooled and the replicate means were analyzed for differences. The weevil population in both 1989 and 1990 was significantly lower in Replicate 1 than in Replicate 2 but not significantly lower than in Replicate 3. The Replicate 2 and Replicate 3 plots did not differ significantly in 1989 but they did in 1990.

Table 1.--Mean number of weevils, *Conotrachelus posticatus*, and sap beetles, *Stelidota octomaculata*, caught per pitfall trap per trap period, 1989 and 1990[a]

Area	Weevil		Sap Beetles	
	1989	1990	1989	1990
Replicate 1	4.8 a[b]	0.3 a	0.9 a	0.1 a
Replicate 2	8.2 b	0.8 b	7.9 b	2.4 b
Replicate 3	6.2 ab	0.3 a	10.0 b	1.9 b

[a]Mean shown for each replicate is the mean of pooled plot data since ANOVA showed no significant differences in either insect population due to different overstory densities or to removal of understories with herbicide in either year.
[b]Means in the same column followed by the same letter are not significantly different at the 95 percent level.

Populations of sap beetles in Replicate 1 were significantly lower in both 1989 and 1990 than in Replicates 2 and 3. There was no significant difference in sap beetle populations between Replicates 2 and 3 in either years.

Populations of the acorn moth *V. glandulella* were not determined from pitfall traps in 1989 or 1990, but many moths were reared from the acorns used as bait in the pitfalls. However, because this insect was thought to be a minor acorn pest, no attempt was made to monitor exact numbers. Subsequently, germinating acorn samples collected on March 15, 1990, near the study plots revealed that the radicle tips of 50 percent of the acorns had been eaten by the moth larvae and laboratory rearing showed that 60 percent of the acorns were infested with moth larvae. As a result, this insect must now be considered a major pest of germinating acorns in Pennsylvania, and future studies should monitor the populations of *V. glandulella*.

Table 2 presents the 1989 results of subsurface- and surface-sown acorns inside and outside of hardware-cloth boxes. There were 192 acorns in each of the four treatments. Analysis revealed no differences due to overstory density, herbicide treatment, or plot location (replication) so the data given in Table 2 is the pooled data from all plots. Acorn placement and rodent protection did result in significant differences in numbers of seedlings, acorns taken by rodents, and acorns destroyed by insects. Rodents destroyed virtually every acorn outside of the boxes -- all of the acorns on the surface and 150 (78 percent) of those buried. Under the boxes, insects destroyed 177 (92 percent) of the acorns on the surface but only 16 (8 percent) of those buried. One hundred and seventy-six (92 percent) of the acorns buried under a wire cage produced a seedling while only 41 (21 percent) of those buried without protection from rodents produced seedlings. Seventeen of the subsurface acorns were destroyed by weevils and sap beetles which enter loose soil to feed on acorns.

Table 2.--Results of 1989 test in which 192 acorns per treatment were surface or subsurface sown, inside or outside of wire boxes -- number of acorns lost to rodents and insects and seedlings produced.*

Treatment	Seedlings	Acorns taken by rodents	Acorns destroyed by insects
	----------number----------		
A - Surface-inside	15	0	177
B - Surface-outside	0	192	0
C - Subsurface-inside	176	0	16
D - Subsurface-outside	41	150	1

*Data pooled for all study areas. T-test showed no significant differences in number of seedlings relative to overstory density, herbicide treatment, or study area. Surface treatment (A) inside and subsurface treatments (C and D) inside and outside boxes significantly increased seedling establishment ($P \leq 0.05$).

As shown in Table 3, insects destroyed 87 percent of the germinating acorns and new seedlings that resulted from 1,800 acorns placed under the wire boxes in autumn of 1989. Insects destroyed 270 (64 percent) of the 422 seedlings that established from 1139 germinating acorns. Only 152 (13 percent) of the 1,139 germinating acorns and seedlings survived insect destruction and 113 of the seedlings were in Replicate 1. The insect damage listed in Table 3 is based only on acorns that germinated since rodents destroyed some of the acorns and nonviable acorns were not subject to insect damage. The insect damage was primarily by the acorn moth and the *Conotrachelus* weevil. Laboratory rearing of the acorns removed from the wire boxes revealed that at least one-third were infested with moths and nearly all with weevils. Most of the newly rooted seedlings were killed due to heavy weevil feeding on the radicles and shoots. There also was some damage to newly rooted seedlings by *S. octomaculata* in concert with the weevils. The sap beetles ate the tender top-shoots as they formed and reproduced in the acorn cotyledons, destroying any chance for the acorn to resprout and form a seedling.

Table 3.--Fate of 1800 northern red oak acorns surface-sown under wire boxes in autumn of 1989 and checked May, June, and July 1990.[a]

	Replicate			Total	Percent
	1	2	3		
	----------Number----------				
A - Germinating acorns destroyed by insects	242	265	210	717	63*
B - Seedlings destroyed by insects	92	129	49	270	64*
A + B - Total number of acorns and seedlings destroyed by insects	334	394	259	987	87*
Surviving seedlings	113**	26	13	152	13

[a]Of the 1,800 surface sown acorns, 661 (37 percent) failed to germinate because of mouse predation (7 percent) and desiccation (30 percent). Plot data pooled for each replicate since ANOVA showed no significant differences within a replicate relative to overstory density or understory control.
*Percentages based on 1,139 acorns that germinated and 422 seedlings that initially established from the 1,139 acorns.
**Significantly different at 99 percent level from Replicates 2 and 3.

The acorn samples removed in November 1989, from the rodent-exclosure plots revealed that 132 of 536 (24.7 percent) were infested with insects, primarily *Curculio* sp. larvae. Less than 2 percent of the acorns were infested with the filbertworm moth, *Cydia latiferreana* (Wlsm.) and the acorn moth, *V. glandulella*. Surprisingly, larvae of *V. glandulella* were found in sound, previously undamaged acorns, having gained entry into the acorn by chewing through the micropyles on the cap end of the acorn. This is the first report of this insect being a

primary invader of sound, ungerminated acorns. It is believed that the larvae are able to chew only into immature acorns. Damage to the cotyledons was confined to the cap ends and had no affect on acorn viability. Sixty-two (47 percent) of the acorns infested with *Curculio* weevils and *Cydia* moths failed to germinate while 70 (53 percent) germinated. Ideal germination conditions in the laboratory probably allowed many insect infested acorns to produce seedlings that otherwise would have desiccated under natural conditions. However, at least 12 percent of the 1989 bumper acorn crop was not viable due to insect damage.

The samples of germinating acorns collected on February 13, 1990, revealed that the acorn moth, which overwinters as an early instar larva, had just begun to feed. In this sample, only 13 of 300 acorn radicles had been damaged, but by March 15 the radicles of 118 of the 235 acorns collected had been damaged by moth larvae. Weevil damage was not observed in the February sample of acorns and by March 15 weevil feeding and oviposition had just begun. Activity by sap beetles was not detected in either of the acorn samples. Adult sap beetles were found on moth- and weevil-destroyed acorns under the wire boxes on May 7, 1990. However, sap beetle reproduction was not detected until a second check of the acorns under the boxes on June 7 revealed that reproduction probably began in late May.

DISCUSSION

The average number of weevils and sap beetles caught in the pitfall traps in 1990 appears very low compared to 1989 (Table 1). In 1990, the traps were competing with a large number of residual acorns from the 1989 bumper crop. By contrast, in 1989, wildlife had consumed nearly all of the acorn crop by June, which resulted in greater numbers of insects being attracted to the traps. Insects destroyed 987 (87 percent) of the 1,139 germinating acorns and young seedlings under the wire boxes in 1990 (Table 3). This indicates that the acorn-insect population actually was very high in 1990. Thus, the number of acorn insects trapped in pitfalls must be evaluated over time in relation to acorn food sources available in the surrounding area to accurately assess populations.

The pitfall trapping period was shorter in 1990 than in 1989 but was conducted during the ideal time for assessment of weevil and sap beetle populations that overwintered within the plots; when temperatures were below the threshold for flight of the acorn insects but high enough for the insects to readily migrate to the traps by walking. The overwintering populations of acorn insects are the most damaging and their populations within an area are best assessed before migration or emigration by flight can occur and before emergence of new adults occurs in late spring and early summer.

Mice destroyed 119 (7 percent) of the 1,800 acorns placed under the wire boxes. However, 95 acorns were eaten by mice in just two plots in Replicate 3. This demonstrates the localized effect of some species of rodents on seedling establishment. The hardware-cloth mesh allowed entry by mice. Mice usually eat off the cap ends of the acorns, leaving a nearly intact acorn hull; other rodents typically leave the acorn hull in pieces.

Of the 152 new seedlings that were established under the wire boxes in 1990, only 51 were undamaged by rodents. Rodents chewed off the tops of most seedlings emerging from the wire boxes. This type of rodent damage also was observed in Ohio (Galford et al. 1988). Seedlings not damaged by rodents ranged in height from 1 to 12 cm and averaged 5.4 cm. The smallest seedlings resulted from acorns heavily damaged by insects; none appeared vigorous.

Snowfall was less than normal during the winter of 1989-90 in the study area, and rainfall was below normal in March and April of 1990. This may account in part for the large number of acorns (30 percent) that did not germinate. Laboratory germination tests of samples of the acorns used in the study showed that 97 percent were viable. The dry conditions at the time of acorn germination also may have influenced the impact of insects on seedling establishment. Delayed acorn germination and a slow rate of radicle growth due to a moisture deficit would expose the radicle tips to insect feeding for a longer period.

The low population of sap beetles in the Replicate 1 plots (Table 1) may have been a factor in a greater number of seedlings being established under the wire boxes in 1990 (Table 3). However, the importance of the sap beetles is not completely known. Additional studies are needed to establish insect and rodent population interrelationships with respect to acorn abundance and seedling establishment.

Examination of several hundred newly established red oak seedlings in and near the plots in 1989 revealed that only two seedlings originated from surface acorns. Nearly all of the seedlings establishing in areas undisturbed by the logging operations resulted from acorns buried or otherwise cached by rodents. By contrast, in 1990 more than 70 percent of the new oak seedlings that were examined originated from surface acorns under leaf litter. Thus, the large acorn crop of 1989 allowed some unburied acorns to survive predation by both insects and rodents.

Data obtained on insect species that feed on germinating acorns and their impact on seedling establishment in central Pennsylvania parallels results from studies on acorn insects in Ohio (Galford et al. 1988).

In conclusion, insects and rodents singly or in combination can significantly limit the number of oak seedlings establishing in central Pennsylvania forests, even in years of large acorn crops. Foresters have long known that logging operations following a good acorn crop can increase oak seedling establishment. Many acorns are covered or pressed into the soil during logging. The results of this study demonstrate that buried acorns are afforded protection from insect and rodent predation and desiccation, which increases oak seedling establishment.

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USING ROUNDUP AND OUST TO CONTROL INTERFERING UNDERSTORIES IN ALLEGHENY HARDWOOD STANDS

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Abstract: Allegheny hardwood stands in the Pennsylvania portion of the type frequently contain dense understories of undesirable species such as hayscented fern (*Dennstaedtia punctilobula* (Michx.) Moore), New York fern (*Thelypteris noveboracensis* L.), grasses and sedges (*Carex* spp.), striped maple (*Acer pensylvanicum* L.) and beech (*Fagus grandifolia* Ehrh.). Once established, they interfere with the establishment of advance regeneration of desirable species. The use of herbicides is a practical means of controlling this vegetation. Initial small-plot studies showed that Roundup controlled all of the undesirable species. Under commercial application conditions, control of vegetation sometimes was less than predicted from the small-plot experiments. Three problems developed as a result of application techniques and subsequent shelterwood cutting in treated stands. First, the use of vehicle-mounted sprayers resulted in regeneration of ferns in the vehicle tracks from small segments of fern rhizome broken off by the treads during herbicide application. When these stands were subsequently shelterwood cut, the fern plants spread rapidly, completely revegetating the stand within a few years. Second, forest floor disturbance created by shelterwood cutting also stimulated germination of grass and sedge seed in the forest floor seed bank, precluding regeneration of desirable hardwoods. Third, striped maple kill was frequently less than expected. The fern, grass, and sedge regeneration problems were solved by using Oust, either alone or tank mixed with Roundup. Control of striped maple was increased by improving coverage of striped maple crowns with Roundup. Current guidelines recommend the use of Oust alone when ferns or ferns and a grass and sedge seed bank are the primary target species. Roundup alone is recommended where striped maple and beech are the primary targets. Where there is a combination of target species, a tank mix of Roundup and Oust is recommended. These herbicides are used in combination with several cutting techniques to obtain regeneration of Allegheny hardwoods.

INTRODUCTION

The cherry-maple or Allegheny hardwood type is a varient of the northern hardwood type found along the Pennsylvania-New York boundary, south through the Appalachians to the

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northern mountains of West Virginia and adjacent areas of Maryland, and in northeastern Ohio. Second- and third-growth stands in this type are composed primarily of black cherry (*Prunus serotina* Ehrh.), red (*Acer rubrum* L.) and sugar maple (*Acer saccharum* Marsh.), white ash (*Fraxinus americana* L.), yellow-poplar (*Liriodendron tulipifera* L.), and beech. In the Pennsylvania portion of the type, more than half of the stands have dense ground covers of herbaceous ferns, grasses and sedges, or woody understories of striped maple and beech root suckers, and are typically difficult to regenerate. Despite the presence of desirable species in the overstory, Allegheny hardwood stands usually lack the knee-high to waist-high regeneration commonly found in other eastern hardwood forest types.

This condition is a result of continuous browsing since the 1920's by a large population of white-tailed deer (*Odocoileus virginianus virginianus* (Boddaert)). Deer browsing has had three effects on forest vegetation: the numbers of seedlings are reduced, surviving seedlings are smaller, and species composition is altered (Marquis and Brenneman 1981; Tilghman 1989). Desirable species such as the maples, ash, and yellow-poplar are highly preferred by deer and tend to be eliminated when they are seedlings. Since black cherry is intermediate in food preference, any large desirable advance regeneration usually is black cherry. The ferns, grasses and sedges, striped maple, and beech are low in food preference and tolerant of understory shade. Thus, they not only remain in the understory but also expand into the growing space formerly occupied by desirable regeneration.

Expansion of undesirable plants also has been encouraged by thinnings which took place in many stands during the late 1950's and 1960's. Rhizome development of hayscented and New York fern and short husk grass (*Brachyelytrum erectum* Schreb.) is greatly accelerated in the partial shade of thinned or shelterwood seed cut stands. Seedlings of striped maple, which can remain in the understory for many years, grow rapidly when additional light is made available. Tolerant beech root suckers sustained by an older root system make surprisingly rapid growth in partially cut stands. Once these undesirable plants occupy the understory, they interfere strongly with the regeneration and establishment of desirable species, even when deer are excluded (Horsley and Marquis 1983). Interference by hayscented and New York fern is particularly serious because they form dense ground covers rapidly and the low intensity, high far-red shade light beneath them results in poor survival of black cherry and other desirable Allegheny hardwood species (Horsley 1986).

When the quantity of interfering plants becomes too great (for guidelines see Marquis et al 1991) steps must be taken to remove them before regeneration can be established. Neither mechanical methods nor fire are effective in the Allegheny hardwood type; however, herbicides are an effective, economical, and safe means of removing interfering plants and minimizing their regeneration so that desirable hardwood species can become established (Horsley et al in press).

Initial small plot studies with several herbicides showed that the herbicide Roundup, manufactured by Monsanto, controlled hayscented and New York fern, short husk grass, and striped maple, and beech, and that the time of application was important in determining the application rate required for effective control (Horsley 1981; Horsley and Bjorkbom 1983). This was particularly true at low rates of application. For example, 95 percent or better control of 1- to 5-foot striped maple could be achieved with 1, 2, or 4 qt/acre of Roundup in early August or early September applications. But, 2-4 qt /acre were required to achieve this level of control if applications were made in early June or early July (Table 1).

Table 1.--Mean percent kill of 1-5 foot striped maple by Roundup applied at different rates and times.[a]

Application Rate	Month of Application				
(qt/acre)	Jun	Jul	Aug	Sep	Oct
1	53 d	81 a-d	95 ab	97 ab	57 cd
2	95 ab	87 abc	97 ab	97 ab	77 bcd
4	97 ab	97 ab	98 ab	99 a	90 ab

[a]Means followed by the same letter were not significantly different or $P \geq 0.05$ using Duncans New Multiple Range Test.

By restricting the application of Roundup to the time between early August and early September, the amount of herbicide needed could be minimized. This is important from both an economic and an environmental standpoint. The same sensitivity to time of application was observed when the 1 qt/acre rate was applied to striped maple stems of increasing size. More than 90 percent control of trees less than 1 foot tall could be obtained with any application date between early June and early October. However, control of larger trees was strongly dependent on application time; optimal control was achieved with early August to early September applications and was less at earlier or later times of application.

Weather conditions early in the growing season affect plant development. Therefore, differences in susceptibility to control by an herbicide can vary due to annual differences in weather conditions. For example, hayscented fern frond development is slower in a cool spring than in a warm spring (Table 2). Thus, early June applications of Roundup made in a year with a cool spring resulted in less control than a similar application in a warm spring.

Sensitivity to timing of Roundup application also was observed at the end of the growing season. When leaf yellowing begins, uptake and translocation of herbicide declines. Roundup applications after this time provided less control of all species we tested. The time of leaf yellowing, which occurs in mid-September in northwestern Pennsylvania, is a practical limit to Roundup application.

Table 2.--Air temperature, hayscented fern frond height, and hayscented fern control by a June 1 application of 1 qt/acre of Roundup.

Year	May Air Temp (°F)			Frond Height (in.)		Fern Control (%)
	Max	Min	Mean	May 1	June 1	
1976[a]	67.7	43.4	55.6	0-2	12	68
1977[b]	77.2	44.5	60.9	1-2	18-24	93

[a]From Climatological Data 81(5):4, Warren, Pennsylvania Station
[b]From Climatological Data 82(5):4, Warren, Pennsylvania Station

Our studies suggest that a high level of plant control can be achieved with 1 qt/acre of Roundup by restricting the time of application. Optimum dates for control of hayscented fern, New York fern, and short husk grass are from early July until leaf yellowing in mid-September. For striped maple, the optimum dates of application are from early August to leaf yellowing and for beech they are from early August to early October.

Once interfering plants are removed, the regeneration process can continue. Where interfering plants are not present, the most important factor determining success of regeneration is the establishment of large numbers of desirable seedlings before the final removal cut (Grisez and Peace 1973). A shelterwood seed cut leaving residual overstory stocking of about 60 percent hastens the development of large numbers of small seedlings (Horsley 1982; Marquis 1979). These seedlings do not grow much because the overstory is still dense enough to provide a light limitation. However, where deer impact is high, this is an advantage because the seedlings are less attractive to deer. Within 3 to 5 years, large numbers of seedlings usually become established, though the process can take longer.

Black cherry and red maple usually predominate in northwestern Pennsylvania stands and the speed with which adequate regeneration develops depends upon the basal area of black cherry greater than 8 inches dbh. Stands with at least 25 square feet of basal area/acre in black cherry usually develop adequate regeneration within a few years after the seed cut; stands with less black cherry often require a longer time. Once adequate regeneration has developed, the remaining overstory can be removed. In stands where herbicide has been applied, the overstory should be removed as soon as adequate regeneration develops to minimize reestablishment of any interfering plants that remain. Concentration of cutting in an area also reduces the impact of deer browsing (Horsley et al in press).

REFINEMENTS IN THE INITIAL PRESCRIPTION

Commercial application of Roundup in an herbicide-shelterwood cut system began in 1979. These applications used air-blast spray equipment mounted on tracked or rubber-tired vehicles. During the first 5 years it became apparent that refinements were required. Three problems developed as a result of application techniques and subsequent shelterwood cutting

in treated stands. The first was that ferns were inadequately controlled in the area traversed by the vehicle carrying the sprayer; instead "fern tracks" were formed. Apparently, the metal cleats on tracked vehicles and the sharp edges of new rubber tires break off small segments of fern rhizome at the time of treatment, preventing translocation of Roundup into them. Over a period of 4 to 6 years in shelterwood cut stands, new fern plants regenerate and can reoccupy the understory before desirable hardwood regeneration becomes established. This process is abetted by variable numbers of small, isolated fern plants that develop from single unkilled rhizome buds, probably as a result of incomplete coverage of foliage with herbicide or incomplete translocation of herbicide within the plant.

The second problem was that, following the shelterwood seed cut, the stand sometimes regenerated to grasses and sedges rather than tree seedlings. The forest floor of most Allegheny hardwood stands contains a seed bank of grasses and sedges that germinate after disturbance. The skidding activities associated with the shelterwood seed cut provided the stimulus for germination in disturbed areas (Table 3). The greater the proportion of forest floor that was disturbed, the greater the amount of grass and sedge that developed. Little grass and sedge developed on undisturbed areas, even where a large seed bank was present. Typically, grass and sedge seeds germinated in the growing season after disturbance. Ground cover by these small plants was low in the first year, but during the second growing season after disturbance they grew to full size, greatly expanding in ground coverage. There was little expansion after the second year. Once a grass and sedge ground cover developed, the regeneration process was slowed so dramatically that little regeneration became established under our conditions that include an extremely high deer population.

Table 3.--Mean percent ground cover by newly germinated grass and sedge on disturbed and undisturbed plots 1, 2 and 3 years after disturbance.[a]

Disturbance	Years after Treatment		
	1	2	3
	----------(%)----------		
Roulette			
Disturbed	13[b] ± 20 a	0.4 ± 0.5 bcd	0 ± 0.2 bd
Undisturbed	1 ± 2 bc	0.4 ± 0.5 bcd	0 ± 0.3 bd
Kane			
Disturbed	43 ± 28 a	1 ± 0.6 b	
Undisturbed	2 ± 2 b	1 ± 1 b	

[a]Disturbance by year after treatment means at a location followed by the same letter were not significantly different at $P \geq 0.05$ using the Bonferroni procedure. Each value is shown ± one standard deviation. n = 63.
[b]Each disturbance by year after treatment value is the mean of 21 observations.

The third problem was that, under commercial operating conditions, striped maple stems were not always controlled by Roundup as well as might be predicted from small-plot experiments.

Stems were almost always defoliated, but some were not killed and refoliated the following year from unkilled axillary buds. Increasing the rate of Roundup application from 1 to 4 qt/acre resulted in complete striped maple kill, but at an unacceptibly high cost.

The problems of "fern track" and grass and sedge reinvasion were solved by the inclusion of the residual herbicide Oust, manufactured by Du Pont, in tank mix with Roundup. A rate and time experiment to evaluate the effectiveness of Roundup in tank mix with Oust and Surflan in minimizing reestablishment of grass and sedge on disturbed sites showed that 2 to 4 oz/acre of Oust or 2 to 4 qt/acre of Surflan reduced reinvasion by grass and sedge originating in the forest floor seed bank for 2 or 3 years, respectively (Horsley, 1990b). Oust now has an EPA registration for this use, Surflan does not.

The study also pointed out that on sites where grass and sedge seed banks were large, herbicide alone was inadequate for reducing reinvasion and that steps were required to reduce the amount of forest floor disturbance on these sites. Another rate and time experiment with Oust alone showed that 2 oz/acre provided nearly complete control of hayscented and New York fern when applied between early July and early October (Table 4) (Horsley 1988).

Table 4.--Percent control of hayscented and New York fern and short husk grass 2 years after treatment with 2, 4, or 8 oz/acre of Oust. Oust was applied at the beginning of each month. Untreated control plots with which treated plots were compared had 100 percent ground cover by the target species.[a]

Rate of	Month of Application						
Application	May	Jun	Jul	Aug	Sep	Oct	Nov
Hayscented and New York fern							
1	9 gh	52 def	98 ab	98 ab	98 ab	97 ab	27 fg
2	40 f	68 cde	99 a	98 ab	97 ab	98 ab	42 ef
3	75 ed	87 gh	100 a	99 a	99 a	99 a	69 cd
Short Husk Grass							
1	0 h	0 h	1 gh	1 gh	10 defg	2 fgh	6 efgh
2	0 h	0 h	10 defg	3 fgh	23 cde	18 def	10 defg
3	0 h	22 cde	50 ab	48 abcd	70 a	31 bcd	53 ab

[a]Month by rate of application means for each species followed by the same letter were not significantly different at $P \geq 0.05$ using the Bonferroni procedure.

Applications of Oust made earlier or later than these dates provided less control and results were rate-dependent. Oust did not provide adequate post emergent control of mature short husk grass plants, regardless of the rate (2 to 8 oz/acre) or time (early May to early November) of application (Table 4), nor did it have any effect on striped maple or beech (data not shown).

Efforts to increase the activity of Roundup on striped maple by the addition of adjuvants or other herbicides into the tank mix showed that none gave better results than Roundup alone (Table 5) (Horsley 1990a). Addition of adjuvants such as ammonium sulfate or EDTA to remove hard water ions that might bind the glyphosate molecule did not increase Roundup activity. Adjuvants that increase herbicide wetting and penetration of leaves, such as X-77 Spreader, Frigate Agricultural Adjuvant, and Sorbicide Herbicide Adjuvant, also did not increase control of striped maple above that obtained with Roundup alone. Inclusion of Sorbicide reduced herbicide effectiveness. Tank mixing Escort with Roundup gave the same results as Roundup alone, and a tank mix of 2,4-D amine with Roundup resulted in less control of striped maple than Roundup alone.

Table 5.--Mean percent kill of 5 - 20 foot tall striped maple stems by Roundup plus adjuvants and other herbicides 2 years after application.[a]

Herbicide Treatment	Percent Kill
Roundup (Control)[b]	81 a
Roundup + 1% EDTA	75 a
Roundup + 0.93% Ammonium Sulfate	71 a
Roundup + 1% Sorbicide Herbicide Adjuvant	51 b
Roundup + 0.5% Frigate Agricultural Adjuvant	86 a
Roundup + 0.5% X-77 Spreader	79 a
Roundup + 1 pt 2,4-D amine	65 b
Roundup + 1/4 oz Escort	70 a
Roundup + 1/2 oz Escort	70 a

[a]Percent kill means followed by the same letter were not significantly different at $P \geq 0.05$ using the Bonferroni procedure.
[b]Roundup was applied at the rate of 1 qt/acre in all treatments.

The most important factor controlling the proportion of striped maple stems killed by Roundup was distribution of the herbicide. The dilemma in ground spray operations with most air-blast spray equipment currently used in the Allegheny hardwood region is that the sprayer volute only allows the main blast of spray to be directed to vegetation in a limited vertical space. Aiming the volute horizontally results in good coverage of vegetation up to about 10 feet in height. Aiming the volute at an upward angle results in good coverage of vegetation from about 5 to 20 feet in height. Shorter vegetation is not well covered because much of the spray is intercepted by the larger vegetation.

Recently, Hammermill (International) Paper Co. purchased a Friend air-blast sprayer. The volute on the Friend has a vertical stack of nozzles that fills the air space with spray from the ground to a height of about 20 feet. Exceptionally good control of both short and tall vegetation in this space has been obtained in commercial spray operations using 1 qt/acre of Roundup in 25 gallons of water.

ECONOMIC CONSIDERATIONS

The decision to use herbicide in Allegheny hardwood stands is triggered by understory stocking (more than 30 percent) with ferns, grasses and sedges, striped maple, or beech (Marquis et al 1991). From a biological standpoint, Oust will effectively control ferns and will provide preemergent reduction of ground cover by grasses and sedges originating from the forest floor seed bank on disturbed areas. Oust has no activity on striped maple or beech. Roundup will control all of the interfering plants present in Allegheny hardwood stands but it has no residual soil activity, and will not provide preemergent control of grass and sedge originating in the forest floor seed bank after soil disturbance.

In commercial operations, fern tracks also are a problem when Roundup is used alone. In stands with ferns alone or with ferns and a grass and sedge seed bank, Oust provides the most effective control at the least cost. In stands with interfering striped maple and/or beech understories, Roundup is the herbicide of choice. Roundup should be applied at the rate of 1 qt/acre and Oust at the rate of 2/acre. Most stands have a combination of ferns, grasses and sedges, striped maple, and beech. In these, Roundup and Oust should be tank mixed with 0.5 percent of a non-ionic surfactant, such as X-77 or Frigate. When a combination of interfering plants is present, the decision to use one herbicide or a tank mix is an economic one based on the stand value at maturity lost by not adding the second herbicide to control interfering plants not controlled by the first herbicide. For example, let us assume that the cost of applying a single herbicide, including both the chemical and application costs, is $100/acre and that the cost of adding a second herbicide brings the total cost to $115/acre. Furthermore, let us assume that Allegheny hardwood stands are managed on an 80-year rotation, have values ranging between $1000 and $5000/acre at that age, and that real (no inflation, no after-inflation increase in timber prices) interest rates range from 3.5-5 percent. Under these conditions, the difference in discounted cost between using one and using two herbicides is $235/acre at 3.5 percent interest and $743/acre at 5 percent interest over 80 years. For stands valued at $5000/acre, $250/acre is lost for every 5 percent of stand area lost to plants not killed by the first herbicide; for stands valued at $1000/acre, $50 is lost for every 5 percent of the stand area lost to plants not killed by the first herbicide. A high-value stand ($5000/acre at maturity) needs less than 5 percent of the area covered by unkilled interfering plants to warrent use of the second herbicide if the interest rate is 3.5 percent, or 15 percent of the area covered by unkilled interfering plants to warrent use of the second herbicide if the interest rate is 5 percent. Comparable values for a low-value stand ($1000/acre at maturity) are 23 percent and 75 percent, respectively. Consideration of the wide range of conditions encountered in the Allegheny forest region suggests that the second herbicide should be added when more than about 15 percent of the regeneration sample plots have interfering plants that would not be killed by the first herbicide.

COMBINING HERBICIDE WITH CUTTING PROCEDURES

In most cases, herbicide is sprayed in the uncut stand, followed by a shelterwood seed cut. However, where large grass and sedge seed banks are present, herbicide alone was not effective in preventing revegetation of the site (Horsley 1990b). Reducing the amount of disturbance in addition to using herbicide is required in this situation. Modifying the herbicide and cutting sequence used to regenerate the stand is an effective way to minimize grass and sedge regeneration. Since shelterwood cutting is the primary source of disturbance that stimulates grass and sedge regeneration, reversing the herbicide and cutting sequence (shelterwood seed cut then herbicide) induces grass and sedge regeneration before the herbicide is applied. The herbicide removes these interfering plants. Since no more disturbance occurs in the stand, regeneration develops unhindered. When this procedure is used, steps must be taken to keep slash close to the ground so that it does not interfere with movement of the sprayer in the stand.

Another alternative is to delay any cutting in the stand until regeneration is established, then make the final removal cut. This procedure is useful in stands with less than 75 percent overstory stocking, since there is enough light to allow desirable seedling establishment. It also avoids soil disturbance which might allow interfering plants such as grasses and sedges to recapture the stand before regeneration becomes established. When the final removal cut is made, the well-established tree seedlings rapidly outgrow any interfering plants that have developed.

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TREE SHELTERS INCREASE HEIGHTS OF PLANTED NORTHERN RED OAKS

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Abstract: A clearcut in southern Michigan was planted to 2-0 northern red oak (*Quercus rubra* L.) seedlings in the spring of 1987. Four treatments included: control (clearcut harvest only), woody brush control, plastic tree seedling shelters 122 cm tall, and woody brush control plus tree seedling shelters. After three growing seasons, the seedlings planted in tree shelters were 53 cm taller than unsheltered seedlings. Sheltered seedlings grew 18 cm/year more than unsheltered seedlings over that same period. Over 65 per cent of sheltered seedlings were 122 cm tall or taller after three growing seasons compared to only 8.5 percent of unsheltered seedlings. The height growth of sheltered seedlings was related to the increased extension of the initial growth flush. The number of growth flushes was similar for sheltered and unsheltered seedlings. Tree shelters thus accelerated the growth of planted red oak into dominant and codominant positions on this clearcut site after three growing seasons. The increased elongation may result from seedlings modifying their growth habit, rather than an a result of increased stem dry weight.

INTRODUCTION

Planting oak as an alternative to natural regeneration has often resulted in failure caused by the slow growth of planted seedlings relative to the rapid growth of competing vegetation (Johnson et al. 1986). However, release of planted oak seedlings from competing vegetation alone does not guarantee success (Hilt 1977). Johnson et al. (1986) recommended that tree planters control undesirable woody vegetation before harvest, establish a medium density shelterwood, use large-diameter oak seedlings, and remove the overstory after three years. Tuley (1983), working in Great Britain, used individual tree shelters similar to those shown in Figure 1 to establish planted oak seedlings. Tree shelters protect planted hardwood seedlings from animal damage and improve seedling survival and height growth. One measure of their effectiveness is reflected in the estimated number of tree shelters used in Great Britain, which increased from 80 in 1979 to over 6 million in 1986 (Potter 1987).

This study investigated oak planting with tree shelters as a method of establishing oak in a clearcut. Lantagne et al. (1990) reported increased growth of northern red oak in tree shelters in a southern Michigan clearcut after two years. This paper presents 3-year results of that study.

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METHODS

The study was established in an oak-hickory forest at the W.K. Kellogg Experimental Forest in southern Michigan. Soils were predominantly sandy loam (Alfisols) developed from stony glacial drift on a rolling, well drained site. Average red oak site index (base age 50) for the study area was 66. The study area underwent a shelterwood seed cut in 1954 and a removal cut in 1964 as part of a previous oak regeneration study (Rudolph and Lemmien 1976). Before the study was established, all stems > 5 cm dbh were removed in a whole-tree clearcut harvest in the fall of 1986. All remaining stems > 2.54 cm dbh were removed by hand.

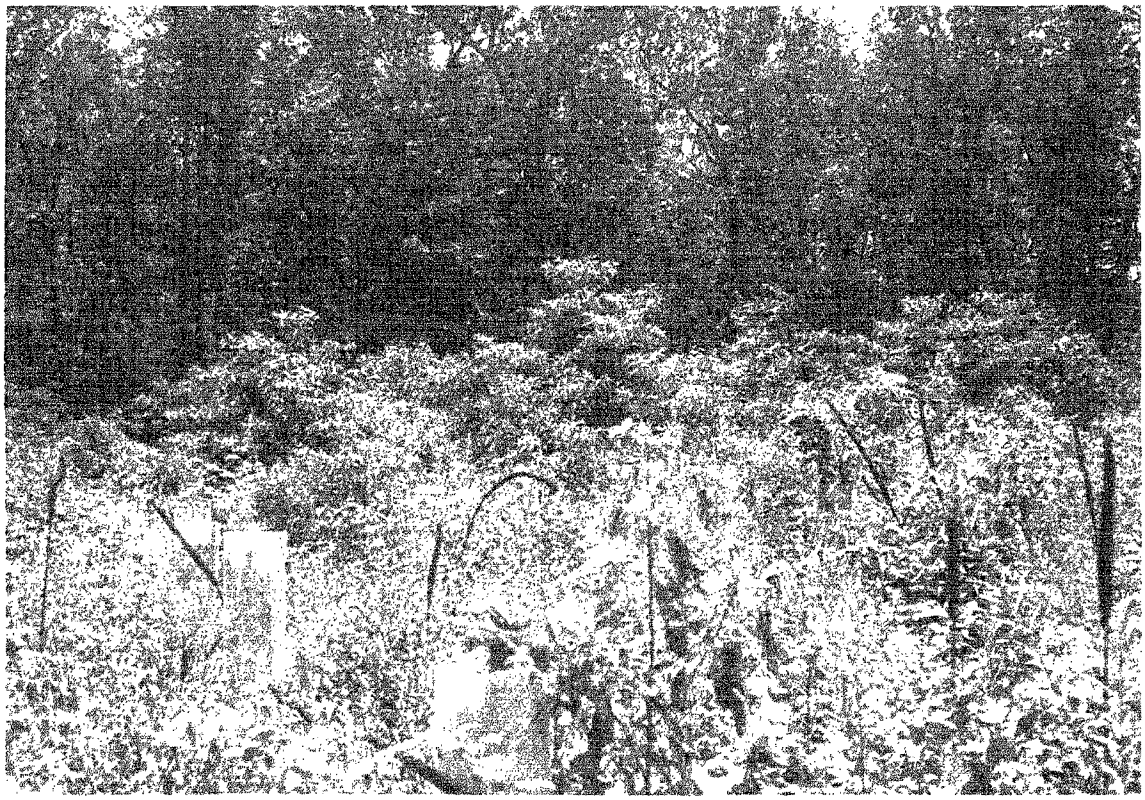

Figure 1. Tops of 1.2-m-tall tree shelters in a woody brush control plot after two growing seasons.

A 2 X 2 factorial combination of treatments was replicated on four 0.5 hectare blocks in a split-plot design. A 0.1-hectare buffer zone was established around each block. Each 0.4-hectare block was split in half to accommodate brush control treatments (main plots). Each main plot was then split in half to accommodate tree shelter treatments (split plots). The four treatments were: control (no woody brush control, no shelters); woody brush control only;

shelters only, and woody brush control and shelters. All treatments were randomly applied within replications.

Woody brush control occurred in five steps, two before harvest and three after harvest. The first steps were a prescribed burn in the spring of 1986 and a basal application of triclopyr and oil to non-oak species in the summer of 1986. The final three steps were post-harvest basal applications of triclopyr and oil to non-oak species during the summers of 1987, 1988 and 1989.

Plastic shelters were constructed from 51 X 122 X 0.63 cm sheets of corrugated polyethylene plastic. Each sheet cost about $1.50. Individual sheets were bent and stapled to 2.5- X 2.5-cm stakes driven into the ground next to planted oak seedlings. Shelters were placed as close as possible to the soil surface but were not sealed at the soil surface or along the stake used for support. Stakes were also driven into the ground next to all unsheltered seedlings.

Northern red oak acorns collected from the study site in the fall of 1984 were immersed in water. "Sinkers" were collected and 86 per square meter were sown in a prepared nursery bed. Following the first growth flush in June 1986, seedlings were undercut at 20 cm to encourage development of a fibrous root system. The 2-0 northern red oak seedlings were lifted in mid-April 1987, sorted to a minimum 1-cm root collar diameter, root pruned to 20 cm, wrapped and stored at 1° C until planting. Seedlings were planted over a two day period in late April 1987 with dibble bars at a 3.4- X 3.4-meter spacing for a total of 90 oak seedlings per treatment. After planting, seedlings were clipped 18 cm above the ground-line. Tree shelters were then installed. All work was completed by May 1, 1987.

Six 4 m^2 permanent regeneration survey plots were randomly placed in the areas without brush control. Seedlings and sprouts of all naturally occurring woody species in the survey plots were counted at the end of the 1988 growing season. Heights of all planted northern red oak seedlings were measured in the fall of 1989. Number and length of flushes were measured on 40 trees in three of the four brush control plots in the spring of 1990. Twenty trees above 125 cm were randomly selected from the shelter plots and the 20 tallest trees from brush-control-only plots.

Analysis of variance and Duncan's new multiple range test were used to test for significant differences among treatment means. Survival percentages were transformed with the arcsine procedure and growth flush data with the square root procedure (Little and Hills 1978). Chi-square analysis was used to test for differences in height class distribution between the sheltered and unsheltered seedlings.

RESULTS

Total vegetative cover averaged 85 to 90 percent across all treatment plots during the first three growing seasons. The predominant species included *Rubus* spp., goldenrod (*Solidago nemoralis* Ait.), wild grape (*Vitis* spp.), aster (*Aster pilosus* Willd.), pokeweed (*Phytolacca*

americana L.), daisy fleabane (*Erigeron strigosus* Muhl.) and bull thistle (*Cirsium vulgare* (Savi) Tenore). Two years after clearcut harvest, there was an average of 1,611 natural oak seedlings per hectare. Non-oak reproduction averaged over 12,429 stems per hectare.

Brush control had no significant affect on total height of planted red oak ($P = 0.25$), but heights of sheltered and unsheltered trees differed significantly ($P < 0.0001$)(Table 1). Seedling survival and height for sheltered seedlings were significantly greater than unsheltered seedlings (Table 2). The height increase of sheltered trees was 1.7 times greater than that of unsheltered trees.

Table 1.--Analysis of variance for total tree height for planted trees.

Factors	DF	Mean Square	F Ratio
Main Plots			
Replication (Rep)	3	242.74	
Brush Control (BC)	1	23.01	0.67
Rep X BC (Error a)	3	102.98	
Split Plots			
Shelters (S)	1	11313.96	199.15***
BC X S	1	37.11	0.45
Error	6	56.81	

*** Significant ($p < 0.0001$)

Table 2.--Effect of shelters and brush control on survival and height of planted northern red oak seedlings after the third growing season.[1]

Treatments	Survival	Total Height	Height Increase[2]
	--(%)--	---(cm)---	---(cm)---
Main Plots			
Brush Control	94a	105(1.9)a	29(1.1)a
No Brush Control	95a	102(1.8)a	25(1.2)a
Split Plots			
Shelter	98a	130(1.7)a	34(1.2)a
No Shelter	90b	77(1.4)b	20(1.0)b

[1]Means (standard errors) within the columns followed by the same letter are not significantly different ($p < 0.05$) using Duncan's New Multiple Range Test.
[2]Height increase was determined by subtracting 1988 total height from 1989 total height for each individual seedling measured.

Figure 2 illustrates the effect of shelters on seedling height class distribution. More sheltered than unsheltered seedlings were in the larger height size classes. A Chi-square analysis

indicated that the distributions were significantly different ($P < 0.0001$). After three growing seasons, over 65 percent of the sheltered seedlings were above shelter height (122 cm), compared to only 8.5 percent of unsheltered seedlings.

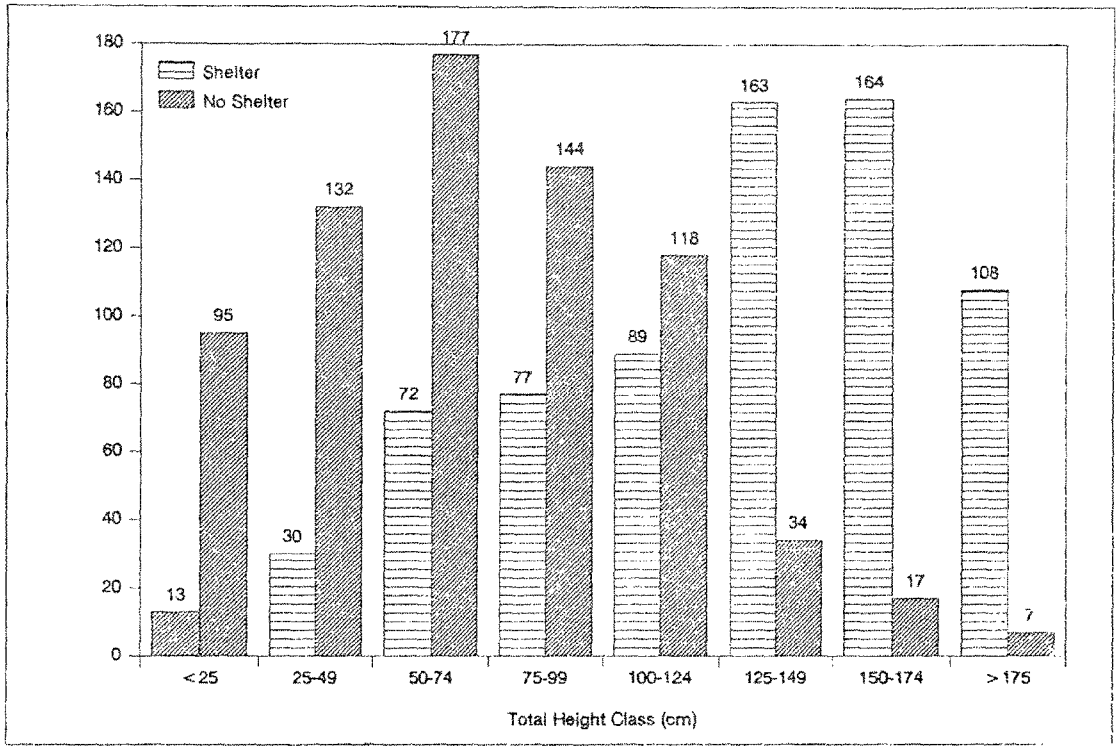

Figure 2. Height distributions of sheltered and unsheltered northern red oak seedlings after the third growing season. (Distributions of the two classes of seedlings differ significantly based on Chi-square ($X^2 = 487$, $p < 0.0001$).

Analysis of variance indicated that shelters increased the number of growth flushes in 1987 ($P = 0.064$) and 1988 ($P = 0.088$), but not in 1989 ($P = 0.423$). The average length of the initial growth flush was also affected by shelters in 1988 ($P = 0.002$) and 1989 ($P = 0.016$). These initial flushes averaged 13 cmgreater in 1988 and 12 cm greater in 1989 than unsheltered trees (Table 3). The average length of secondary growth flushes did not differ significantly between sheltered and unsheltered trees.

DISCUSSION

Tree shelters can improve both survival and height growth of oak seedlings (Tuley 1983, Lantagne et al. 1990). This was reaffirmed by the third year data,which showed a greater increase in total height and growth for sheltered seedlings than for unsheltered controls

Table 3.--Effect of shelters and brush control on the number and length of growth flushes of planted northern red oak seedlings for the first three growing seasons.

Treatments	Number of Flushes[1]			Length of First Flush[2]		
	1987	1988	1989	1987	1988	1989
	(cm)					
Shelters/Brush control	33a	32a	37a	23a	40a	39a
Brush control only	27b	28b	36a	19a	27b	27b

[1]Means were derived by counting the total number of flushes for twenty trees for each treatment in each of three replications. Means within the columns followed by the same letter are not significantly different ($p < 0.1$) using Duncan's New Multiple Range Test.
[2]Means within the columns followed by the same letter are not significantly different ($p < 0.05$) using Duncan's New Multiple Range Test.

(Figure 3). Sheltered red oak seedlings averaged 53 cm taller than unsheltered seedlings after three growing seasons. Average height increases over the past three growing seasons show that sheltered seedlings grew 18 cm/year more than unsheltered seedlings (Figure 3). This additional growth has placed over 65 percent of the sheltered seedlings in a dominant crown position in areas with woody brush suppression and the same percentage in an intermediate or codominant crown position in areas with unsuppressed woody vegetation. Only 8.5 percent of unsheltered seedlings reached an equivalent height of at least 122 cm after three growing seasons and most were in a subordinate canopy position.

The increased growth of sheltered seedlings over unsheltered seedlings has been attributed to several possible factors: (1) a microenvironment that promotes multiple flushes, (2) a reallocation of growth from roots, stem caliper and branches to the terminal leader and (3) physical protection from breakage and animal browse (Lantagne et al. 1990). The data showed that the increased growth of the initial terminal flush was more important to total height growthof the seedling than an increased number of flushes. During the second and third growing seasons, sheltered trees averaged 12.5 cm/year more elongation of their first growth flush than unsheltered trees.

Sheltered trees exhibit three physical stem characteristics which unsheltered trees do not exhibit: longer stems, few, if any branches and limited caliper growth. These characteristics indicate that increased height growth of sheltered seedlings may not be synonymous with increased stem dry weight. Rather, sheltered seedlings may simply be modifying their height growth at the expense of structural stability and branch formation. As a consequence of less stem caliper, trees must be supported for two years after exiting the shelters. The affect of shelters on root growth has not been studied. However, Johnson (1979) working with northern red oaks in a root regeneration study found no reduction in the rate of root growth during periods of shoot elongation. Therefore, increased shoot elongation of sheltered seedlings may not be negatively impacting root system establishment.

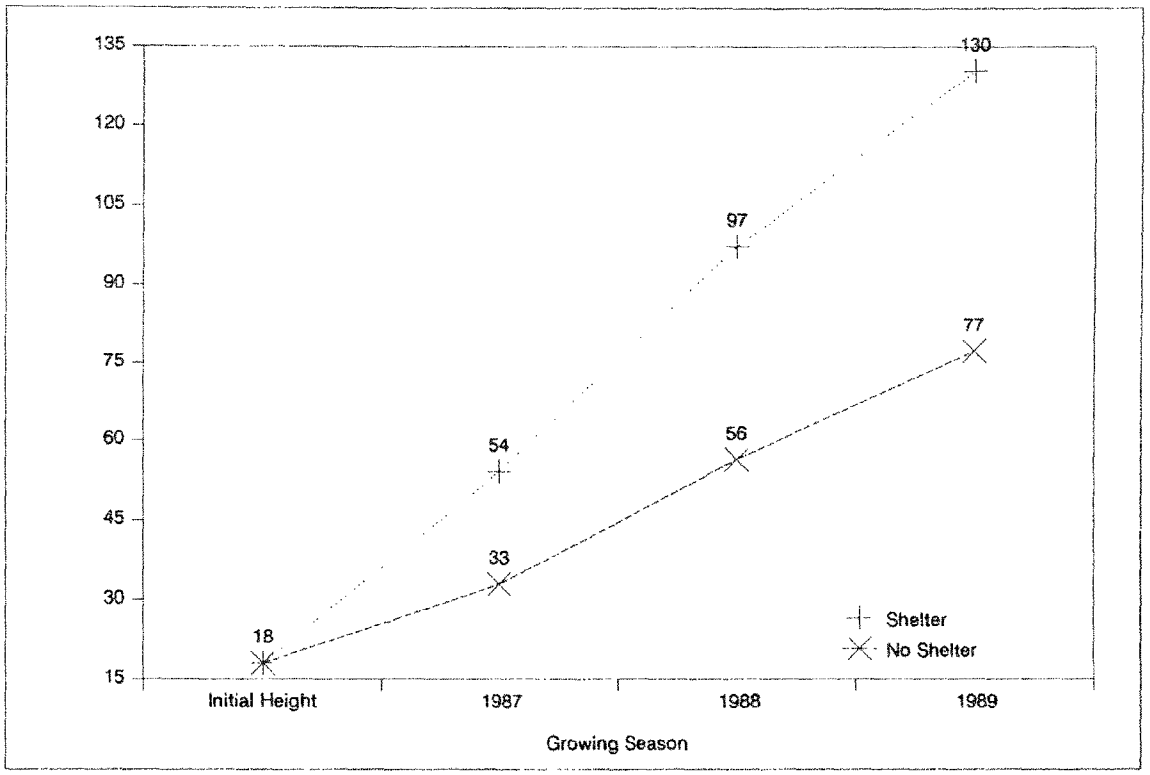

Figure 3. Means Heights of surviving planted northern red oak seedlings. (All seedlings were top pruned at 18 cm above the groundline immediately following planting. Sheltered seedlings were significantly taller at the end of each growing season.)

SUMMARY

Many sheltered trees grew into dominant and codominant crown positions, where÷áas few other planted seedlings or natural oak reproduction did. The mechanism for increased growth is not a result of increased number of growth flushes, but an increase in the amount of elongation of the initial growth flush. This increased elongation may result from seedlings modifying their growth habit, rather than an a result of increased stem dry weight. The cost and environmental issues associated with the use of plastic tree shelters for oak regeneration have to be evaluated and discussed as additional growth data is collected.

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MAMMAL CACHING OF OAK ACORNS IN A RED PINE AND A MIXED-OAK STAND

Eugene R. Thorn and Walter M. Tzilkowski[1]

Abstract: Small mammal caching of oak (*Quercus* spp.) acorns in adjacent red pine (*Pinus resinosa*) and mixed-oak stands was investigated at The Penn State Experimental Forest, Huntingdon Co., Pennsylvania. Gray squirrels (*Sciurus carolinensis*) and mice (*Peromyscus* spp.) were the most common acorn-caching species. Acorn production was estimated at 104,200 red oak group acorns/ha and 80,250 white oak group acorns/ha. Acorn caches in the red pine stand were estimated at 900 red oak acorns/ha and 650 white oak acorns/ha. In contrast, in the mixed-oak stand 45,350 red oak acorns/ha and 24,150 white oak acorns/ha were cached. Gray squirrels cached 38% of the acorns produced; 98% of the acorns were cached in the mixed-oak stand. Gray squirrels cached 38% of the acorns produced; 98% of the acorns were cached in the mixed-oak stand.

INTRODUCTION

In the northeastern United States, foresters and wildlife managers consider oaks (*Quercus* spp.) to be the most important tree species (Martin et al. 1951, Shaw 1971). Cahalane (1942), Janzen (1971) and Potter (1978) reported dispersal and planting of acorns by mammals and birds are beneficial for oak regeneration. However, the role of small mammals in oak regeneration is unclear; Marquis et al. (1976) and Gottschalk (1983) reported mammal predation of acorns and small seedlings has a serious negative effect on oak regeneration and contributes to regeneration failure.

Size and frequency of acorn crops vary yearly and are unpredictable (Sharp and Chisman 1961). Size and viability of acorns also differ with geographic location (Marquis et al. 1976). Acorn crops vary from 0 to 250,000+ acorns/acre (Olson and Boyce 1971). Acorns ripen and are dispersed from late August to early December. Acorns of the white oak group mature in one year, whereas acorns of the red oak group require two years (Olson 1974). In autumn white oak acorns germinate immediately upon dropping and the radicle may reach a depth of 8 inches before onset of cold weather (Watt 1979). Red oak acorns do not germinate until spring, as they require 32-41°F and moist stratification for at least 30-60 days (McQuilken

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1983). Byrne (1961) stated when oak is well-established, the next stand will be mostly of seed origin.

Northeastern mammals that cache acorns are the gray squirrel, fox squirrel (*Sciurus niger*), red squirrel (*Tamiasciurus hudsonicus*), southern flying squirrel (*Glaucomys volans*), northern flying squirrel (*Glaucomys sabrinus*), deer mouse (*Peromyscus maniculatus*), white-footed mouse (*Peromyscus leucopus*), and eastern chipmunk (*Tamias striatus*) (Martin et al. 1951). Other small mammals such as voles (*Microtus* spp., *Clethrionomys gapperi*), jumping mice (*Zapus hudsonius*, *Napaeozapus insignis*), and the eastern woodrat (*Neotoma floridana*) may be of minor importance.

Two different strategies of seed-caching exist, larderhoarding and scatterhoarding (Stapanian and Smith 1978). Larderhoarding is the process of gathering seeds into one, or at most a few, large, concentrated, defended caches. Scatterhoarding is the process in which seeds are stored in numerous, widely scattered, small (one to a few seeds) caches. Scatterhoarders, such as the gray squirrel, have potential to benefit oak regeneration. Burying an acorn increases survival and may create ideal conditions for germination (Griffin 1971, Janzen 1971, Barnett 1977). Scattering caches ensures appropriate conditions for survival of some acorns and a good distribution of seedlings (Cahalane 1942). Therefore, scatterhoarders may be of greater benefit to successful oak regeneration than larderhoarders.

Small mammals may be the prime distributors of acorns regardless of stand type. Gray squirrels may be the prime mammalian distributors of acorns in conifer stands. Our objective was to compare acorn dispersal by small mammals between oak and red pine stands. Funding was provided by the School of Forest Resources, The Pennsylvania State University. We thank T. W. Bowersox, G. M. Kelly, R. D. Shipman and L. M. Woebkenberg for advice.

METHODS

Established within a 60-yr-old, 12-ha mixed oak stand located in the Penn State Experimental Forest, Huntingdon Co., Pennsylvania, the study area was a 45-year-old, 1-ha red pine plantation with 3 x 3 m spacing. A 1-ha mixed oak site that shared a 100-m border with the red pine plantation was delineated.

The census and assessment lines technique developed by O'Farrel et al. (1977) provided small mammal abundance estimates. Sherman traps baited with rodent chow were used for live-trapping. Flyger's (1959) time-area count method was used to estimate chipmunk and squirrel abundance.

Acorn production was estimated by the number of caps, and acorn availability was estimated by the number of acorns present on 40 4-m2 plots in the 1-ha oak site. All acorns and acorn caps were counted, by red oak group or white oak group, but not removed. Counts were conducted bi-weekly from the last week of September through November. Each count consisted of 40 plots that were randomly selected each sample period.

Sound acorns (1,000 white oak (*Quercus alba*) and 1,000 red oak (*Quercus rubra* L.)) were selected to estimate acorn dispersal. A location was randomly selected on the oak-red pine border. On 16 September, blue paint-marked acorns, 500 of each species, were placed in two adjacent piles, in a covered bait station, which was used to discourage birds and mammals larger than squirrels from removing the acorns. The station was monitored daily until all acorns were removed. This procedure was repeated on 12 November with green paint-marked acorns. Yellow fluorescent pigment was used for 3 days to monitor species of mammals removing acorns. For 4 2-week intervals, stands were searched for caches. For each 2-week interval, 50 points were randomly selected in each stand. A 4-m2 area was systematically searched at each point by raking the litter and soil to a depth of approximately 12 cm with a procedure similar to Montgomery et al. (1975). Marked and unmarked acorns, by species and distance from the red pine-oak border, were recorded. Jackson's Positive Method for analyzing capture-recapture data (Begon 1979) was used to determine density of cached acorns.

RESULTS AND DISCUSSION

Mean small mammal abundance in the oak stand, August through November, was 2.02, 0.0, 0.63 and 3.95 (August only) individuals/ha for gray squirrels, red squirrels, chipmunks, and *Peromyscus* spp., respectively. In the red pine stand, gray squirrel, red squirrel, chipmunk and *Peromyscus* mean abundance estimates were 0.31, 0.07, 0.16 and 7.89 (August only) individuals/ha, respectively. Gray squirrel abundance was low to average as compared to estimates of Nixon et al. (1968). Captures of *Peromyscus* in the oak and pine stands were 77 and 66, respectively. M'Closkey (1980) stated capture frequency of live-trapped rodents provides a good estimate of foraging effort. Red oak production peaked at 66,050 acorns/ha (SD=39,425), whereas peak white oak production was 35,325 (SD=33,225) (Table 1).

All acorns marked in September and November were removed from the bait station in 2 and 6 days, respectively. There was no difference (P=0.11) in the disappearance rate between red and white oak acorns. Marked acorn recovery rate was 0.053 and 0.030 in the oak and red pine stand, respectively. Maximum number of acorns cached in the oak stand was 45,350 (SD=27,650) and 24,150 (SD=22,850) for red and white oak, respectively (Table 2). In the red pine stand, maximum number of acorns cached was 900 (SD=1,950) and 650 (SD=1,225) for red and white oak, respectively (Table 2). Gray squirrels, as revealed by tracks of yellow fluorescent pigment, removed all acorns from the bait stations.

Caches containing marked acorns were observed only within 20 m of the oak-pine border in the pine stand; marked caches were within 50 m in oak stand, but were concentrated (85%) within 20 m of the border. The farthest unmarked cache was within 50 m in the pine stand; caches were distributed throughout the oak stand.

Table 1.--Red and white oak acorns/ha and caps/ha on the ground at bi-weekly intervals (n=40 4-m2 plots per interval).

	Red Oak				White Oak			
	Acorns		Caps		Acorns		Caps	
Week	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
21 Sep.	39,550	28,850	8,550	6,250	25,750	27,325	5,575	6,800
5 Oct.	66,050	39,425	46,800	25,650	35,325	33,225	30,375	25,175
19 Oct.	18,300	16,225	72,825	42,950	950	1,750	55,125	48,900
2 Nov.	2,200	3,300	82,200	51,125	450	1,175	61,625	48,450
16 Nov.	500	1,150	104,200	51,400	325	825	80,250	58,000

Table 2.--Red and white acorns cached/ha in the oak and red pine stands per sample period (n = 50 4-m2 plots).

Elasped	Red Pine				Oak			
time	Red Oak		White Oak		Red Oak		White Oak	
(weeks)	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD	$\bar{X}$	SD
3	450	1,200	300	825	8,550	7,700	1,350	1,700
5	500	1,125	450	1,075	37,100	22,750	18,550	27,700
7	700	1,425	650	1,225	43,650	28,450	24,150	22,850
9	900	1,950	500	1,125	45,350	27,650	15,400	16,375

Comparison of total acorn production (caps) (184,450/ha) to total peak caches (69,500/ha) indicated 37.7% of total acorn production was reflected in caches. Activity of small mammals in the oak stand resulted in 70,000 well-distributed caches/ha. Gray squirrels were the important species in acorn dispersal. Their style of caching, a single acorn buried approximately 3 cm deep, may be beneficial for acorn storage and germination. Core (1971) reported gray squirrels are so important in dispersal that a diminishing squirrel population could have adverse effects on acorn distribution. Gray squirrels used many of the 70,000 cached acorns/ha, however, nondormancy of white oak may have added seedlings that may not have become established otherwise. Chew (1978:175) stated, "The number of seeds that are consumed can easily be overly impressive . . . If there has been a long evolutionary relationship of plant and predator, the loss of 99% of the plant's seed crop to the granivore is not necessarily of any consequence to the plant's future destiny and productivity. Measurement of this loss per se is not proof of an effect of the seed predator on the plant."

Gray squirrels cached 38% of the acrons produced; the mixed-oak stands was preferred for caching. This information could be used as a basis for intensely managing squirrel

populations in areas where enhancement of oak reproduction is a priority. Some options would be leaving den trees when cutting, altering rotation length to favor squirrels, and manipulating the opening date of squirrel hunting season. Perhaps squirrel hunting season should open after the majority of acorns has fallen and been cached, to enhance oak regeneration potential.

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ROLE OF SPROUTS IN REGENERATION OF A WHOLE-TREE CLEARCUT IN CENTRAL HARDWOODS OF CONNECTICUT

C. Wayne Martin and Louise M. Tritton[1]

Abstract: Stump sprouts were the single most important type of regeneration in a central hardwood forest in Connecticut during the first 5 years after whole-tree clearcutting. Herbs, shrubs, tree seedlings, and stump sprouts were inventoried using stratified permanent plots on a 6-ha watershed during the first, third, and fifth years after harvest. The first year after cutting 1,540 kg ha^{-1} of living biomass, including herbs, shrubs, and tree seedlings and sprouts, accumulated on the watershed. Of that, 54% was in tree seedlings and sprouts from stumps < 10 cm, and 13% in sprouts from stumps ≥ 10 cm. Oaks produced the most sprout biomass from large stumps, followed by maples and chestnut. By the fifth year, 17,990 kg ha^{-1} of living biomass had accumulated with 56% in tree seedlings and sprouts from small stumps, and 15% in sprouts from large stumps. Approximately 28% of the initial number of sprouts from large stumps had survived through year 5, and sprout biomass of oaks was still greater than that of maples and chestnut. Our study indicates that sprouts are highly active in the initial accumulation of biomass and nutrients after harvest.

INTRODUCTION

Rapid revegetation of sites following clearcutting can reduce soil erosion, conserve nutrients, and promote the development of a new forest. Stump sprouts are one means for rapidly establishing many hardwood species (Smith 1986). Their prevalence has been documented after clearcutting in Tennessee (Mann 1984), North Carolina (Boring et al. 1981), West Virginia (Wendel 1975), Georgia (Miller and Phillips 1984), and Michigan (Mroz et al. 1984). Factors that influence the potential contribution of sprouts to development of a commercially desirable forest include rate of growth and quality of sprouts (Wendel 1975); species, diameter, and height of parent stumps (Miller and Phillips 1984, Solomon and Blum 1967); mortality and long-term survival of sprouts (Johnson 1977, McIntyre 1936); and susceptibility of sprouts to decay (Jones and Raynal 1987, Roth and Hepting 1943). A better understanding of the role of sprouts in revegetation of hardwood sites is needed to guide logging practices and forest management.

As part of long-term research on the effects of whole-tree harvesting on a Connecticut hardwood forest ecosystem (Hornbeck et al. 1990, Tritton et al. 1987), we are following the

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species composition, biomass, and nutrient content of revegetation on the site (Martin et al. 1987). This paper summarizes data from the first, third, and fifth years after cutting in order to evaluate: 1) Whether stump sprouts are a viable means for regenerating a commercially desirable Connecticut hardwood forest, 2) The importance of stump sprouts in conserving nutrients on the site immediately after cutting, thereby acting to maintain site fertility; and 3) How management practices influence the importance of stump sprouts.

THE STUDY SITE

The study site is a 6 ha forested watershed located on the Cockaponset State Forest in Chester, CT. The soils of the upper slopes generally are of the Hollis-Chatfield-Rock association, loamy, mixed, mesic Lithic Dystrochrepts, which consist of shallow, somewhat excessively drained soils with occasional outcrops of exposed bedrock. The bedrock is of the upper Middletown formation, an assemblage of gneisses and schists with inclusions of sillimanite quartz and pegmatite. The soils of the lower slopes are deep, well-drained, coarse, loamy, mixed, mesic Typic Dystrochrepts of the Chatfield-Canton association. The soils of the valley floor are poorly drained, acidic, coarse-loamy, mixed, mesic Aeric Haplaquepts of the Leicester series (USDA Soil Conserv. Serv. 1981).

Prior to whole-tree clearcutting, the watershed supported an 80- to 110-year-old mixed age oak-birch-maple forest typical of Connecticut and southern New England (Martin et al. 1987, Stephens and Waggoner 1980). The basal area of the trees and shrubs larger than 2 cm dbh was 23 m^2 ha^{-1}, with a density of 1,163 stems ha^{-1}. The aboveground living biomass was 168 metric tons ha^{-1}, with 303 kg ha^{-1} of total nitrogen, 589 kg ha^{-1} of calcium, and 180 kg ha^{-1} of potassium (Hornbeck et al. 1990, Tritton et al. 1982).

In the winter of 1981-82, the watershed was whole-tree clearcut. All living and standing dead trees greater than 5 cm dbh were cut. Trees less than 30 cm stump diameter were cut with a rubber-tired feller buncher; larger trees were cut by chain saw. Whole trees of all diameters were skidded to the landing outside the watershed by rubber-tired, articulated, skidders. Sawlogs were separated and the remaining stems, tops, and branches were chipped on site. Harvesting was completed in March 1982, and was confined to the dormant season.

METHODS

Sample plots were selected randomly from a 25 X 25-m grid established on the watershed. A stratified, nested design was chosen for sampling of herbaceous and woody plants, including seedlings and sprouts. Seedlings of trees, shrubs, and herbs < 1.3 m tall were inventoried on fifty 1 X 1-m plots by 0.5-m height classes. Seedlings and sprouts taller than 1.3 m from stumps < 10 cm in diameter were measured on sixteen 1 X 25-m transects by 1-cm dbh classes. Sprouts of all heights from stumps ≥ 10 cm in diameter were inventoried on four 25 X 25-m plots. One plot was placed at random on the grid within each of four strata: dry ridge

top, midslope westerly aspect, midslope easterly aspect, and poorly drained Leicester soils. The four plots were equal in area to 4% of the watershed.

Inventories of all three types of plots were made in August of 1982, the first growing season, in August of 1984, the third growing season, and in August and November of 1986, the fifth growing season. By mid-August, woody plants had not yet completed the growing season, though many herbs were senescent. Because of the density of the stump sprout clusters at year 5, the 25 X 25-m plots of stumps ≥ 10 cm diameter were inventoried in November after leaf fall.

Biomass of tree seedlings, shrubs, and herbs was estimated by harvesting twenty-one 1 X 1-m plots selected using a ranked-set sampling technique (McIntyre 1952). Biomass of sprouts was estimated by harvesting three stems of each 0.5-m height class for sprouts < 1.3 m tall, and for each 1-cm diameter class for the larger sprouts, by species. The mean oven-dry weight of the three harvested stems for each size and species was then multiplied by the estimated number of stems of that size and species per hectare. Estimates of all size classes were then summed to estimate total biomass per hectare.

Nutrient analyses were performed on each biomass sample collected from the twenty-one 1 X 1-m plots and from each sprout and seedling. Nutrient data were reported as a percent per unit of biomass. The average of the three samples for each species and size class was multiplied by the estimated biomass for that species and size and summed. All samples were dried to a constant weight at 65°C, weighed, and chemically analyzed. The tissues were digested in a Technicon BD-20[2] block digestor. Total Kjeldahl nitrogen was measured on the digested samples with colorimetric analyses performed on the Technicon Autoanalyzer. Cation concentrations of the digested samples were determined by flame atomic absorption spectroscopy (Franson 1975).

RESULTS

Whole-tree clearcutting removed 91% of the aboveground biomass, including some sound dead wood. In the process, all of the trees were cut, and nearly all advance regeneration and shrubs were crushed by the equipment. The vegetative cover quickly reestablished after this treatment. By the end of the first growing season, there were nearly 800,000 living plants ha^{-1} on the area, of which 60% were herbs and shrubs, and 40% were tree seedlings and sprouts (Fig. 1). By the end of the fifth growing season, there were more than one million plants ha^{-1}, of which 90% were herbs and shrubs and only 10% were tree seedlings and sprouts. There was a systematic increase in the total number of stems of all vegetation ha^{-1} over the 5 years, but a consistent decrease in the numbers of stems of tree species. *Betula* represented nearly

[2]The use of trade, firm, or corporation names does not constitute an official endorsement or approval by the U.S. Department of Agriculture or the Forest Service of any product or service to the exclusion of others that might be suitable.

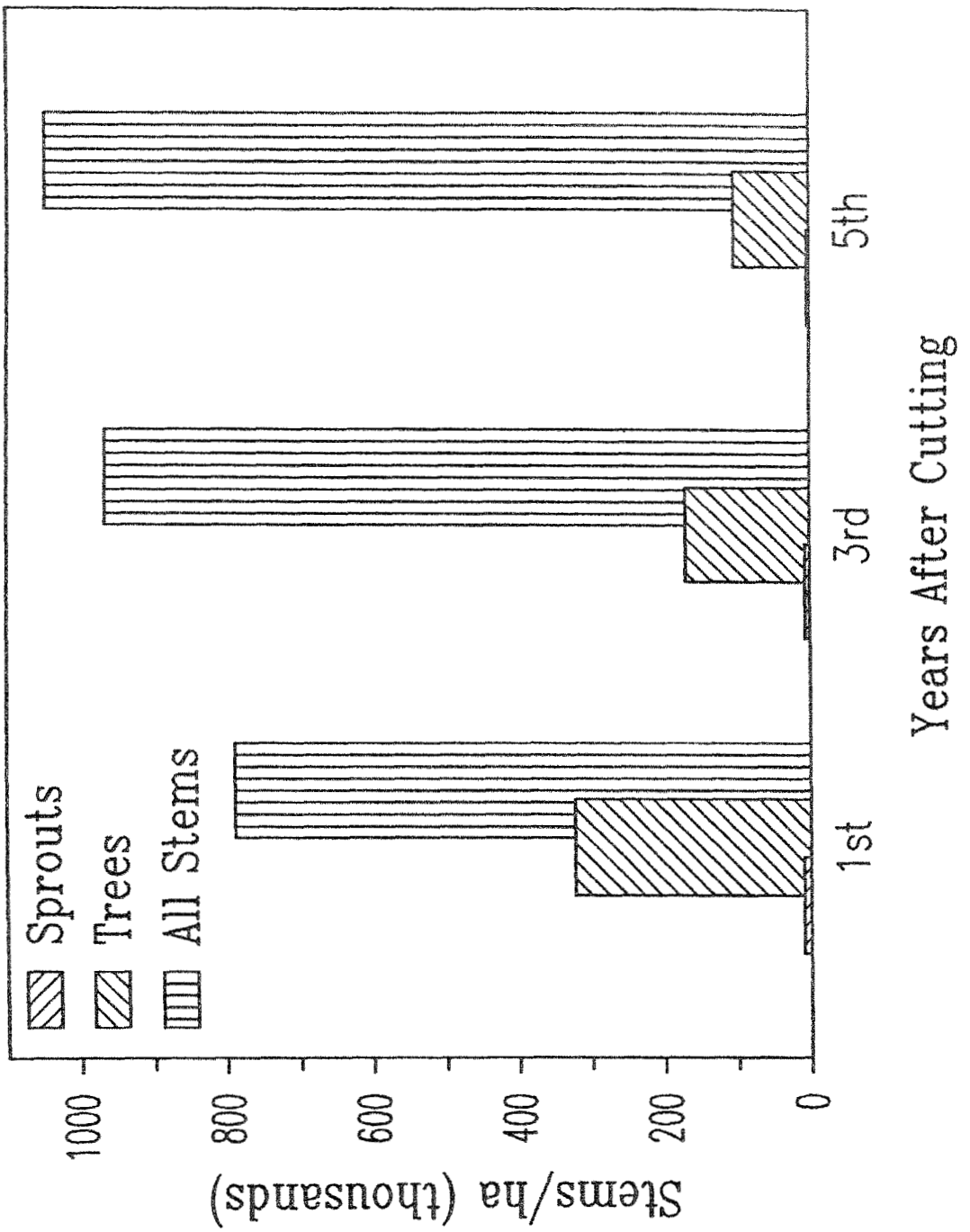

Figure 1. Stems per hectare, in thousands, by year after cutting. The tallest bars include herbs, shrubs, tree seedlings, and sprouts; the bars labeled trees include seedlings and sprouts.

75% of the tree seedlings and sprouts the first year after cutting, and nearly 60% at year 5. *Betula*, *Acer*, *Quercus*, and *Castanea* represented 90% of all the stems of tree seedlings and sprouts on the site the first year after cutting, and 95% in the fifth year.

By the end of the first growing season, plants had produced more than 1,500 kg ha^{-1} of aboveground living biomass. Tree seedlings and sprouts accounted for about 65% of this biomass with herbs and shrubs accounting for the remainder. By the end of the fifth growing season, there were nearly 18,000 kg ha^{-1} of aboveground living biomass on the watershed with tree seedlings and sprouts accounting for more than 70% (Fig. 2). While the number of stems of tree species continued to decline, tree species clearly dominated the site in terms of biomass by year 5. *Acer* accumulated biomass more rapidly than any other genus throughout the 5 years. By year 5, *Acer* accounted for nearly one-third of the biomass of tree species on the site, followed by *Quercus*, *Betula*, and *Castanea*. These four genera comprised nearly 90% of the biomass of tree species at year 5.

By the end of the first growing season, nearly 30 kg ha^{-1} of nitrogen was stored in aboveground living biomass; this increased to more than 130 kg ha^{-1} by the end of the fifth growing season. Trees, including both seedlings and sprouts, accounted for more than 60% of this nitrogen accumulation the first year, and more than 70% by the fifth year (Fig. 3). Aboveground living biomass accumulated nearly 10 kg ha^{-1} of calcium and nearly 20 kg ha^{-1} of potassium the first growing season. Calcium and potassium in the biomass had increased to nearly 80 kg ha^{-1} for both elements by the fifth year, with tree seedlings and sprouts accounting for more than 60% in both cases.

Sprouts from stumps ≥ 10 cm in diameter at time of cutting were a major component of the regeneration on the clearcut watershed. They represented only about 3% of the total numbers of stems of tree species during the first 5 years after cutting (Fig. 1). But they represented 20 to 25% of the biomass of tree species throughout that period (Fig. 2). And by the fifth year after cutting, about 20% of the nitrogen, calcium, and potassium sequestered by tree species, including both seedlings and sprouts, was stored in sprouts from stumps ≥ 10 cm in diameter. These sprouts had accumulated about 13% of the nitrogen, calcium, and potassium stored in all aboveground vegetation on the watershed (Fig. 3).

During the first year after cutting, more than 55% of the sprouts on the watershed were *Quercus*, followed by *Acer*, *Betula*, and *Castanea*. By the fifth year, more than 40% of the sprouts were *Acer*, followed by *Quercus*, *Betula*, and *Castanea* (Fig. 4). Throughout the 5 years, *Quercus* sprouts accumulated the most biomass followed by *Acer* and *Castanea*, with *Betula* a distant fourth (Fig. 5).

At the time of cutting, there were an average of 424 live trees per hectare with stump diameters ≥ 10 cm. By the end of the first growing season, an average of 252 stumps ha^{-1} had sprouted to produce about 9,400 sprouts, an average of 37 live sprouts per live stump. By the end of year 5, an average of 212 stumps ha^{-1} remained alive with about 2,540 live sprouts, an average of 12 live sprouts per live stump.

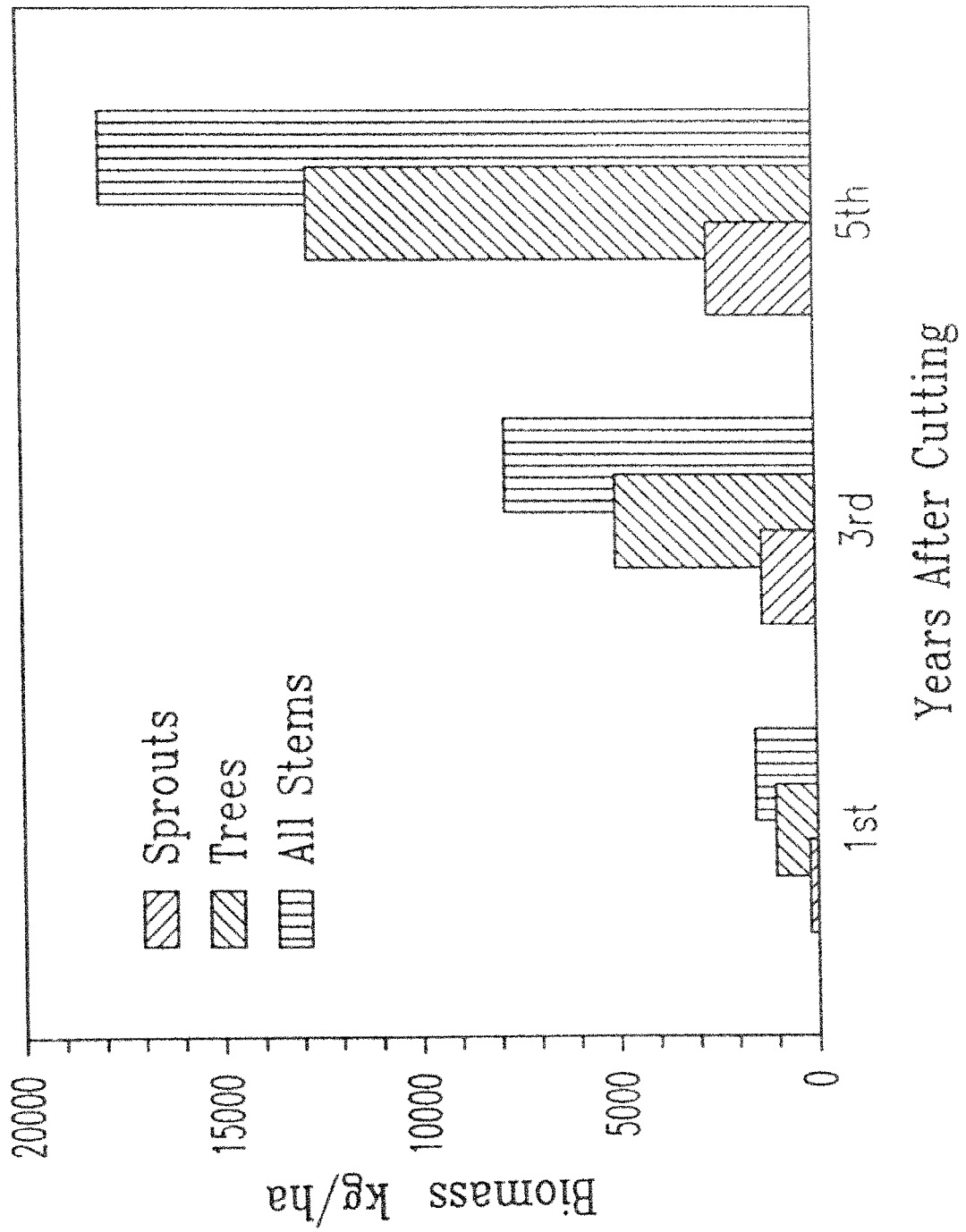

Figure 2. Biomass of revegetation in kg ha^{-1} by year after cutting. The tallest bars include herbs, shrubs, tree seedlings, and sprouts; the bars labeled trees include seedlings and sprouts.

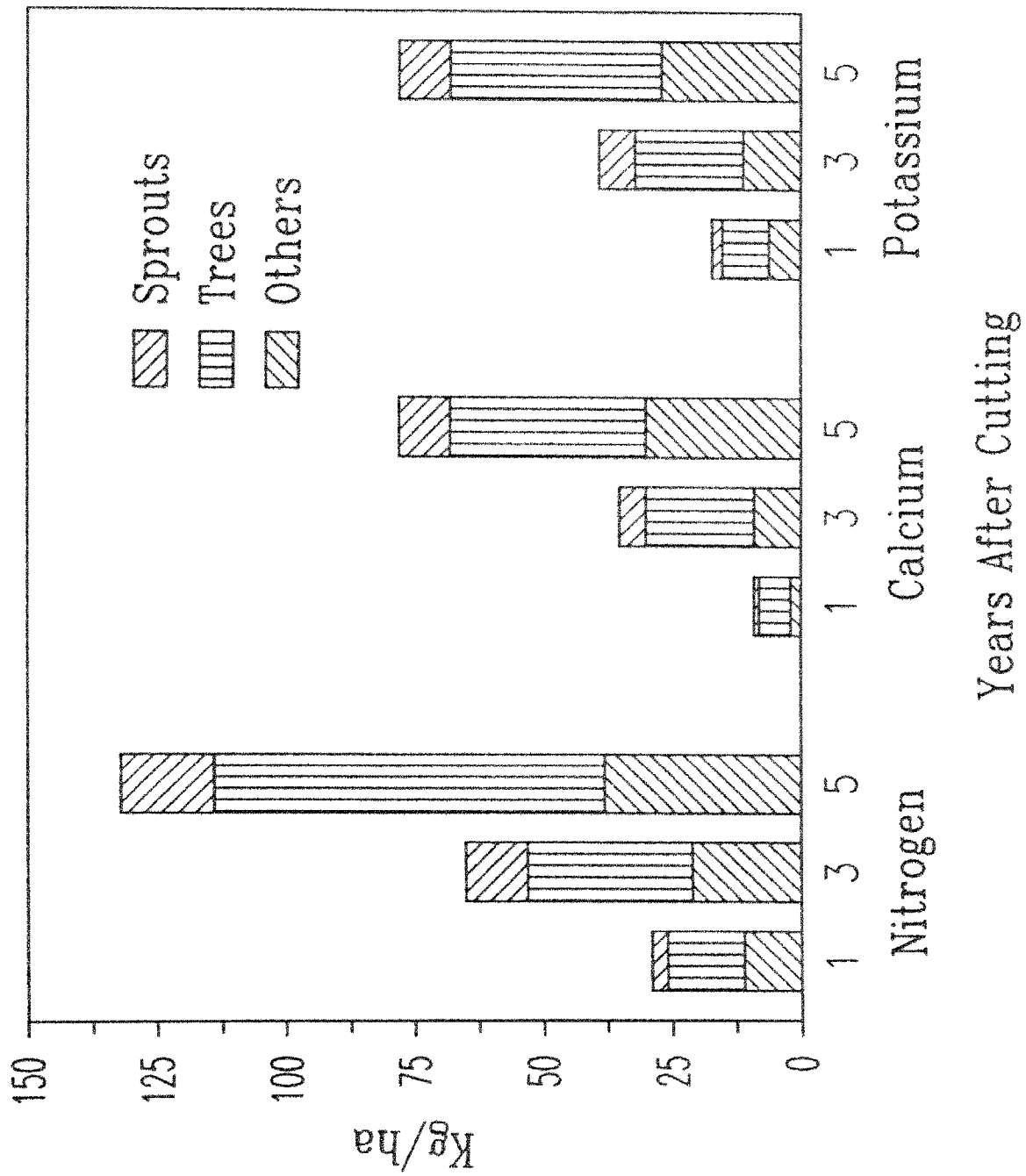

Figure 3. Mass of nutrients accumulated in the aboveground living biomass by years after cutting.

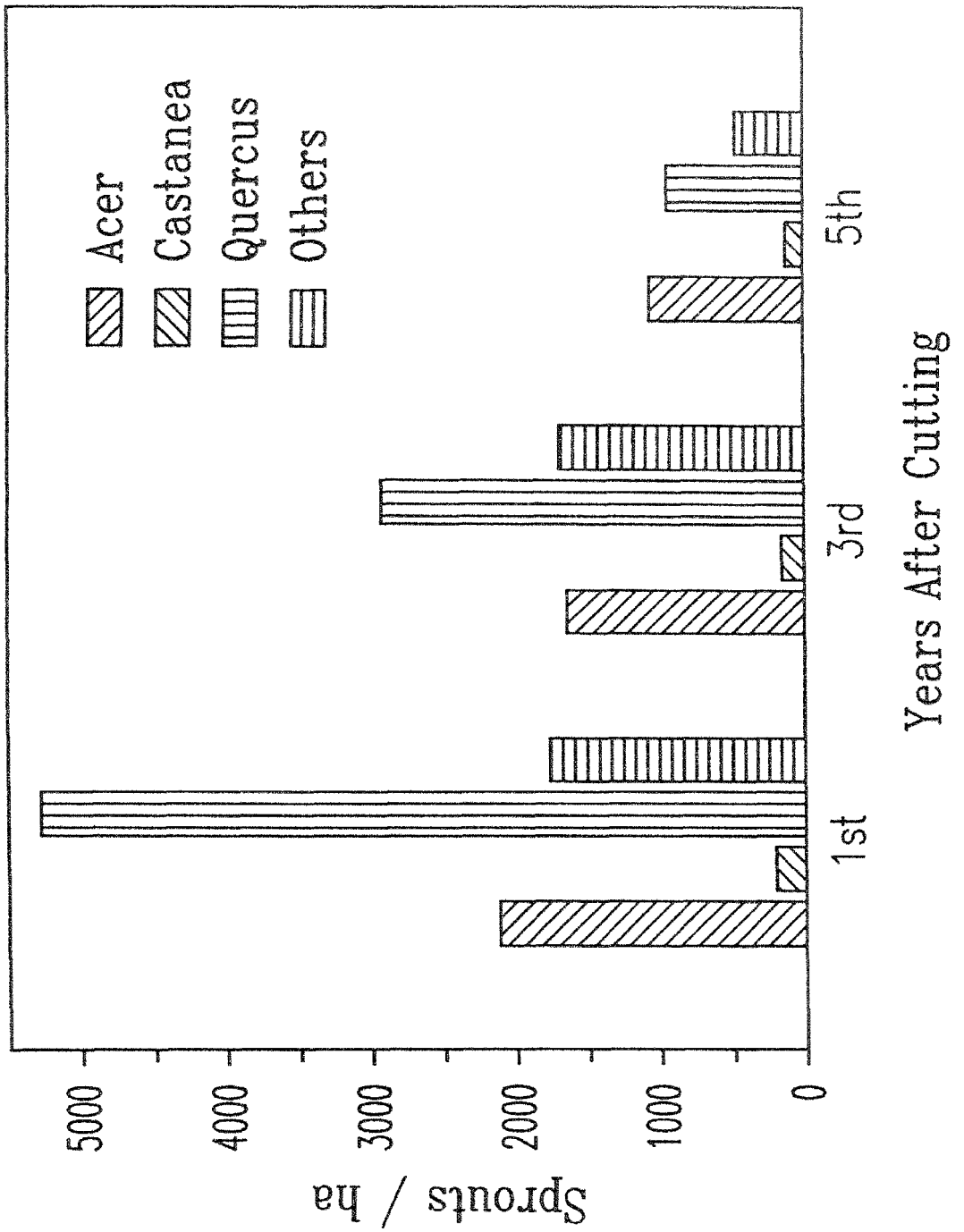

Figure 4. Numbers of sprouts per hectare by species and years after cutting.

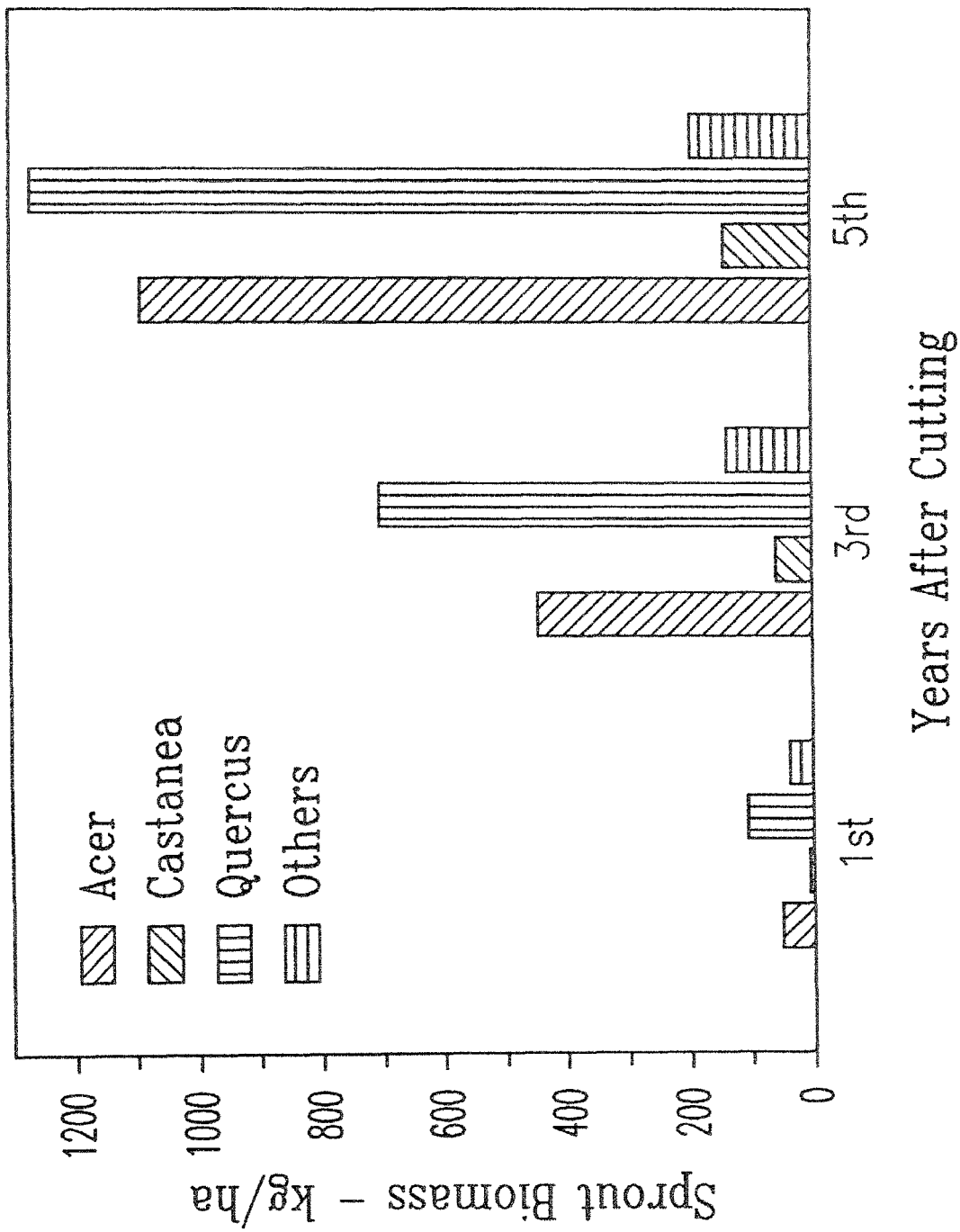

Figure 5. Aboveground living biomass of sprouts per hectare by species and years after cutting.

More than 80% of the *Acer* stumps on the four sample plots sprouted the first year after cutting, and all continued to have live sprouts throughout the 5 years. About 75% of the *Quercus* stumps sprouted but that percentage dropped to about 60% by year 5. Only about 25% of the *Betula* stumps sprouted (Table 1).

Table 1.--Number of live stumps by genus on the four 25 x 25 m sample plots.

Genus	Years after cutting		
	0	1	5
Acer	12	10	10
Betula	35	9	8
Quercus	37	28	22
Others	22	16	13

Of all the genera, *Acer* produced the most sprouts per stump and retained the greatest number of live sprouts over the 5 years. Approximately 50% of the *Acer* sprouts and 75% of the *Quercus* sprouts died over the 5-year period. (Table 2).

Table 2.--Average number of sprouts per live stump by genus. (Standard errors).

Genus	Years after cutting	
	1	5
Acer	53 (7)	26 (6)
Betula	21 (9)	4 (2)
Quercus	47 (8)	11 (1)
Others	19 (6)	9 (3)

DISCUSSION

The importance of sprouts in a regenerating forest can be evaluated in terms of biomass, density, and species represented. Density is an indicator of stand age and structure; biomass reflects dominance; species indicates future worth. Together, we used these three variables to characterize revegetation on our study area.

Sprouts as a Component of Regeneration

Beginning with the first growing season after cutting, tree seedlings and sprouts had the greatest amount of aboveground living biomass on the site. Stump sprouts represented 19% of that biomass and, on average, accumulated 10 times more biomass than seedlings. However,

sprouts accounted for only 3% of the total stems of tree species on the site. Other studies have reported larger numbers of sprouts than were tallied in our study. Boring et al. (1981) found that both density and biomass of sprouts exceeded density and biomass of tree seedlings following cable logging of a watershed in North Carolina. Mann (1984) reported that sprouts dominated whole-tree and saw-log clearcut sites in Tennessee, both in terms of numbers of stems of tree species and biomass.

Betula seedlings and sprouts far exceeded the total number of seedlings and sprouts for other genera of tree species in the first growing season. Initially, scarified soil conditions following whole-tree harvest probably favored the establishment of *Betula* seedlings. Although the total numbers of *Quercus* stems were less than either *Betula* or *Acer*, a far greater proportion (72%) of *Quercus* stems were sprouts. In addition, almost all (97%) *Quercus* biomass was in sprouts, compared with 16% for Acer and 4% for *Betula*. Thus, sprouts were a more important form of regeneration for *Quercus* than for other genera in the first growing season.

Dynamics of Sprouts over the First Five Years

Sprouts continued to account for a small proportion of the total numbers of stems per hectare of all plants over the 5 years studied (Fig. 1). Whereas the total number of plant stems increased, both the total number of stems of all tree species and the total number of sprouts decreased. These data suggest that initiation of sprouts occurred largely in the first (and second) growing season after harvest. Roth and Hepting (1943) reported that there was rarely further sprouting of oaks beyond the second year after cutting.

By contrast, herbaceous plants and tree seedlings apparently continued to fill in open spaces on the forest floor for several years after cutting. Skid trails and other severely disturbed areas may take several years to stabilize before plants can become established. Light and moisture conditions at the soil surface are rapidly changing at this time (Bormann and Likens 1979), resulting in changes in species dominance (Hornbeck et al. 1987). Our study suggests that although species dominance may shift, the tree species present in the first and fifth growing seasons will be the components of the future forest, as discussed by Martin et al. (1987).

It is not possible to predict the long-term survival of sprouts with certainty. At our site, more than three quarters of the *Quercus* sprouts had died by the fifth year. McIntyre (1936) reported that mortality of oak sprouts continued to be high during the first 10 years following cutting but slowed thereafter. McIntyre also found that the basal area of sprouts decreased with stand age. Therefore, clearcut sites may be characterized by dominant, rapidly growing sprouts only in the first one or two decades after clearcutting.

Although we did not carry out a systematic study of causes of sprout mortality, we found evidence of several diseases which probably contributed to mortality. Fruiting bodies of *Armillaria* spp. were observed on numerous stumps over the entire site. This root disease reduces not only sprouting capability of stumps but also sprout survival (P.M. Wargo, USDA For. Serv. pers. comm.). By the fifth year, some of the largest sprouts apparently were too

heavy to be supported by the thin living cambial layer of the stump, and whole clusters of these sprouts peeled away from the stump, fell over, and died. *Castanea*, which had been a very minor component of the precut forest, demonstrated extensive sprouting after harvest. These sprouts grew rapidly in diameter and height and rapidly accumulated biomass. But by year 5, the majority of sprouts showed evidence of chestnut blight (*Cryphonectria parasitica* (Murr.) Barr) and died.

Quercus stumps sprouted quickly and prolifically, accounting for nearly twice as much biomass as the other species in the first growing season and retaining that dominance through year 5. However, *Acer* accumulated biomass more slowly but nearly equalled *Quercus* by the fifth year. Mroz et al. (1985) similarly found that red maple biomass accumulated slowly during the first 3 years after cutting and then increased dramatically in the fourth year.

Sprouts Relative to Precut Forest

Prior to harvest, *Acer* was the most numerous tree genus and *Quercus* accounted for the most biomass at the Connecticut site (Martin et al. 1987). Since Mann (1984) found a greater average number of sprouts per live stump for red maple than for oak in Tennessee, we expected *Acer* to dominate the site immediately. However, this was not the case, and there was no clear relationship between species and sprouting at the Connecticut site. Nor was there an obvious effect of stump diameter on sprouting. Roth and Hepting (1943) showed that for *Quercus*, sprout initiation increases up to a stump diameter of around 12 inches (30 cm) and then decreases. Dominant *Quercus* trees on the Connecticut site were 80 to 100 years old and averaged 20 to 30 cm dbh. Allowing for the difference between dbh and stump diameter, these trees fell well within the range of stump diameters capable of producing large numbers of sprouts. However, approximately half of all stumps ≥ 10 cm at the Connecticut site failed to sprout.

Intensive use of mechanized equipment may partially explain the small percentage of stumps sprouting and the small number of sprouts measured in Connecticut relative to findings from studies by Mann (1984) and Boring et al. (1981). Mann (1984) found a lower number of sprouts on a whole-tree-harvested site compared with a sawlog-harvested site. She reported that skidding of whole trees tended to increase mechanical damage to stumps and soil, and removal of nonmerchantable residues reduced protection of soil surface and stumps afforded by leaving these materials in conventional harvests. Miller and Phillips (1984) demonstrated that shearing by fellers damaged stumps and resulted in lower numbers of sprouts. Whole-tree harvesting disturbed approximately 70% of the soil surface of our site in Connecticut (Martin 1988). Although we did not assess associated damage to stumps, we observed that shearing tended to shatter stumps, especially birch. It is likely that mechanical harvesting reduced the number of stumps that sprouted as well as the number of sprouts per stump to some degree. Site quality is another factor that may have influenced sprouting. Mroz et al. (1985) concluded that sprout numbers for northern hardwoods were independent of site quality, but similar studies have not been reported for central hardwoods.

One of the major concerns with clearcutting in general and with whole-tree clearcutting in particular is the potential for a substantial loss of nutrients from the site both by the removal of wood products and leaching losses. Rapid revegetation of the site will reduce these losses in several ways (Bormann and Likens 1979, Hornbeck 1986). The first is by the sequestering of available nutrients from the soil into long-term storage in aboveground biomass. The second is by covering the watershed with vegetation which shades the site, increases transpiration, slows the velocity of raindrops which reduces erosion and increases infiltration, and works toward restoring the microclimate of the site. Sprouts play a major role in both processes since they have rapid initial growth rates.

Throughout the first 5 years after cutting at our site, sprouts stored about 13% (11 to 18%) of the nitrogen, calcium, and potassium accumulated on the watershed by all aboveground living biomass, and about 20% of those elements stored in tree species. The first year after cutting, this represented 1 to 3 kg ha^{-1}, but by year 5 had increased to 10 kg ha^{-1} of potassium and calcium and 18 kg ha^{-1} of nitrogen. These fifth-year values represented 6% of the nitrogen stored in aboveground living biomass of the precutting forest, 2% of the precutting calcium, and 6% of the precutting potassium.

Boring et al. (1981) reported biomass from a 1-year-old clearcut in the southern Appalachians that was similar to ours. They reported 1,725 kg ha^{-1} to our 1,540 kg ha^{-1} for all living biomass. Accumulations of nitrogen and potassium were similar on both sites, but nearly twice the calcium accumulated at the North Carolina site. However, they reported 63% of their biomass was sprout biomass, with 57% of the nitrogen, 35% of the potassium, and 61% of the calcium occurring in sprouts.

The southern Appalachian site may represent one extreme in the amounts of nutrients that may be sequestered by 1-year-old biomass because of the lack of soil disturbance and stump damage and the longer growing season of North Carolina. Our site may represent the other extreme due to the more northern climate and the severe site disturbance and stump damage caused by mechanical whole-tree clearcutting.

SUMMARY

1. Stump sprouts are an important component in the revegetation of a central hardwood forest after whole-tree clearcutting. They are especially important in the early stages of forest development. They play an important role initially in reestablishing the microclimate of the site; then they play a transitional role in forest development. However, stump sprouts alone may not regenerate a viable forest.

2. Competitive thinning and root diseases change the dynamics of the sprout population too rapidly to predict, at year 5, whether trees of sprout origin will be a major component of the future forest.

3. Revegetation of all types, including herbs, shrubs, and tree seedlings and sprouts, play a vital role in conserving nutrient elements on the site.

4. Whole-tree clearcutting does not seem to have radically changed the species composition of the site. The composition of the regeneration on the whole-tree clearcut is similar to that of the preharvest forest. Before cutting, *Acer* was the most common genus followed by *Quercus* and *Betula*. At year 5, *Betula* is the most common, followed by *Acer* and *Quercus*. Prior to harvesting, *Quercus* contained the most biomass, followed by *Betula* and *Acer*. At year 5, *Acer* had accumulated the most biomass, followed by *Quercus* and *Betula*.

5. *Quercus* is the most commercially valuable genus in the region. Therefore, forest managers are likely to encourage oak regeneration in this region. If so, it is important for them to consider the sprouting potential of the site before cutting, including:

a. species,
b. stump diameters,
c. season of cutting,
d. stump- and root-disease potential,
e. soil-disturbance potential,
f. stump damage during logging.

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PLANTING STOCK TYPE X GENOTYPE INTERACTIONS AFFECT EARLY OUTPLANTING PERFORMANCE OF BLACK WALNUT SEEDLINGS

J. W. Van Sambeek, James W. Hanover, and Robert D. Williams[1]

Abstract: A provenance/progeny test was established in south central Indiana with seedlings from 72 open-pollinated families from across the commercial range of black walnut (*Juglans nigra* L.). The seedlings were grown in a conventional hardwood nursery and in containers in a greenhouse. Seedlings were outplanted in 1981 on an old-field site in Johnson County using a split plot design with families randomly assigned within planting stock type. Survival after three growing seasons averaged 95% across all families and planting stock type. A planting stock type x genotype interaction existed for height growth for the first 2 years after establishment. Both nursery-grown and container-grown seedlings showed varying amounts of dieback during the first growing season. After the second growing season, the container-grown stock has initiated positive height growth while the nursery-grown seedlings continued to die back. Three years after establishment, effects of genotype and planting stock type had dissipated and effects of seed collection zone (provenance) were still not present. Results with container-grown seedlings are consistent with other studies using nursery-grown seedlings and show that effects of genotype and site account for increasingly more of the tree growth variation as the planting gets older.

INTRODUCTION

Nursery-grown seedlings of black walnut (*Juglans nigra* L.) characteristically have a long taproot with few lateral roots to serve as future sites for new root initiation. In addition, the taproot on nursery-grown seedlings is frequently cut during lifting or planting, thus altering the shoot-to-root balance which may also contribute to transplant shock. Because container-grown seedlings usually have a well-developed fibrous root system, they have many more sites for initiating new roots following outplanting. Past research has shown that

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seedlings grown in containers initiate height growth sooner than bare-root seedlings from nursery beds (Van Sambeek et al. 1987, von Althen 1986).

The effects of genotype and/or provenance (geographical source) on early field performance of nursery-grown seedlings are well documented (Bey 1979; Rink 1984, Rink and Van Sambeek 1987); however, similar studies with container-grown seedlings have not been done. The extent to which planting stock type and genotype may interact with seedling growth following outplanting is unknown for black walnut seedlings. Therefore, we established a study in 1980 to determine the extent to which growth interactions occur among nursery-grown and container-grown seedling from the same open-pollinated families from across the commercial range of black walnut.

MATERIALS AND METHODS

In the fall of 1979, seed from 250 single-tree or stand collections from 14 provenances (seed collection zones) were collected, assigned accession or family numbers, and cleaned. Collections were limited essentially to the commercial range of black walnut (Funk 1978). Half of the seed from each collection with more than 300 sound seed were sown by seedlot in single plots at the Vallonia Tree Nursery near Brownstown, Indiana, in December of 1979. Seedlings were lifted in November and December of 1980. A random sample of 32 seedlings from each seedlot was measured for basal diameter (3 cm above the root collar), root and shoot length, and an index (0 to 2) of root fibrosity (0 = less than three lateral roots per cm of taproot, 1 = three to five lateral roots per cm of taproot, 2 = six or more lateral roots per cm of taproot). For each seedlot, seedlings were randomly divided into bundles of four seedlings each with one seedling labelled with the seedlot number. Four bundles of four seedlings for each seedlot were packaged in kraft paper for overwinter storage at 4° C for each planting to be established.

In June 1980, germinating seed from each seedlot were sown in 6- x 6- x 30-cm polyethylene-coated paperboard plant bands in a Michigan State University greenhouse and grown according to the techniques described by Wood and Hanover (1981). Briefly, seedlings were grown in RediEarth, a commercial peat-vermiculite soil mix, under continuous fluorescent light and carbon dioxide enrichment for approximately 4 months. Seedlings were hardened-off for approximately 3 months before being removed from the containers for packaging and overwinter storage. For each collection, 16 seedlings were randomly divided into four bundles of four seedlings each with one seedling from each bundle labelled with seedlot number. Labelled bundles were packaged in kraft paper for cold storage and shipping to the Indiana planting site in late March.

Container-grown and nursery-grown seedlings were both slit-planted using the MICHOTIP hardwood tree planter on March 25, 1981. Nursery-grown seedlings with excessive lateral roots or taproots over 25 cm long were root pruned before planting. Seedlings were planted on an open, grass-covered old field in the Atterbury State Fish and Wildlife Area located in Johnson County, Indiana. Soils are primarily poorly- to moderately-well drained Crosby

(fine, mixed, mesic, Aeric Ochraqualfs) and Miami (fine-loamy, mixed, mesic, Typic Hapludalfs) silt loams. Seedlings were planted in 4-tree row plots at a nominal spacing of 2.0 m within rows and 3.0 m between rows using a split plot design for planting stock type with individual seedlots randomly arranged within each planting stock type.

The planting site was sprayed in the fall of 1980 with glyphosate (2.5 l ai per ha) using 1-m wide bands at 3-m intervals. Immediately after seedlings were outplanted, all rows were strip-sprayed with simazine (4.5 kg ai per ha). There was no additional weed control in subsequent years to control competition from the grass sod. Climatological data for 1980 to 1983 for central Indiana were obtained from records published by the National Oceanic and Atmospheric Administration.

Survival, live height, and basal diameter (3 cm above soil line) were recorded at outplanting and annually after each growing season for 3 years. Means for height, basal diameter, and net growth for all live trees were determined for each four tree plot. For this report, only data from 72 open-pollinated families (single-tree collections) that had both nursery-grown and container-grown seedlings and were replicated across all four blocks were analyzed. Families were assigned to provenances according to the preliminary seed collection zones identified for black walnut in 1980 (Deneke et al. 1987). Variation was analyzed as a split-plot experiment using plot means to determine if differences ($p < 0.05$) existed among planting stock type and/or genotype or if an interaction was present. Pearson correlation analyses were used to generate correlation matrices on a family mean basis.

RESULTS

Analysis by Family Means

Survival for both the nursery-grown and the container-grown seedlings has been excellent on this questionable site for black walnut. After the first growing season, survival for the nursery-grown seedlings averaged 98.9% with the container-grown seedlings averaging 97.4%. After three growing seasons, survival for the nursery-grown seedlings averaged 95.7% compared to 96.2% for the container-grown seedlings (Table 1). Survival among the families after three growing seasons ranged from 81% for family 189 from Bell County, Kentucky, to 100% for 21 of the 72 families. Overall, there were no statistically significant differences for survival among families or planting stock type.

A highly significant interaction for height growth existed among planting stock types x genotype during the first two years after outplanting which disappeared after the third growing season (Table 2). Many of the walnut seedlings showed substantial dieback after the first growing season; however, because of the interaction there was no consistent genotypic response among families outplanted as nursery- and container-grown planting stock. For example, dieback on nursery-grown seedlings for family 295 from Alexander County, Illinois, averaged 30.9 cm compared to 15.2 cm for the container-grown seedlings. Conversely,

Table 1.--Third year survival, annual net height growth, and root fibrosity index for nursery-grown and container-grown black walnut seedlings by family and seed collection zone.

Seed Coll. Zone[1]	Family number[2]	Location State	County	Third Year Survival Nurs.	Cont.	Net annual height growth First year Nurs.	Cont.	Second year Nurs.	Cont.	Root Fibr. Index[3]
				- - - % - - -		- - - - - - - - - - - - cm - - - - - - - - - -				
2	328	IA	Cedar	94	100	- 8.5	- 4.6	- 4.7	1.5	0.50
	329	IA	Clayton	100	4	- 2.1	-10.1	- 0.7	6.3	0.47
	330	IA	Taylor	100	100	0.9	- 7.9	- 6.4	7.1	0.22
	333	IA	Marshall	100	81	- 0.8	-10.9	-17.1	5.2	0.16
	336	IA	Jefferson	100	94	- 3.9	- 7.0	- 3.8	8.0	0.28
	339	IA	Taylor	100	94	- 2.3	-13.0	- 8.9	- 3.9	0.16
	340	IA	Marshall	94	94	- 5.6	-14.5	- 0.1	4.8	0.13
Seed Collection Zone Means				98	94	- 3.3	- 9.7	- 6.0	4.1	0.27
3	297	IL	Fulton	94	94	7.3	- 9.6	-12.3	- 6.1	NA
	298	IL	Warren	100	100	- 1.0	- 1.2	4.0	7.9	0.44
	299	IL	Henry	100	100	6.3	- 1.4	- 5.9	7.4	0.88
	300	IL	Carroll	100	100	0.5	- 4.2	-14.6	8.5	0.66
Seed Collection Zone Means				98	98	3.3	- 4.1	- 7.2	4.4	0.66
4	127	MI	Allegan	100	100	- 7.2	5.9	- 1.0	1.2	0.88
	131	MI	Berrien	100	92	- 5.8	- 6.0	- 8.7	1.1	0.00
	134*	MI	St. Joseph	94	88	- 1.6	- 4.4	- 4.0	3.4	0.13
	139	MI	Branch	94	94	-10.4	-16.6	- 1.4	0.1	0.28
	143*	MI	Eaton	100	81	- 2.4	- 5.2	2.1	8.9	0.50
	146*	MI	Jackson	88	100	-12.0	- 6.2	0.7	1.8	0.00
	147	*MI	Jackson	100	100	- 7.2	-13.0	-15.9	0.8	0.13
	212	ON	Middlesex	100	100	1.8	- 6.3	0.6	6.4	0.84
	215	ON	Brantford	94	94	- 2.9	- 8.1	- 3.8	1.5	0.56
	218	NY	Chautauqua	100	94	-15.4	- 4.7	- 8.0	1.7	0.56
	222	OH	Huron	94	100	3.4	0.6	4.3	2.2	0.25
	247	MI	Igham	100	100	- 8.8	- 1.0	- 7.3	3.5	0.16
Seed Collection Zone Means				97	95	- 5.7	- 6.4	- 3.5	2.7	0.36
6	345	MO	Adair	100	100	- 9.0	- 1.4	- 4.9	8.2	0.13
	354	MO	Pike	94	100	- 6.7	- 9.0	-13.1	- 0.1	0.13
	384	IL	Macon	100	88	- 6.4	-10.5	-15.1	6.5	0.25
	386	IL	Macon	100	100	- 1.9	- 1.8	-16.5	13.9	0.31
Seed Collection Zone Means				97	97	- 6.0	- 5.7	-14.9	7.2	0.20

7	261	IN	Owen	100	100	- 5.6	- 0.1	- 3.1	-11.2	0.09
	264	IN	Putnam	100	100	- 0.1	- 7.0	-11.2	0.6	1.19
	266	IN	Bartholomew	94	100	- 4.4	-16.1	-21.6	4.6	1.00
	274	IN	Lawrence	100	100	- 5.9	-20.7	-27.9	5.3	0.97
	277	IN	Lawrence	94	94	-13.9	- 1.9	- 8.3	1.8	0.72
	286	IN	Lawrence	94	100	7.0	- 3.6	2.9	12.0	1.22
Seed Collection Zone Means				97	99	- 3.1	- 9.2	-13.0	3.5	0.86
10	174	KY	Hancock	100	100	- 4.9	- 5.2	-16.5	5.2	0.19
	202	KY	Ohio	100	94	- 7.1	-14.4	- 2.1	- 4.2	0.66
	295	IL	Alexandria	69	100	-30.9	- 7.7	-15.2	6.9	0.00
	296	IL	Hardin	94	94	- 3.8	- 4.0	-17.5	6.0	1.00
	341	MO	Texas	100	94	-18.7	- 3.4	- 7.6	3.7	0.50
	348	MO	Perry	88	88	-17.1	-15.3	- 8.7	3.4	0.38
	380	IL	Jackson	94	100	-21.6	- 6.6	- 2.7	6.1	0.19
	381	IL	Randolph	100	88	- 3.3	- 1.3	-11.4	10.4	0.88
	382	IL	Williamson	88	100	-15.8	- 5.5	-24.8	8.9	0.19
Seed Collection Zone Means				92	95	-13.7	- 7.0	-11.8	5.2	0.44
11	158	KY	Hardin	100	100	- 0.9	-14.1	-11.9	8.3	0.50
	172	KY	Boyd	94	94	- 4.9	- 5.2	- 3.0	9.2	0.50
	194	KY	Barrier	100	100	- 2.7	-14.4	-11.9	- 0.1	1.19
	203	KY	Wolfe	94	100	- 5.2	-11.9	-16.6	6.4	0.66
	207	KY	Washington	100	100	- 2.2	- 5.9	- 6.1	2.3	0.75
	233	WV	Tucker	100	100	3.4	-13.1	0.1	3.2	0.75
	242	WV	Tyler	94	94	2.5	- 4.8	- 5.1	3.4	0.47
	244	WV	Mason	94	94	4.7	- 1.7	1.9	4.3	0.41
	320	WV	Harrison	100	100	4.2	- 7.1	- 4.4	0.8	0.22
Seed Collection Zone Means				97	98	- 0.1	- 8.7	- 6.3	4.2	0.60
13	342	MO	Ripley	94	100	-11.8	-22.6	-25.8	8.0	0.53
	356	MO	Pulaski	100	81	0.3	- 7.4	-13.3	2.6	0.56
	357	MO	Oregon	100	94	-10.6	-13.5	-22.5	3.1	0.28
Seed Collection Zone Means				98	92	- 7.4	-14.5	-20.5	4.6	0.46
14	253	TN	Macon	88	100	0.2	- 3.2	- 0.6	7.6	0.31
	254	TN	Macon	100	94	- 1.6	- 4.7	- 6.2	7.2	0.34
	369	TN	Smith	94	100	- 6.1	- 8.8	-17.4	- 1.4	0.28
Seed Collection Zone Means				94	98	- 2.5	- 5.6	- 8.1	4.5	0.31
15	180	KY	McCreary	94	94	- 6.6	- 4.1	-15.0	3.8	0.06
	189	KY	Bell	69	94	-10.7	- 7.5	- 1.4	1.7	0.09
	192	KY	Clay	94	94	- 5.4	-11.5	- 9.9	3.6	0.50
	225	WV	Greenbriar	100	94	3.6	-10.2	0.9	12.5	0.53
	228	WV	Rock Bridge	94	94	- 7.0	-16.0	- 2.3	8.5	1.19
	229	WV	Rogne	88	100	-14.1	- 9.1	-10.8	3.1	0.38

	236	WV	Mercer	88	94	1.4	- 4.9	- 0.5	5.5	0.69
	246	WV	Wyoming	81	100	- 4.6	-14.6	- 9.9	3.7	0.59
Seed Collection Zone Means				88	96	- 5.4	- 9.7	- 6.1	5.3	0.50
16	149	TN	Anderson	94	100	- 4.5	-19.7	- 7.9	10.2	0.84
	360	TN	Lincoln	100	100	- 1.6	- 9.6	- 9.2	0.9	0.50
	363	TN	Washington	94	94	- 1.0	-11.0	-35.9	1.6	0.69
	366	TN	Warren	94	100	- 5.2	-10.8	-18.1	7.9	0.22
	372	TN	Overton	100	94	2.6	-16.6	- 1.4	- 1.8	0.97
	374	TN	White	100	100	1.9	- 3.6	-16.6	3.4	1.03
	376	TN	Knox	100	100	- 2.0	- 3.1	- 6.1	2.4	1.19
Seed Collection Zone Means				98	97	- 1.4	-10.6	-13.6	3.5	0.78

[1]Provenance is based on the preliminary seed collection zones for black walnut identified by Deneke et al. (1987).
[2]Family number can be converted to the North Central Forest Experiment Station Accession Number or the MICHOTIP Accession Number by adding 10,200 or 47,350,000, respectively. An * indicates seed was collected from an above average tree in a small black walnut planting.
[3]Root Fibrosity Index ranges from 0 for seedlings with less than 3 lateral roots per cm of taproot to 2.00 for seedlings with 6 or more lateral roots per cm of taproot.

Table 2.--Analyses of variance for seedling height and basal diameter growth from 72 families grown as both nursery- or container-grown planting stock.

Source of variation	Degrees of freedom	Height growth			Basal diameter growth		
		Year 1	Year 2	Year 3	Year 1	Year 2	Year 3
		mean sum of squares[1]					
Stock type	1	1,953	25,120	834	22.41	10.43	37.38*
Blocks	3	443	1,245	38	18.77	0.33	7.96
Error A	3	649	1,190	1,122	9.53	2.84	4.23
Families	71	166**	176**	77	0.61	0.98	1.10
S x F	71	128**	165**	61	0.73	0.82	1.20
Error B	426	65	100	62	0.61	0.82	1.43

[1]Mean sum of squares followed by an * or ** are statistically significant at the alpha = 0.05 and 0.01 levels, respectively.

dieback on container-grown seedlings for family 386 from Lawrence County, Indiana, averaged 3.6 cm while nursery-grown seedlings of the same family averaged 7.0 cm of net height growth.

Overall, nearly all families showed some first-year dieback for both the nursery-grown and the container-grown seedlings. Nursery-grown seedlings after outplanting were on the average 50.6 cm tall compared to only 46.0 cm after the first growing season. Conversely, container-grown seedlings showed a significantly greater percentage of dieback after the first growing season having averaged 31.3 cm at outplanting and only 23.1 cm after the first growing season. Only family 222 from Huron County, Ohio, outgrew the initial stem dieback for both the nursery-grown and container-grown seedlings and were taller after one growing season than when outplanted.

The variable growth of the nursery-grown seedlings was primarily responsible for the planting stock type x genotype interaction found after the second growing season (Table 2). The second-year growth of both the nursery- and container-grown seedlings for many families was similar. While for approximately one-third of the families, the nursery-grown seedlings showed extensive dieback with little or no dieback on the container-grown seedlings (Table 1). For example, family 146 from Jackson County, Michigan, and family 244 from Mason County, West Virginia, averaged 2 to 4 cm of net height growth for both the nursery-grown and container-grown seedlings, while family 274 from Lawrence County, Indiana, and family 363 from Washington County, Tennessee,continued to show substantial dieback of the nursery-grown seedlings (27.9 and 35.9 cm, respectively) with net height growth for the container-grown seedlings (5.3 and 1.6 cm, respectively).

After the second growing season, many of the nursery-grown seedlings showed additional dieback and were 8.9 cm shorter than after the first growing season. Conversely, the container-grown seedlings were 4.3 cm taller than after the first growing season and had recovered approximately half of the initial dieback. After the second growing season, seedlings from 9 of the 72 families for both the nursery-grown and container-grown planting stock were taller than after the first growing season. Conversely, seedlings from only 8 families showed net dieback for both types of planting stock during the second growing season.

After the third growing season, the interaction between planting stock type and genotype for height growth was no longer present and no differences among families were present (Table 2). Nearly all families showed 4 to 7 cm of net height growth for both types of planting stock. Differences in diameter growth were found only for the planting stock type after the third growing season. Diameter growth for the container-grown seedlings averaged 0.1 mm compared to -0.4 mm for the nursery-grown seedlings. Over two-thirds of the families outplanted as nursery-grown stock showed net negative diameter growth. The negative values occur because of stem dieback on one or more seedlings within these families and subsequent resprouting from the root collar.

Analysis By Seed Collection Zones

Analyses of height growth by seed collection zone and planting stock type again showed a highly significant interaction after the first and second growing seasons. Height growth

during the first growing season within each collection zone was extremely variable for planting stock types with no apparent pattern (Table 1). For example, in seed collection zone 6, container-grown and nursery-grown seedlings showed approximately 6 cm of dieback. In contrast, container-grown seedlings from seed collection zone 13 showed extensive dieback (14.5 cm) while nursery-grown seedings from seed collection zone 3 were 3.3 cm taller than when outplanted. The amount of dieback did not appear to follow any geographical pattern related to seed collection zone.

After the second growing season, container-grown seedlings from all seed collection zones consistently showed height growth of 3 to 7 cm (Table 1). In contrast, the amount of dieback on nursery-grown seedlings ranged from 4 to 20 cm across the eleven seed collection zones. Seedlings from the northernmost seed collection zones tended to show the least dieback; however, they also tended to be the shortest when outplanted. A seed collection zone x planting stock type interaction was not found after the third growing season when seedlings from all collection zones averaged 2 to 9 cm of height growth without any apparent geographical pattern.

Results of family mean correlation coefficients showed that increased root fibrosity of nursery-grown seedlings was positively correlated with outplanting basal diameter, first-year height growth, and third-year survival (Table 3). Root fibrosity of container-grown seedlings was not determined and the lack of any correlation between nursery-grown seedling fibrosity and container-grown seedling characteristics of the same family suggests that small changes in root fibrosity on container-grown seedlings are not as important as the well-developed fibrous root system itself.

The lack of any correlation between root fibrosity of nursery-grown seedlings and container-grown seedling growth may also mean that the growth patterns and morphology of seedlings from the same family can be quite different when grown under forcing conditions in a greenhouse. The latter conclusion is supported by the fact that basal diameter of the container-grown seedlings was not correlated with the basal diameter of the nursery-grown seedlings ($r = 0.066$). The outplanting height of the nursery-grown seedlings was correlated with that of the container-grown seedlings; however, the correlation coefficient was relatively low ($r = 0.401$).

DISCUSSION

Survival after three growing seasons in this provenance/progeny test has been exceptional and is substantially better than in an adjacent planting methods study using nursery-grown and container-grown seedlings (Van Sambeek et al. 1987). Survival rates for the nursery-grown planting stock in the adjacent planting after three growing seasons was less than 70% compared to 96% in the present study. We attribute the lower survival in the adjacent planting to the somewhat poorer internal drainage. Survival of container-grown stock after three growing seasons averaged around 95% in both the provenance/progeny and the adjacent planting.

Table 3.--Correlation matrix for initial seedling characteristics and outplanting performance of nursery-grown and container-grown seedlings of 72 black walnut families.

Variables	Root fibr. index	Outplanting: Basal diameter	Outplanting: Stem height	Annual height growth: First year	Annual height growth: Second year	Annual height growth: Third year	Third year survival
				r[1]			
xxxxxxx				FOR NURSERY-GROWN FAMILIES			
Root fibrosity	xxxxxx	0.367**	-0.104	0.350**	0.015	-0.046	0.238*
Basal diameter	-0.087	xxxxxxx	0.273*	0.497**	-0.128	-0.125	0.183
Stem height	0.129	0.454**	xxxxxxx	-0.386**	-0.778**	-0.123	-0.101
First year growth	-0.144	0.053	-0.700**	xxxxxxx	0.221	-0.176	0.443**
Second year growth	0.094	-0.035	-0.332**	0.154	xxxxxxx	-0.056	0.001
Third year growth	0.144	-0.203	-0.123	0.002	0.437**	xxxxxxx	-0.126
Third year survival	0.167	0.193	0.184	-0.005	0.020	0.285*	xxxxxxx
				FOR CONTAINER-GROWN FAMILIES			

[1]Correlation coefficients followed by an * and ** are statistically significant at the alpha = 0.05 and 0.01 levels, respectively.

The outplanting height for the nursery-grown seedlings was not well correlated with their basal diameter (Table 3). This may be a reflection of the wide variation in seedling density present in the nursery beds due to low germination in some families. Likewise, the outplanting height of the container-grown seedlings was not highly correlated with their basal diameter suggesting that the position of the containers on the greenhouse bench may have affected seedling growth rates.

The overall poor height growth of both the nursery-grown and container-grown seedlings was probably in response to inadequate weed control, moisture stress, and competition from the invading grasses. During the first growing season, many of the nursery-grown seedlings, especially the larger seedlings, showed some dieback with 2 to 5 cm of new shoot growth from lateral buds. Over the winter, the stems on many of these seedlings died. Most seedlings resprouted from the root collar which resulted in large net negative height growth for the second growing season. During the latter part of the second growing season and again

during January through March of 1983, rainfall was substantially below normal. This was followed by excess moisture on a somewhat poorly drained site during April and May of the 1983 growing season.

The first- and second-year height growths were negatively correlated with the outplanting height for both the nursery-grown and container-grown seedlings (Table 3). Potentially, the taller seedlings were unable to obtain adequate soil moisture and showed repeated dieback until the root-to-shoot ratios become balanced under stressful conditions. First-year height growth of nursery-grown, but not container-grown seedlings, was positively correlated with outplanting basal diameter. Since taproot volume is highly correlated with basal diameter and is not substantially reduced by root pruning, seedlings with large basal diameters may have had more stored reserves available for root and shoot growth during the first year.

Overall, the container-grown seedlings initiated positive height growth sooner than the nursery-grown seedlings. Similar results have also been found for container-grown planting stock by von Althen and Prince (1986) on a good walnut site and Anderson et al. (1983) on a reclaimed minespoil. Earlier height growth results in our provenance/progeny test are consistent with those from the adjacent planting methods study reported earlier (Van Sambeek et al. 1987). As in the planting methods study, container-grown seedlings in this provenance/progeny test overcame dieback during the second growing season, while nursery-grown seedlings did not show net height growth until the third growing season. Repeated annual dieback for 1 to 3 years in response to site or competition is not uncommon and has been reported for several other provenance/progeny tests (Williams et al. 1985). Heritabilities for height growth were not calculated because previous research has shown them to be highly variable until after the fourth growing season (Rink 1984).

The dissipation of the genotype x environment interaction in Atterbury provenance/progeny test for early height growth is not uncommon in black walnut provenance/progeny tests. In two separate studies, Rink et al. (1982) and Williams et al. (1985) found that the interaction between where the nursery seedlings were grown and genotype also dissipated several years after outplanting. Although seed collection zone (provenance) effects were not found, we expect these effects to be evident in later measurements based on results from other black walnut provenance/progeny tests.

The highly significant planting stock type x genotype interaction during the first two growing seasons reinforces the conclusion from other studies that early height growth cannot be used as a predictor of future height growth, at least for nursery-grown seedlings (Clausen 1984, Rink 1984). Whether early height growth can be used as a reliable predictor for future height growth of black walnut established with container-grown planting stock remains to be determined. The poor initial growth of the container-grown stock in this provenance/progeny, however, makes it unlikely that our study will satisfactorily answer the question. The study has shown that planting stock type x genotype interactions can significantly affect the early field performance of black walnut plantings.

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TEN YEAR REGENERATION OF SOUTHERN APPALACHIAN HARDWOOD CLEARCUTS AFTER CONTROLLING RESIDUAL TREES

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Abstract: Two upland hardwood stands were clearcut in 1978 and three treatments to control the unmerchantable and/or cull trees were applied. The treatments applied to the residual trees were chainsaw felling, herbicide injection, and a control, where residual trees were left standing. Regeneration was sampled 10 years after the cutting. Variables such as total number of stems, number of free-to-grow stems, and number of free-to-grow commercial species were used to evaluate the effect of the treatments. Statistical analysis showed that hardwood regeneration is promoted by controlling residual trees. Total number of stems, number of free-to-grow stems, and number of free-to-grow commercial species of the large regeneration class (stems ≥4.5 ft height) were significantly increased by the chainsaw and injection treatments. Controlling residuals significantly increased sprouting of all species (including commercial and non-commercial), the number of free-to-grow trees,and the number of commercial species and free-to-grow commercial species with respect to the control treatment. The number of oaks being regenerated was not affected by either treatment. The injection treatment did not result in a significant increase of the seedling component in the regeneration. Differential mortality was observed among the treatments from years five to ten, resulting in the attenuation of treatment differences, especially between the chainsaw and injection treatments. A shift towards early successional species was observed after the harvest, but the specific composition was unaffected by the treatments. Ten years after the clearcut, the chainsaw treatment is recommended as a means of controlling residual trees. This treatment promoted adequate hardwood regeneration, and compared to the injection treatment, is easier to implement, cheaper and aesthetically more pleasing.

INTRODUCTION

Commercial clearcutting results in the removal of all merchantable trees leaving saplings, small poles and cull trees standing. If residual trees are left uncut they may develop into wolf trees and seriously interfere with the regeneration of commercially desirable species (Trimble 1972; Marquis 1981a).

Regeneration guidelines recommend the removal of those residual trees when clearcutting (Kellison et al. 1981, Roach and Gingrich 1968). Controlling residuals can be done in several

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ways. Large culls can be deadened or felled, and the small residuals can be injected or sprayed with chemicals, lopped with saws or axes or reduced by shearing or drum chopping (Beck 1980).

In this study, two methods of controlling residuals were chosen to examine the response of hardwood regeneration: chainsaw felling and herbicide injection. They were compared to a commercial clearcut in which the residuals were left standing. Deadening of the residual trees with herbicide has the intention of promoting the seedling origin component in the new stand as opposed to chainsaw felling of residuals which should favor the stems of stump origin. This paper reports the differences in the quantity and quality of the regeneration among the different methods of controlling residuals ten years following clearcutting.

METHODS

The two study sites (the Robertson and the Willits tracts) are included within the Chestnut Oak Forest region and are located in western North Carolina on lands that belong to Champion International Corporation. The Willits tract is located in Jackson County on a north to northeast aspect with a red oak site index of 80 ft on a 50 year base (good site). The Robertson tract is located on a north to northwest aspect with a red oak site index of 70 ft (average site).

Portions of the forest on the Willits tract were in pasture or cultivation around the turn of the century, while the Robertson tract was always forested but subjected to repeated highgrading. Both stands were experimentally clearcut in the winter to evaluate alternative methods of controlling residuals. The installation of the study was done by Champion International Corporation in cooperation with the North Carolina State University Hardwood Research Cooperative, and followed the study design found in Kellison and Gardner (1977).

At the time of clearcutting, the Willits tract had a merchantable basal area of 69 square feet per acre in 124 trees per acre aged 60 to 80 years. The trees were mainly red maple (*Acer rubrum* L.), yellow-poplar (*Liriodendron tulipifera* L.), cucumber magnolia (*Magnolia acuminata* L.), hickories (*Carya* spp.), white oaks (*Quercus alba* L., *Quercus prinus* L.), sweet birch (*Betula lenta* L.) and red oaks (*Quercus rubra* L., *Quercus coccinea* Muenchh., *Quercus velutina* Lam.). The Robertson tract had 114 merchantable trees per acre aged 75 to 150, and a basal area of 76 square feet per acre. The primary species at the Robertson tract were white and red oaks, hickories and red maple.

Twelve plots of 1.25 acres were established on each site to allow for 4 replications of three treatments in a randomized complete block design. In each plot, four 0.004 ac subplots were established for regeneration subsampling. The treatments applied to control the residual trees were:

1.- Control: all residual trees left standing to represent the typical condition following commercial clearcutting with a diameter limit of 6 inches dbh.

2.- Chainsaw: clearfelling all residual stems bigger than 1-in dbh with chainsaws.

3.- Injection: injecting all residual stems bigger than 1-in dbh with the herbicide TORDON 101[R] using hypo-hatchets[R].

The original subplot centers were permanently marked for regeneration sampling. Effects of the treatments were evaluated five years after the clearcut by Petruncio (1985).

Ten year regeneration was measured during the summer of 1988. Large regeneration or stems ≥ 4.5 ft tall were sampled on enlarged subplots of 0.02 acres having as a center the smaller 0.004 ac subplots. Species, dbh in inches, height in feet and origin were recorded for every stem. Origin was classed as seedling or sprout. In the case of sprouts, only one dominant stem was measured, but total number of stems per clump was recorded. No distinction was made between seedlings and seedling sprouts. In addition, stems were judged whether they were overtopped by competitors or free-to-grow. Trees identified as present prior to the 1978 harvest were not included in the analysis of regeneration. On the basis of fiber and timber values, species were classified as commercial and non commercial. All oaks (*Quercus* spp.), hickories, pines (*Pinus* spp.), maples (*Acer* spp.), yellow-poplar, cucumber magnolia, blackgum (*Nyssa sylvatica* Marsh.), beech (*Fagus grandifolia* Ehrh), sycamore (*Platanus occidentalis* L.), sweet birch, black cherry (*Prunus serotina* Ehrh), white ash (*Fraxinus americana* L.), eastern red cedar (*Juniperus virginiana* L.), yellow buckeye (*Aesculus octandra* Marsh.), hemlock (*Tsuga canadensis* Carr.) and basswood (*Tilia heterophylla* Vent.) were considered commercial. All other species were considered as having non-commercial value.

To analyze treatment effects on regeneration, number of trees, which is considered to be acceptable in stands less than 15 years old (Gingrich, 1967), has been used as a measure of stand density. The statistical analysis was done on the square root transformation of the data to stabilize the variance (Rawlings, 1988). Analysis of variance was used and planned comparisons among the treatments were done at the 10 percent significance level.

RESULTS AND DISCUSSION

At the time of harvest, the control plots had a residual basal area of 30 ft^2 per acre on both of the tracts. Ten years after the clearcut, the residual basal area was 33 ft^2 on the Willits tract and 22 ft^2 on the Robertson tract. From years 5 to 10, residual tree mortality was 32 percent on the Willits tract and 20 percent on the Robertson. Although mortality has been greater on the Willits tract, the surviving residuals have been able to withstand the severe conditions of sudden exposure better than the ones in the Robertson tract. Quality of the residual trees varies and many show signs of crown dieback and epicormic branching. The high rate of residual mortality surpasses what Marquis (1981) reported for the residual trees in the Allegheny hardwoods. This mortality may be due to the fact that these trees were not selected in any way for species or quality. On the injection plots, many of the trees that were herbicided were still standing as dead snags. The herbicide treatment was almost 100 percent

effective on the Robertson tract; however, on the Willits tract some trees survived and at year ten accounted for 7 ft^2 of the basal area per acre. Where mortality occurred, injection resulted in total kill of the tree with no subsequent sprouting.

Large regeneration

Besides analyzing the effects of the treatment on the total number of stems of the large regeneration class (stems ≥ 4.5 ft tall), several species groups were also analyzed separately. Free-to-grow stems were analyzed because they have either a dominant or codominant position in the canopy, commercial species and free-to-grow commercial species were analyzed because of their economic importance, and finally oaks were analyzed due to the interest of silviculturists and the public to promote their regeneration in the Southern Appalachians.

On both tracts, there were more stems per acre of the large regeneration class when the residual trees were controlled, either by chainsaw felling or by herbicide injection, than when the residuals were left standing. In general, the chainsaw treatment resulted in more stems per acre than the injection treatment for the two sites (see Tables 1 and 2). The statistical analysis for the Willits tract (Table 1) revealed that when all large regeneration stems were considered together, no significant differences arose among the treatments, but there were significantly more free-to-grow stems in the chainsaw and injection treatments than in the control treatment . The number of stems per acre of commercially desirable species was not affected by the treatments. The injection treatment produced significantly more free-to-grow commercial species with respect to the control treatment. Petruncio (1985) reported a significant increase in the number of seedling origin stems of commercial species on the injection plots compared to the control plots. The ten year results showed that this trend has not persisted over time and that the number of seedling-origin stems was unaffected by the treatments. On the other hand, the proportion of sprout origin stems was significantly increased by the chainsaw and injection treatments compared to the control treatment. This significance was found for the total stem regeneration, free-to-grow stems, commercial species and free-to-grow commercial species.

Oak regeneration was examined separately from the other species because of poor oak regeneration among the treatments, although the injection plots provided a slightly higher number of oaks per acre than the control and chainsaw plots.

On the Robertson tract, stem density of the large regeneration class was lower than on the Willits tract, but the number of free-to-grow stems and the number of free-to-grow commercial species were greater than on the Willits tract (Table 2). Again, this reflects the difference in site quality between the two tracts. Since the Willits tract was able to support a greater stem density, by year ten it had already reached canopy closure. Although, the Robertson tract had fewer stems per acre and canopy closure was not fully reached, the site had more stems per acre that were not overtopped, compared to the Willits tract. Overall,

few significant differences were detected, even though there was a tendency for the chainsaw plots to have higher regeneration densities than on the other plots.

Table 1.--Mean density (stems/acre) of large regeneration stems (≥4.5 ft height) on the Willits tract.

	Treatment		
	Control	Chainsaw	Injection
All species[1]			
Total stems[2]	3938	6100	5191
Seedling stems	1494	1803	1562
Sprout stems[3]	800[a]	1563[b]	1338[b]
Free-to-grow stems			
Dominant stems[4]	675[a]	1178[b]	1240[b]
Seedling stems	306	422	519
Sprout stems	369[a]	756[b]	722[b]
Commercial species			
Total stems	2796	3403	3322
Seedling stems	1146	1403	1796
Sprout stems	434[a]	700[b]	697[b]
Commercial species free-to-grow			
Dominant stems	461[a]	684[ab]	824[b]
Seedling stems	265	334	453
Sprout stems	196[a]	350[b]	371[b]
Oaks			
Total stems	678	875	925
Seedling stems	253	431	588
Sprout stems	163	228	188

Means designated with different letters are significantly different at 0.10 significance level
[1]All species include commercial and non-commercial species.
[2]Total stems include all stems per sprout clump plus seedlings.
[3]Sprouts include only one dominant stem per sprout clump.
[4]Dominant stems include one dominant stem per clump plus seedlings.

The control plots had significantly less total numbers of stems per acre than either the chainsaw or the injection plots. This difference was also observed for the number of stems of sprout origin. The number of free-to-grow stems per acre was increased by the chainsaw treatment when compared to the control treatment. The chainsaw treatment also increased the total number of stems of seedling origin, and the number of stems of sprout origin for the

Table 2.--Mean density (stems/acre) of large regeneration stems (≥4.5 ft height) on the Robertson tract.

	Treatment		
	Control	Chainsaw	Injection
All species[1]			
Total stems[2]	3309[a]	6716[c]	4500[b]
Seedling stems	1772[a]	3263[b]	2847[ab]
Sprout stems[3]	422[a]	841[c]	659[b]
Free-to-grow stems			
Dominant stems[4]	869[a]	2019[b]	1247[ab]
Seedling stems	566	1378	806
Sprout stems	303[a]	641[b]	441[ab]
Commercial species			
Total stems	2381	3134	2750
Seedling stems	1328	1834	1500
Sprout stems	269	319	347
Free-to-grow commercial species			
Dominant stems	629	1134	865
Seedling stems	413	884	584
Sprout stems	216[a]	250[ab]	281[b]
Oaks			
Total stems	856	984	1022
Seedling stems	313	438	366
Sprout stems	147	134	175

Means designated with different letters are significantly different at 0.10 significance level
[1]All species include commercial and non-commercial species.
[2]Total stems include all stems per sprout clump plus seedlings.
[3]Sprouts include only one dominant stem per sprout clump.
[4]Dominant stems include one dominant stem per clump plus seedlings.

free-to-grow class in comparison to the control treatments. It is interesting to note that the injection treatment significantly increased the number of sprout origin stems of free-to-grow commercial species with respect to the control treatment. Also the injection treatment did not have any effect on the number of seedling-origin stems present in the ten year regeneration.

The analysis of the five year regeneration (Petruncio,1985) revealed significantly higher quantities of commercial species in the chainsaw treatment than in the control treatment, and

Table 3.--Mean density (stems/acre) of large regeneration stems (≥4.5 ft height) for the Willits tract and the Robertson tract combined.

	Treatment		
	Control	Chainsaw	Injection
All species[1]			
Total stems[2]	3623[a]	6407[c]	4845[b]
Seedling stems	1633[a]	2533[b]	1955[b]
Sprout stems[3]	611[a]	1202[c]	999[b]
Free-to-grow stems			
Dominant stems[4]	772[a]	1599[b]	1243[b]
Seedling stems	436[a]	900[b]	663[b]
Sprout stems	336[a]	699[b]	580[b]
Commercial species			
Total stems	2589	3269	3036
Seedling stems	1236	1619	1648
Sprout stems	352[a]	509[b]	521[b]
Free-to-grow commercial species			
Dominant stems	545[a]	909[b]	844[b]
Seedling stems	339	609	518
Sprout stems	206[a]	300[b]	326[b]
Oaks			
Total stems	767	930	973
Seedling stems	282	434	477
Sprout stems	155	181	181

Means designated with different letters are significantly different at the 0.10 significance level.
[1]All species include commercial and non-commercial species.
[2]Total stems include all stems per sprout clump plus seedlings.
[3]Sprouts include only one dominant stem per sprout clump.
[4]Dominant stems include one dominant stem per clump plus seedlings.

a significant decrease in the number of oaks of large and small regeneration classes on the injection plots with relation to the control plots. None of these differences have persisted.

To determine if the treatments react differently at both locations, a combined analysis of variance of the two study sites was done (Table 3).

The control treatment presented significantly less total number of stems, free-to-grow stems, and free-to-grow stems of commercial species than the chainsaw and injection treatments . The chainsaw and injection treatments significantly increased seedling origin and sprout origin stems of the total large regeneration and free-to-grow regeneration with respect to the control plots. The proportion of sprout origin stems was also significantly increased by the chainsaw and injection treatments in the commercial species, and the free-to-grow commercial species, compared with the control treatment. The lack of difference in number of sprout origin stems of commercial species between chainsaw and injection treatments is probably a result of the treated residual stems being of non-commercial species.

Neither the number of oaks, nor the seedling or sprout components in the oak regeneration was affected by the treatments. As verified by the treatment means analysis for every location, the injection treatment did not promote the seedling component nor did it decrease the number of sprouts present in the regeneration.

Stand composition

Free-to-grow stems have reached a dominant or codominant position in the canopy so they provide insights into the stand composition for the immediate future. Treatment distribution of the most important species coupled with their sprout percentage is shown for both tracts in Tables 4 and 5.

On the Willits tract, four species, red maple, yellow-poplar, sweet birch, and black locust (*Robinia pseudoacacia* L.), accounted for more than 45 percent of the total stocking and together with the non-commercial group dominated the stand (Table 4). Yellow- poplar was the tallest species in every treatment averaging 22 feet in the control and injection plots and 26 feet in the chainsaw plots. Red maple, sweet birch and black locust followed in height respectively, without marked differences among them. Red maple was by far the most prolific sprouter, averaging 10 stems per clump on the control plots, 6 on chainsaw plots and only 3 on the injection plots.

Both Wendel (1975) and Lamson (1976) demonstrated for hardwood stands such as these, where a high proportion of the regeneration is of sprout origin, that usually one sprout per clump will develop into a good quality tree in the new stand. Sweet birch and yellow-poplar were usually the only species that could germinate from seeds and grow fast enough to occupy the canopy. After clearcutting in the Southern Appalachians, black locust often forms dense thickets that can severely reduce growth of other commercial species (Beck and McGee, 1974). This is why black locust was not considered to be a commercial species in this study. Nonetheless, the effect of black locust on the stand was not seen as detrimental. Black locust sprouted from root suckers and was distributed in small clumps of 2 to 3 individuals scattered throughout the plots but did not form dense thickets. In addition, as Boring and Swank (1984) have pointed out, black locust's short life span coupled with its capacity of increasing soil nitrogen through fixation provides conditions which may facilitate forest growth and successional species replacement.

Table 4.--Number of free-to-grow stems per acre and sprout percentage by species and treatment on the Willits tract.

Species	Control treatment		Chainsaw treatment		Injection treatment	
	Stems/ac	Sprout %	Stems/ac	Sprout %	Stems/ac	Sprout %
Red maple	87	93	99	92	147	74
Yellow-poplar	85	48	125	53	159	33
Northern red oak	32	50	78	44	78	28
Red oaks	15	40	32	41	122	39
White oak	38	66	91	52	59	80
Sweet birch	172	9	140	24	66	33
Black locust	81	100	238	100	188	100
Other commercia	134	22	119	55	192	37
Other non-commercial	131	68	256	66	228	71
Total	675	55	1178	64	1240	58

Table 5.--Number of free-to-grow stems per acre and sprout percentage by species and treatment on the Robertson tract.

Species	Control treatment		Chainsaw treatment		Injection treatment	
	Stems/ac	Sprout %	Stems/ac	Sprout %	Stems/ac	Sprout %
Red maple	200	40	362	22	200	42
Yellow-poplar	115	5	294	4	165	4
Red oaks	48	60	134	30	123	46
Chestnut oak	122	54	153	45	144	46
White oak	44	30	47	34	62	45
Dogwood	100	53	463	54	175	59
Other commercial	170	20	161	21	207	23
Other non-commercial	168	13	400	34	171	29
Total	869	35	2019	31	1247	37

Red oaks predominated the oak regeneration. The amount of northern red oak (*Quercus rubra* L.) present in every treatment was much greater than the density reported by McGee and Hooper (1975) in a ten year old clearcut on the Bent Creek Experimental Forest (North Carolina) of higher site quality. The authors found only 10 free-to-grow red oak stems per acre contrasting with what is reported here; 32 stems per acre in the control treatment and 78 stems in the chainsaw and injection treatments. Beck and Hooper (1986), reevaluating the same stand as in the previous study, reported that 10 years later oaks comprised less than 4 percent of the stand's basal area and northern red oak was less than 1 percent. The northern red oak trees present in this study were 4 to 6 feet shorter than yellow-poplar. More than 55 percent of the chainsaw and injection subplots and 37 percent of the control subplots had one or more northern red oak stem present. The uncertainty that remains is whether these red oaks are going to be able to maintain their present position in the canopy. Oliver (1980) thinks that red oaks will eventually out compete the other species and form the dominant canopy. Beck and Hooper (1986) and Loftis (1988) believe that this will not occur on high quality sites in the Southern Appalachian hardwood forests where yellow-poplar is the major competitor. Species included in the non-commercial group, including dogwood (*Cornus florida* L.), sassafras (*Sassafras albidum* (Nutall) Nees), and sourwood (*Oxydendrum arboreum* (l.) DC), are expected to be soon relegated to the understory. These lower stratum species can act as a "trainers" (Ross et al. 1982) and keep the upper stratum trees well pruned (Oliver, 1980).

On the Robertson tract (Table 5) black locust and sweet birch were absent in the dominant strata. The commercially dominant species, red maple, yellow-poplar, white oaks (especially chestnut oak (*Quercus prinus* L.)) and red oaks, comprised 64 percent of the free-to-grow stems in the control plots, 50 percent on chainsaw and 56 percent on the inject plots. Yellow-poplar had outgrown chestnut oak by 6 feet on the control plots. On the other two treatments, chestnut oak was the tallest tree, although it surpassed yellow-poplar and red maple by only 4 to 2 feet. Because the Robertson tract is of lower site quality than the Willits tract, yellow-poplar was not able to compete as aggressively as it had on the Willits tract. When considering all species together, sprouting percentages were generally lower on the Robertson tract than on the Willits tract. Red maple stems of sprout origin made up 74 to 93 percent of the free-to-grow stems on the Willits tract, but on the Robertson never exceeded 42 percent. This may result from older trees being logged on the Robertson tract, which would decrease the sprouting capacity of the stumps (Wendel, 1975).

Of the non-commercial free-to-grow species, dogwood made up more than 37 percent of the stems, but it was 6 to 12 feet shorter than the tallest dominant tree. Other species that comprised the non-commercial group, mainly sassafras, sourwood and Carolina silverbell (*Halesia carolina* L.) were also shorter than the tallest tree. These species will continue to lag behind the overstory and can regulate sprout clump competition from the side, so they will not expand and dominate large areas (Ross et al. 1982).

The total number of stems in the large regeneration class, including all stems per clump plus all seedlings, have declined over time for both tracts (Figure 1). From years 5 to 10 both tracts had control plot mortality rates near 30 percent. The chainsaw plots had mortality rates of 44 and 27 percent on the Willits and the Robertson tracts, respectively. The injection plots had less than 10 percent mortality on both tracts. Mortality rates have decreased the

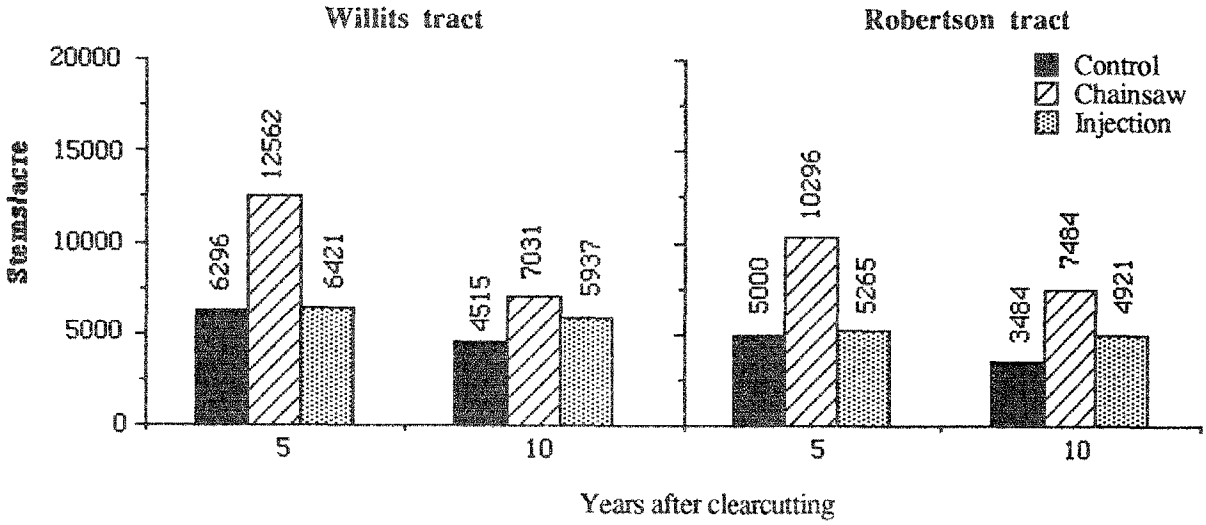

Figure 1. Change in the total number of stems per acre of the large regeneration class (stem≥4.5 ft height) from year 5 to year 10 following clearcutting, by treatment and site.

differences among treatments, especially among the chainsaw and inject treatments. Figure 2 follows sprout-origin (includes only one stem per clump) evolution over the years. Sprout origin stems have decreased by more than 50 percent for every treatment on the Willits and the Robertson tracts with the exception of the inject treatment on the Robertson tract which had only a 22 percent sprout decrease. Again, the differences at year five, particularly among the chainsaw and the injection treatments, have been attenuated to the point that an analysis of variance only detected significant differences among the control and either the chainsaw and injection treatments but not between the chainsaw and the injection treatments (see Tables 1 and 2). A higher reduction of the sprout component was reported by Gammon et al. (1968) for a seven year old hardwood clearcut in southern Michigan where only 22 percent of the sprouts survived. By contrast, seedling origin stems have increased dramatically over time (Figure 3). This increase can be attributed to several factors: seedlings growing over 4.5 feet and moving from the small to the large regeneration class, natural thinning and healing of stems sprouting from stems of small stumps (that at year ten were indistinguishable from true seedlings), and germination of new seedlings that continue to reproduce since the cut (as is the case of yellow-poplar, Minckler and Woerheide, 1965). From years 5 to 10 after clearcutting, the difference in the number of seedling-origin stems between the chainsaw and injection treatments has decreased for both tracts, contrasting to the control treatment where differences have increased in relation to the other two treatments.

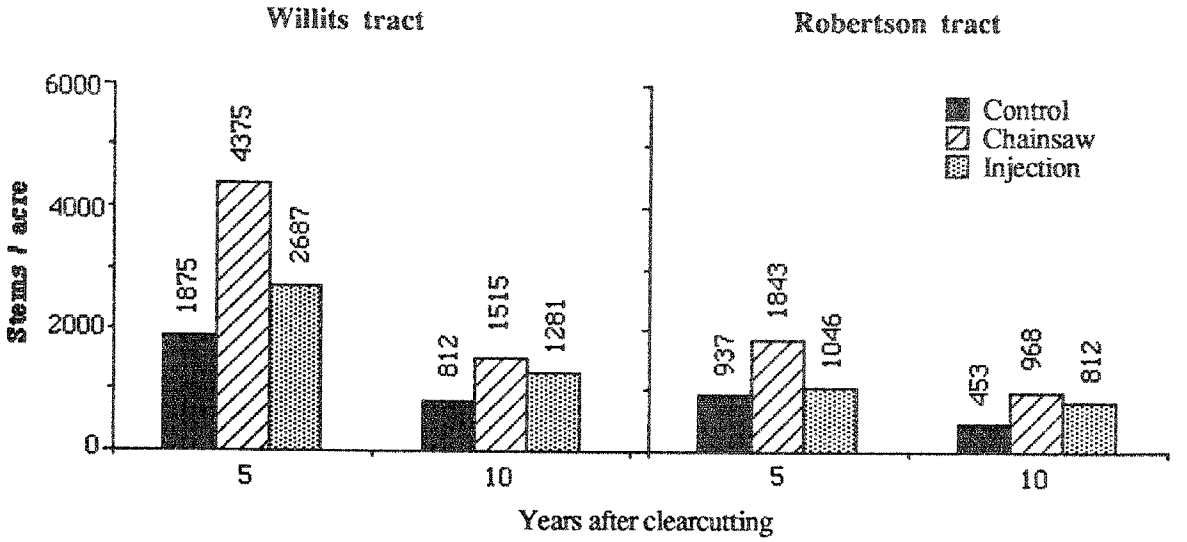

Figure 2. Change in the total number of sprout origin stems per acre (only one stem per clump) of the large regeneration (stems≥4.5 ft height) from year 5 to year 10 following clearcutting, by treatment and site.

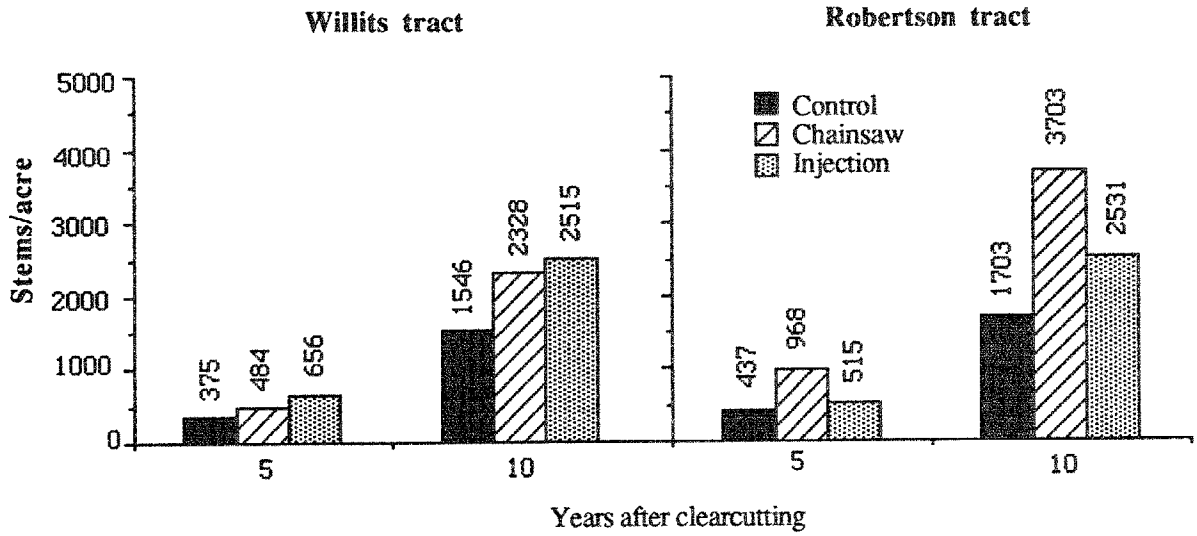

Figure 3. Change in the total number of seeding origin stems per acre of the large regeneration class (stems≥4.5 ft height) form year 5 to year 10 following clearcutting by treatment and site.

SUMMARY

The absence of many of the significant differences that were observed in the evaluation of the study five years ago was a consequence of the differential mortality rates presented by the treatments. This mortality had especially attenuated the differences between the chainsaw and injection treatments. After 10 years, the amount and quality of regeneration promoted by the chainsaw treatment, coupled with its economic and aesthetic advantages over the injection treatment, indicated that chainsaw felling the residuals is the most desirable management option when regenerating hardwood stands of good to average productivity in the Southern Appalachians.

Natural thinning is expected to continue in the years to come as a result of competition, and as Beck and Hooper (1986) reported, the decline may be more rapid in the next five years than what has been observed until now. A follow up of this study is necessary to determine the degree and intensity of the treatments at the end of the rotation.

Besides timber values, other considerations concerning the removal of residuals have to be examined, for example, the economic implications of the treatments. Chainsaw felling the residuals either at the time of harvest or after, is considered to be less expensive than herbicide injection of the residuals (Brenneman, 1988). In regard to aesthetic values, the standing dead trees left by the injection treatment, which persist for at least a decade after logging, can have an adverse impact on the scenic beauty of the stand (Vodak et al. 1985). If wildlife is a matter of concern, leaving chosen residual trees will provide nesting cavities, some mast, and vertical stratification (Smith, 1988). Ultimately, landowner objectives, whether timber oriented or others, will dictate whether and how to remove the residual trees.

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DEVELOPMENT OF REGENERATION FOLLOWING GYPSY MOTH DEFOLIATION OF APPALACHIAN PLATEAU AND RIDGE & VALLEY HARDWOOD STANDS[1,2]

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Abstract: The effects of gypsy moth defoliation and subsequent overstory mortality on regeneration were examined in 26 stands in Pennsylvania and Maryland. The Pennsylvania stands were located in the Appalachian Plateau physiographic province, and the Maryland stands were located in the Ridge & Valley province. Pre–defoliation data (1984-1986) were compared with post–defoliation data (1989) from the same 315 six-foot–radius plots. Seedlings of all woody vegetation were counted by species and height class. Separate matched pair t-tests were used to test for differences in pre- and post–defoliation regeneration counts for the most common species in each province. In the Appalachian Plateau, the total numbers of white oak, chestnut oak, and northern red oak decreased while the numbers of less desirable species (red maple, blueberries, raspberries, and greenbriers) increased following defoliation. In the Ridge & Valley, the total number of white oak also decreased; however there was an increase in the number of chestnut oak and northern red oak. The number of less desirable species increased as well, specifically red maple, black cherry, serviceberry, blueberries, and raspberries. In both provinces, there were fewer than 165 oak seedlings per acre in the greater-than-3-foot-height class following defoliation. Therefore, it appears that adequate oak regeneration had not become established in these stands at the time of our study.

INTRODUCTION

The impact of gypsy moth (*Lymantria dispar* L.) defoliation and subsequent overstory mortality on regeneration is of concern to forest managers interested in regenerating oak stands, yet little is known about this impact. It has been reported that some species of

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advance regeneration beneath a defoliated oak canopy (e.g., red maple (*Acer rubrum* L.)) may benefit from the increased light intensity and nutrients in the insect frass (Collins 1961). In a mature oak forest in New Jersey, Ehrenfeld (1980) found that 7-year-old gaps caused by the gypsy moth were dominated by the red maple, American beech (*Fagus grandifolia* Ehrh.), and black birch (*Betula lenta* L.) that had become established in them at or before the time of defoliation. Very little new establishment of plants had occurred; tree reproduction was apparently inhibited or excluded. In 1985, Gansner observed that after 10 years a particular heavily-defoliated oak–hickory stand in northeastern Pennsylvania had very little regeneration of commercial species. Blueberries (*Vaccinium* spp.), witch-hazel (*Hamamelis virginiana* L.), raspberries (*Rubus* spp.), and several species of ferns dominated the understory, along with some tree seedlings that had been heavily browsed by deer. More recently, Allen and Bowersox (1989) found that defoliated oak stands in the Allegheny Mountains and the Ridge & Valley Provinces had understories dominated by red maple, birch, and non–commercial species. Only 4-16% of the stems were northern red oak (*Quercus rubra* L.) or white oak (*Q. alba* L.). In all these studies, the stands were examined several years after defoliation, and their pre–defoliation understory compositions were unknown.

Our study benefitted by the availability of pre–defoliation data, so we were able to compare prior understory compositions with the regeneration that existed after defoliation. The purpose of this paper is to examine the effects of gypsy moth infestation on the development of hardwood stand regeneration in the Appalachian Plateau and Ridge & Valley physiographic provinces.

METHODS

A total of 26 stands were sampled in this study. Seventeen stands were located in the Appalachian Plateau physiographic province in Somerset County, Pennsylvania (Figure 1). These stands are on tracts managed by either the Pennsylvania Game Commission, Westvaco Company, or a private landowner. Topography of the stands ranged from relatively flat, elevated plateaus at 2,250 feet above sea level to rugged, mountainous terrain with many short ridges and steep coves. The average site index for northern red oak was 55 feet (range 32-91). Stands were primarily of pole- and small sawtimber-size and of mixed-oak composition (oaks averaged of 74 percent of the basal area). In general, these stands were moderately defoliated in 1985, severely defoliated in 1986, lightly defoliated in 1987, and virtually undefoliated in 1988 and 1989. The average reduction in percent stocking over the five-year period was 28%. A more detailed description of these Appalachian Plateau stands including their defoliation and mortality histories can be found in Fosbroke and Hicks (1989).

Nine more stands were located in the Ridge & Valley province of western Maryland (Figure 1). All Ridge & Valley stands used in the study are on Green Ridge State Forest in Allegany County, Maryland. Elevations range from 475 to 2,309 feet above sea level. The primary forest type of this area is mixed-oak (oaks averaged 66 percent of the basal area). The average site index was 56 feet (range 34-76). In general, these stands were moderately defoliated in 1985 and 1986. The study stands received little defoliation in 1987, 1988, or

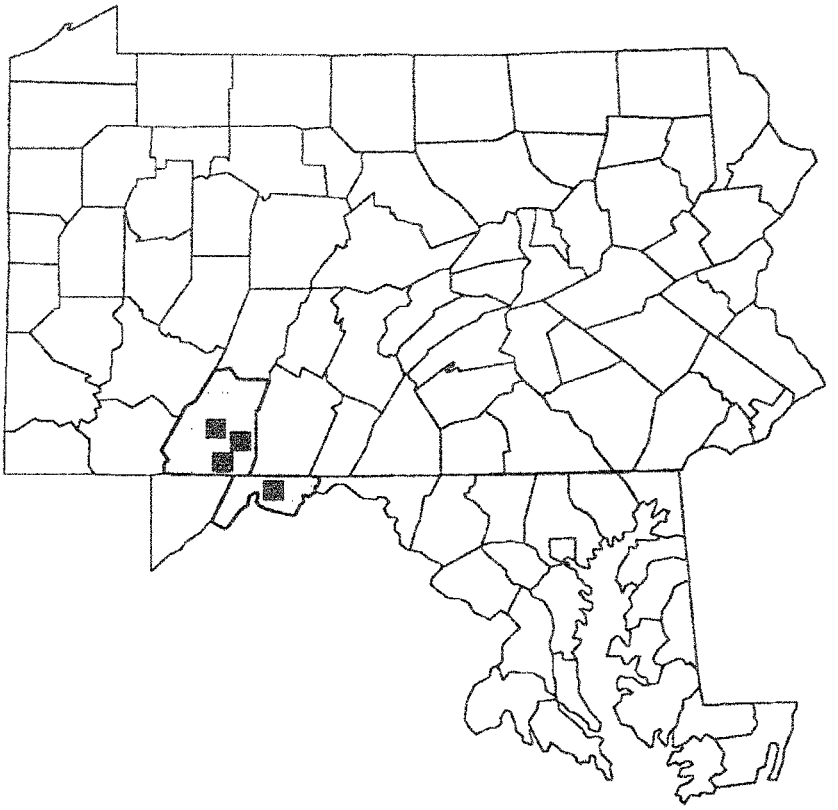

Figure 1. Regeneration plots were located in Pennsylvania and Maryland. The Pennsylvania stands were located in the Appalachian Plateau physiographic province, and the Maryland stands were located in the Ridge and Valley province.

1989. The average reduction in stocking was 14 percent. Though portions of Green Ridge State Forest were defoliated by a looper complex in 1981, none of the stands used in this study were involved in this previous defoliation event. Crow and Hicks (1990) provide a more complete description of the Ridge & Valley stands.

Within each stand, the understory vegetation was surveyed on a series of 6-foot–radius plots. The number of plots per stand ranged from five to thirty. All woody vegetation was tallied by species and height class (< 1.0 ft, 1.0-3.0 ft, and > 3.0 ft but less than 2.9 in. dbh). From 1984 to 1986, 315 plots (194 in PA, 121 in MD) were inventoried prior to gypsy moth defoliation. These same plots were again inventoried following defoliation in 1989.

Analysis of variance indicated that many of the most abundant species differed between physiographic provinces in their response to gypsy moth defoliation and subsequent mortality

(Fosbroke, unpublished data). Therefore, the development of regeneration in each province was analyzed separately.

Since the same plots were measured pre- and post-defoliation, matched pair t-tests were used to determine if there was a significant change in the number of understory stems per acre following gypsy moth defoliation and subsequent tree mortality. A separate test was done for each of the 13 most abundant species (chestnut oak (*Quercus prinus* L.), northern red oak, white oak, red maple, sugar maple (*Acer saccharum* Marsh.), black cherry (*Prunus serotina* Ehrh.), black birch, witch-hazel, downy serviceberry (*Amelanchier arborea* (Michx. f.) Fern.), dogwoods (*Cornus* spp.), blueberries, raspberries, and greenbriers (*Smilax* spp.)). Separate tests were also done for each height class of white oak, northern red oak, chestnut oak, red maple, sugar maple, black cherry, and black birch. Only plots which had a given species either before or following defoliation were included in the test for that species. Therefore, the means reported in Tables 1 and 2 represent the average number of stems per acre for those plots in each province where each species was present. These means do not represent the average number of stems of each species for the entire province.

Each of the species was then placed into one or more of four broad groups for additional testing. The commercial tree species group consisted of red maple, sugar maple, northern red oak, white oak, chestnut oak, black oak (*Quercus velutina* Lam., scarlet oak (*Q. coccinea* Muenchh.), black birch, black cherry, American beech, yellow-poplar (*Liriodendron tulipifera* L., hickories (*Carya* spp.), butternut (*Juglans cinerea* L.), cucumbertree (*Magnolia acuminata* L.), eastern white pine (*Pinus strobus* L.), table-mountain pine (*P. pungens* Lamb.), and eastern hemlock (*Tsuga canadensis* (L.) Carr.). An all oak group contained northern red oak, scarlet oak, black oak, white oak, and chestnut oak. Non-commercial tree species included black locust (*Robinia pseudoacacia* L.), American elm (*Ulmus americana* L.), slippery elm (*U. rubra* Muhl.), sassafras (*Sassafras albidum* (Nutt.) Nees), pin cherry (*Prunus pensylvanica* L.), and black gum (*Nyssa sylvatica* Marsh.). The final group includes shrubs, vines and small trees which are usually restricted to the understory and considered competing vegetation. The species that make up this "all other woody plants" group are blueberries, raspberries, greenbriers, dogwoods, witch-hazel, downy serviceberry, mulberries (*Morus* spp.), crabapples (*Crataegus* spp.), minniebush (*Menziesia pilosa* (Michx.) Juss.), spicebush (*Lindera benzoin* (L.) Blume), eastern redbud (*Cercis canadensis* L.), azaleas (*Azalea* spp.), American chestnut (*Castanea dentata* (Marsh.) Borkh.), honeysuckles (*Lonicera* spp.), currants (*Ribes* spp.), boxelder (*Acer negundo* L.), striped maple (*A. pensylvanicum* L.), grapes (*Vitis* spp.), Virginia creeper (*Parthenocissus quinquefolia* (L.) Planch.), poison ivy (*Toxicodendron radicans* (L.) Kuentze), mountain laurel (*Kalmia latifolia* L.), roses (*Rosa* spp.), devil's walkingstick (*Aralia spinosa* L.), American hornbeam (*Carpinus caroliniana* Walt.), and eastern hophornbeam (*Ostrya virginiana* (Mill.) K. Koch). Comparisons were made for the total number of stems and for each height class for each of these four species groups.

RESULTS

Appalachian Plateau Province

For many tree species, the matched pair t—tests indicated that the average pre-defoliation numbers of stems per acre of various height classes were significantly different from the post-defoliation numbers (Table 1). For instance, prior to defoliation the most common commercial tree species was red maple (5038 stems/acre). The total number of red maple significantly increased ($P < 0.001$) to 10,763 following defoliation. Other commercial tree species that increased in total number following defoliation were black cherry and black birch, while sugar maple decreased (Table 1). However, these changes were not significant ($P > 0.1$). It is interesting to note that the number of stems in the 1-3—foot height class of each of these four species increased following defoliation, although only two of these increases were significant at the 10% level (Table 1). The trend for the all commercial tree species group was similar with significant increases ($P < 0.001$) in all height classes except the greater-than-3-foot class (Table 2).

Numbers of chestnut oak, northern red oak, and white oak of most height classes significant decreased ($P < 0.1$) in numbers after defoliation, with the exception of the 1-3-foot classes (Table 1). But, the increases in the 1—3—foot class for all three major oak species were not significant ($P > 0.2$). However, there was a significant increase ($P < 0.01$) in this height class for the species group that includes all oaks (Table 2). Otherwise, the total number of all oaks and the 0-1—foot class of all oaks significantly decreased ($P < 0.03$) following defoliation. Following defoliation, an average of only 162 oak stems per acre greater than 3 feet tall were present (Table 2).

As a group, the total number of non-commercial tree species increased from 2282 to 2729 stems per acre following defoliation (Table 2). This increase was not significant at the 10% level.

The overall increase in density following defoliation was primarily the result of the large significant increase ($P < 0.001$) in total number of the all other woody plants species group (Table 2). Most of these stems were less than 1 foot tall (Table 2). The two most common species groups following defoliation were blueberries and raspberries, numbering approximately 41,000 and 19,000 stems per acre, respectively (Figure 2). Greenbriers also increased significantly ($P < 0.04$) after defoliation, although by a lesser amount (Figure 2). The total numbers of witch-hazel and serviceberry increased significantly ($P < 0.06$) following defoliation, while there was a significant decrease ($P < 0.02$) in the total number of dogwoods (Figure 2).

Table 1.--Average numbers of stems per acre of the major tree species by height class and paired t-test significance levels for hardwood stands before and after gypsy moth defoliation in the Appalachian Plateau and Ridge & Valley provinces.

Species	Height class	Appalachian Plateau			Ridge & Valley		
	(feet)	Pre-	Post-	P > t	Pre-	Post-	P > t
Chestnut oak							
	0-1	1491	856	0.050	3326	6411	0.009
	1-3	372	440	0.412	754	987	0.365
	> 3	122	77	0.032	192	128	0.132
	All	1985	1373	0.086	4172	7526	0.010
Northern red oak							
	0-1	1825	959	0.004	1045	1537	0.049
	1-3	262	363	0.203	175	434	0.004
	> 3	79	41	0.023	8	19	0.181
	All	2166	1363	0.007	1228	1991	0.010
White oak							
	0-1	1981	1438	0.014	4355	3043	0.004
	1-3	420	426	0.959	347	323	0.777
	> 3	144	137	0.742	185	81	0.033
	All	2545	2002	0.056	4888	3447	0.003
Red maple							
	0-1	4143	9807	0.0001	1749	7463	0.001
	1-3	580	756	0.078	821	927	0.340
	> 3	314	199	0.015	271	208	0.219
	All	5038	10763	0.0001	2842	8599	0.001
Sugar maple							
	0-1	1699	1586	0.729	544	1269	0.326
	1-3	498	634	0.235	476	227	0.531
	> 3	709	498	0.076	90	45	0.332
	All	2908	2719	0.583	1110	1540	0.665
Black cherry							
	0-1	1544	1243	0.254	650	5135	0.004
	1-3	385	1010	0.0001	333	465	0.168
	> 3	84	80	0.867	40	160	0.028
	All	2013	2333	0.128	1023	5761	0.002
Black birch							
	0-1	1528	1023	0.250	--*	--	--
	1-3	657	1193	0.167	--	--	--
	> 3	549	751	0.320	--	--	--
	All	2734	2968	0.707	--	--	--

*In the Ridge & Valley province, black birch was found on only one plot prior to defoliation, and it was not found on any plots following defoliation.

Table 2.--Average numbers of stems per acre of species groups by height class and paired t-test significance levels for hardwood stands before and after gypsy moth defoliation in the Appalachian Plateau and Ridge & Valley provinces.

Species	Height class	Appalachian Plateau			Ridge & Valley		
	(feet)	Pre-	Post-	P > t	Pre-	Post-	P > t
All oaks							
	0-1	3195	2163	0.001	6267	6375	0.864
	1-3	594	934	0.001	953	1067	0.427
	> 3	195	162	0.108	222	124	0.011
	All	3984	3259	0.027	7442	7566	0.854
All commercial trees							
	0-1	8138	12052	0.0001	8620	16956	0.0001
	1-3	1703	2909	0.0001	2298	2521	0.319
	> 3	889	782	0.256	729	551	0.028
	All	10730	15743	0.0001	11647	20028	0.0001
All non-commercial trees							
	0-1	1900	1864	0.907	2116	1921	0.441
	1-3	300	751	0.008	997	820	0.071
	> 3	82	114	0.259	172	131	0.431
	All	2282	2729	0.262	3285	2873	0.149
All other woody plants							
	0-1	22405	35700	0.0001	19945	30233	0.0001
	1-3	5688	8988	0.0001	5077	8120	0.0001
	> 3	1503	972	0.0004	2200	1264	0.0001
	All	29595	45660	0.0001	27222	39617	0.0001
All of the above							
	0-1	31519	48577	0.0001	30125	48539	0.0001
	1-3	7566	12277	0.0001	8231	11217	0.0002
	> 3	2456	1811	0.0002	3247	1907	0.0001
	All	41541	62665	0.0001	41603	61663	0.0001

*Species groups are defined in the Methods section.

Ridge & Valley Province

As was true in the Appalachian Plateau province, the matched pair t-tests indicated that the average pre-defoliation numbers of stems per acre of various height classes of many tree species were significantly different from the post-defoliation numbers (Table 1). Prior to

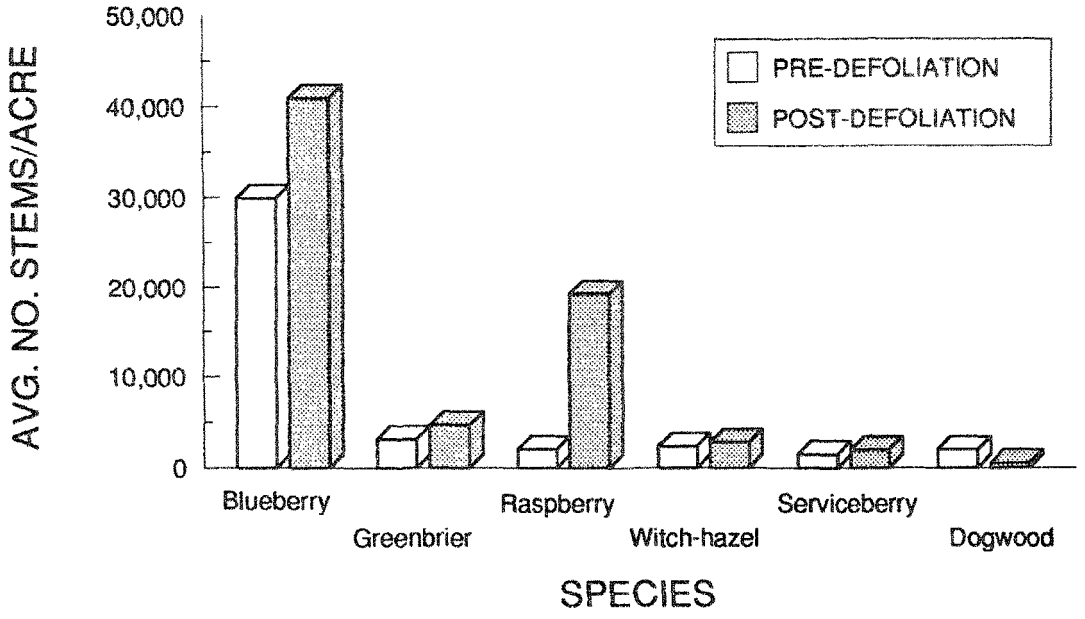

Figure 2. Histograms of the average numbers of stems per acre of the major species of competing vegetation before and after gypsy moth defoliation on the Appalachian Plateau province. All differences between the pre- and post–defoliation numbers were significant at the 10% level.

defoliation, the most common commercial tree species were white oak and chestnut oak (4888 and 4172 stems/acre, respectively). These two oak species reacted differently following defoliation; chestnut oak significantly increased ($P = 0.01$) to 7526 stems per acre while white oak significantly decreased ($P < 0.01$) to 3447 stems per acre. The vast majority of the oak stems were still less than 1 foot tall in 1989. Following defoliation, red maple was again the most common commercial tree species with 8599 stems per acre. Two other commercial tree species that significantly increased ($P < 0.011$) in total number following defoliation were northern red oak and black cherry (Table 1). Sugar maple also increased following defoliation but not significantly ($P > 0.6$). As a group, all commercial tree species approximately doubled with significant increases ($P < 0.001$) in both total number and in the 0-1-foot height class (Table 2). The greater-than-3-foot class significantly decreased ($P < 0.03$) following defoliation.

The only significant change ($P = 0.011$) in any height class for the all oaks species group was a 44% decrease in the greater-than-3-foot class (Table 2). Following defoliation, an average of only 124 oak stems per acre greater than 3 feet tall were present (Table 2).

Each height class of the all non-commercial tree species group decreased following defoliation (Table 2), but only the decrease in the 1-3-foot height class was significant ($P < 0.1$).

Following defoliation, there was a large significant increase ($P < 0.001$) in total number and in the 0-1-foot-height class of the all other woody plants species group (Table 2). Blueberries were still the most common species group following defoliation, with about 16,000 stems per acre present (Figure 3). Raspberries also increased significantly ($P < 0.02$) after defoliation (Figure 3). The total number of serviceberry increased significantly ($P = 0.01$) following defoliation, while there was a significant decrease ($P < 0.001$) in the total number of dogwoods (Figure 3). The total numbers of witch-hazel and greenbriers did not significantly change ($P > 0.7$) after defoliation (Figure 3).

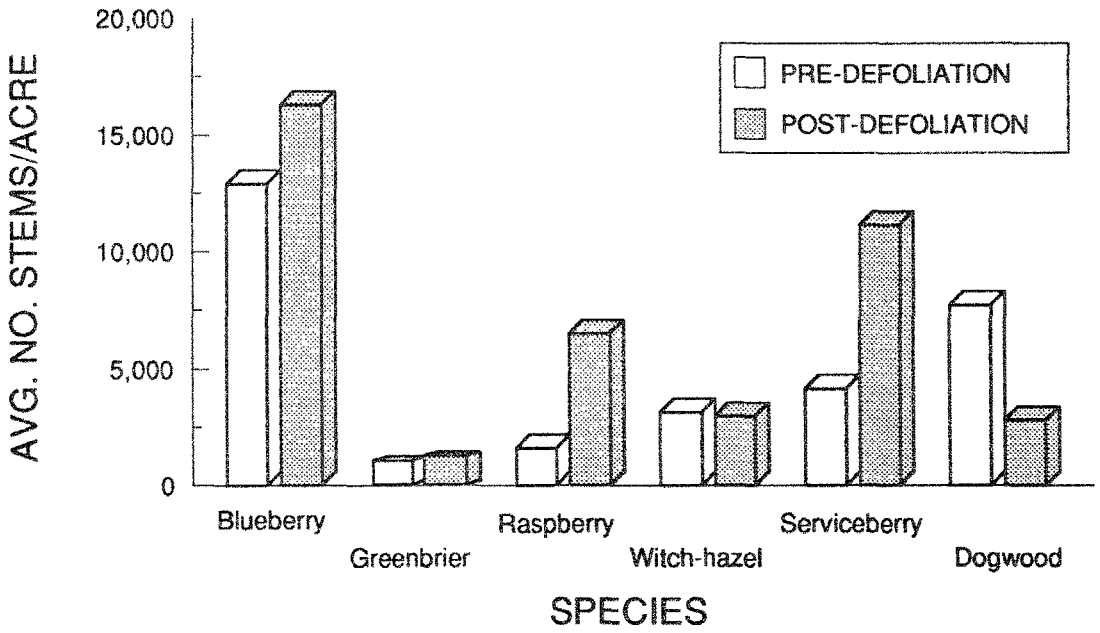

Figure 3. Histograms of the average numbers of stems per acre of the major species of competing vegetation before and after gypsy moth defoliation on the Ridge & Valley province. Differences between the pre- and post–defoliation numbers for blueberry, raspberry, serviceberry, and dogwood were significant at the 10% level.

The total densities, before and after defoliation, were very similar between the two provinces (Table 2). The changes in the number of stems per acre in each height class were also very similar in magnitude and direction (Table 2). All of these changes were highly significant

($P < 0.001$). It is interesting to note that the only decreases were in the greater—than-3—foot-height class.

DISCUSSION

Comparisons of the Results with Other Studies

Tree mortality in gypsy moth-defoliated stands is often patchy, and the result is a mosaic of gaps interspersed within an otherwise continuous forest canopy. Ehrenfeld (1980) studied these kinds of gaps in a New Jersey oak forest seven years following gypsy moth defoliation, and found that their understory composition contrasted sharply with the surrounding "recovered forest". Allen and Bowersox (1989) examined the understories of Pennsylvania stands which had suffered at least a thirty percent volume reduction of the overstory due to gypsy moth-induced mortality. Their regeneration counts were made six to seven years following mortality. They concluded that although commercial tree species were adequately regenerating, lower-value species were still much more common than the oaks. The results from the current study provide additional information about the change in regeneration occurring over a short period of time following defoliation and subsequent overstory mortality. Our data come from stands which experienced a range of defoliation levels and suffered various degrees of tree mortality. In stands where mortality was moderate to severe, trees began dying by the summer of 1986. Therefore, these data represent a point in time 2-3 years following the initiation of tree mortality, and it remains to be seen how the regeneration will develop in these stands in the future.

A lack of an increase in species richness led Ehrenfeld (1980) to suggest that new species are not recruited following gypsy moth-induced tree mortality. Those species which were already present on the site expanded to fill canopy gaps. We also did not find new species establishing 1-3 years following tree mortality. In fact, prior information about the number of stems of a given species prior to defoliation is highly significant in determining the importance of that species in the understory following defoliation (Fosbroke unpublished data).

This paper does not attempt to describe differences in the response of understory vegetation to gypsy moth under varying levels of defoliation, mortality, and site quality. However, it is expected that the higher the level of defoliation and subsequent mortality, the greater the understory response. Results of analysis of variance tests by Fosbroke (unpublished data) indicate that overstory mortality, site index, and physiographic province are all important factors related to the differences between pre- and post-defoliation regeneration.

There seems to be a consensus among forest managers who have seen the effects of gypsy moth defoliation that the understories in defoliated stands are dominated by low-value species. Results from earlier studies suggest that this is usually the case (Ehrenfeld 1980, Allen and Bowersox 1989). The results of our study also indicate a profusion of seedlings of species

which will either not become a part of the overstory or will be of low value. In ours and other studies, red maple, black birch, blueberries, and raspberries were often the species which increased the most following defoliation. There is also an increase in the total density from about 42,000 to 62,000 stems per acre in both provinces, as a result of the additional light, nutrients, and moisture reaching the forest floor.

In both provinces, the dogwood genus reacted differently than the other major species of competing vegetation. There were significant decreases in the total numbers of dogwoods (primarily *Cornus florida* L.) following defoliation. This is in contrast to the stands studied by Ehrenfeld (1980) where flowering dogwood became the most common species in the understory following defoliation. Perhaps this difference between the two studies is due to site or geographical factors, or it may indicate the increased incidence of the lethal disease dogwood anthracnose (Hibben and Daughtrey 1988) in forests of the study area.

Differences in Regeneration Between Provinces

Though we did not test for differences in regeneration counts between provinces as did Allen and Bowersox (1989), some comparisons can be made between their results and ours. The Allegheny Mountains are a subregion of the Appalachian Plateau physiographic province. Plots located there by Allen and Bowersox were geographically near our study areas. In comparing post-defoliation densities between the two studies, both studies show a similar trend for red maple with respect to province: the Ridge & Valley province had fewer red maples per acre in the understory following defoliation than the Appalachian Plateau province. However, Allen and Bowersox found roughly twice as many red maple per acre in both provinces as we did. In contrast, Allen and Bowersox found less than half as many birch stems per acre in the understories of Allegheny Mountain stands following defoliation than we did on the Appalachian Plateau. The greatest difference between the two post-defoliation regeneration tallies was that we found virtually no birch in the Ridge & Valley province compared with the 7,986 stems per acre found by Allen and Bowersox. Differences are expected between the means of any two regeneration studies of this type due to random variability and to the unequal amounts of time following defoliation. Regardless, in both studies red maple and black birch appear to be thriving in post-defoliation understories and are likely to become serious competitors with the more valuable species for growing space, nutrients, moisture, and light.

Other forms of ground vegetation besides tree seedlings are very important restrictors of the future establishment and growth of desirable regeneration. Allen and Bowersox (1989) found ferns and blueberries to be the most common species in the ground cover. Ferns occupied an average of 38 percent of the ground in the Allegheny Mountains and 6 percent in the Ridge & Valley province. Blueberries covered 14 percent of the Allegheny Mountain sites and 21 percent of the plots in the Ridge & Valley province. Although we did not determine the coverage of ferns, there is no doubt that blueberries and raspberries are also important competitors in the stands we studied. In the Appalachian Plateau province, we found approximately 35,000 stems per acre of these two species prior to defoliation. Following

defoliation, the number increased to 65,000. In the Ridge & Valley province, both the pre- and the post-defoliation number of these species were somewhat lower, 15,000 and 23,000 stems per acre, respectively.

Future Development of Oak Stands in These Provinces

The problem of regenerating oaks on good sites is a serious concern of forest managers throughout most of the eastern United States (Lorimer 1989). In this study, white oaks of all height classes consistently declined in numbers following gypsy moth defoliation. Northern red oak and chestnut oak also decreased in total number in the Appalachian Plateau province, but increased in the Ridge & Valley province. The majority of the increases were in numbers of stems less than 3 feet tall. Interestingly, there was even an increase in the numbers of these two oak species in the 1-3–foot height class for the Appalachian Plateau province. Oak seedlings were generally more common in the Ridge & Valley province than in the Appalachian Plateau province. Allen and Bowersox (1989) also found more oak seedlings in the Ridge & Valley.

It appears that the existing advance regeneration of oaks is responding to defoliation by increasing in height. However, only about 125-165 oak stems per acre are presently tall enough (greater than 3 feet) to have a chance of successfully competing with other faster-growing species like black cherry, black birch, and red maple. It is unknown precisely how many oak seedlings (and of what size) should be established in a stand before it is regenerated. Sander *et al.* (1976) concluded that at least 430 seedlings at least 4.5 feet tall would be needed to ensure a pole-size stand containing 30% oaks. In our stands, regeneration is currently insufficient to meet this criterion. The oak component in future stands will depend to a great degree on how many of the small oak seedlings (0-1 foot tall) survive and grow. Because of the influx of competing vegetation (e.g., red maple, blueberries, and raspberries), we speculate there may be a reduced oak component of gypsy moth–defoliated stands in the future. Because of this shift in composition and the increased species diversity of stands, the future impact of the gypsy moth may be diminished in these provinces.

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SILVICULTURAL CUTTING OPPORTUNITIES IN OAK-HICKORY FORESTS OF WEST VIRGINIA

Stanford L. Arner, David A. Gansner, Martin E. Dale, and H. Clay Smith[1]

Abstract: Analysis of cutting opportunities for oak-hickory forests of West Virginia reveals a storehouse of economic opportunity. The potential cut from silviculturally sound thinning, regeneration, and harvest opportunities totals 100 million cords, or 60 times the current annual harvest of growing stock volume from the state. On the stump, the conversion value of this material totals $2.4 billion. Moreover, the good housekeeping associated with this silviculture would improve timber productivity and quality.

INTRODUCTION

During the early 1900's, West Virginia was a lumbering giant. In 1909, some 1,500 mills in the state produced 1.5 billion board feet of lumber to feed the needs of a growing industrial Nation. Unfortunately, "cut and move" was the rule in those days and little attempt was made to revegetate the landscape (Clarkson 1965). Wildfires followed the logging to complete the virtual destruction of the forest. Many believed the resource was ruined and never would return to the way it was.

But a recent inventory shows that West Virginia's woodlands are well on the road to recovery (Gansner et al. 1990). And the wood-using industry has taken notice. Log exporters and domestic mill operators are looking to West Virginia for more high-quality logs and bolts (Widmann 1990). Also, more of the small and low-grade material that has had limited markets in the past is finding its way into products such as pulpwood, pallets, and fuelwood. Concurrently, resource managers and policymakers, determined not to repeat the mistakes of a reckless past, are emphasizing cutting practices that are environmentally sound. The time is ripe to reevaluate cutting opportunities in the Mountain State.

This study looks at cutting opportunities for oak-hickory forests of West Virginia, a 9.2-million-acre resource that accounts for four-fifths of the state's timberland and is a major contributor to local and regional economies. Effects of timber prices, characteristics of ownership, woodland accessibility, traditional cutting practices, and other factors that influence the economic availability of timber were not considered in the analysis. An

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assessment of how these variables affect timber supplies would be extremely difficult and perhaps meaningless at a time when timber inventories and growth seem more than adequate to satisfy most current needs.

Instead, we have identified the acreage of timberland and yields of timber associated with recommended silvicultural cutting practices for the oak-hickory timber type. This same procedure could be used to determine cutting opportunities for all 118 million acres of the oak-hickory timber type in the Eastern United States. With modification, this approach could be used to analyze other forest types.

PROCEDURE

West Virginia's oak-hickory forest exhibits virtually every stage of stand condition and development. Our first task was to sort this highly variable resource into general yet well-defined cutting opportunities that are in keeping with the principles of sound silviculture (Roach and Gingrich 1968). A cutting decision guide that incorporates information about acceptable tree stocking, stand size, and recommended removals of timber was used (Fig. 1). The guide indicates, for example, that a well-stocked (B+) sawtimber-size stand with more than 50 percent of its sawtimber volume in trees 16 inches d.b.h. and larger should be harvested. B-level stocking is the lower limit of full stocking based on a stand's d.b.h., basal area, and number of trees per acre. Harvest opportunities with harvest volumes of more than 8,000 and less than 8,000 board feet/acre are identified as opportunities 1 and 2, respectively. A well-stocked sawtimber-size stand with less than 50 percent of its sawtimber volume in trees 16 inches d.b.h. and larger should be thinned to B-level stocking so that residual trees will make most efficient use of the site. Thinning opportunities in sawtimber stands where the recommended cuts amount to more than 5 cords and less than 5 cords/acre are recognized as opportunites 3 and 4, respectively. And so on. In all, 10 distinct cutting opportunities are identified by the guide.

The cutting decision guide was used to sort data from 1959 inventory plots from the latest forest survey of West Virginia (DiGiovanni 1990), representing 9.2 million acres of oak-hickory timberland. This separated the resource into cutting opportunities and provided information for estimating the acreage and stand characteristics for each opportunity (Table 1).

Information on tree d.b.h. and merchantable height was used to estimate total volume in cords and sawtimber volume in board feet (Scott 1979, 1981). Dollar values are based on tree-value conversion standards for tree species in the Northeastern United States.[2] These standards represent consistent regional measures of a standing tree's net value (marginal value

[2]DeBald, Paul S, and Martin E. Dale. Tree value conversion standards revisited. Research Paper, Northeastern Forest Experiment Station. [In preparation]

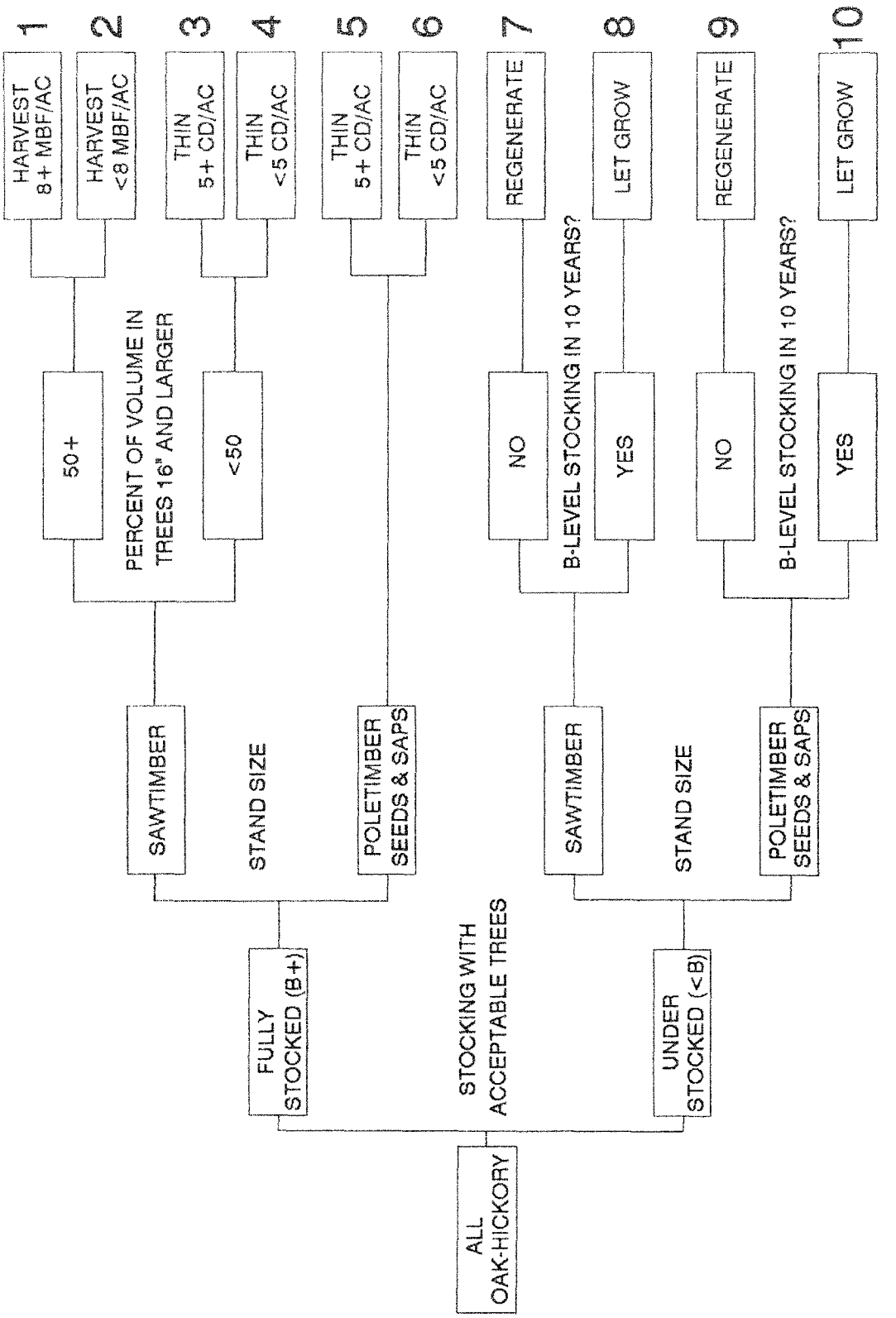

Figure 1. Guide for sorting oak-hickory forest into cutting opportunities.

Table 1.--Acreage and stand characteristics of cutting opportunities in oak-hickory forests of West Virginia

Cutting Opportunity	Area	Average d.b.h.	Basal area per acre	Stand volume per acre		Stand value per acre
				Total	Sawtimber	
	Thousand acres	Inches	Ft^2	Cords	Mbf	Dollars
1. Harvest fully stocked mature sawtimber stand (removals 8+ Mbf/acre)	1,065	10.5	139	34.7	10.9	1,139
2. Harvest fully stocked mature sawtimber stand (removals <8 Mbf/acre)	1,078	8.4	122	23.4	5.9	582
3. Thin fully stocked immature sawtimber stand (removals 5+ cords/acre)	,773	8.9	137	30.5	7.1	564
4. Thin fully stocked immature sawtimber stand (removals <5 cords/acre)	743	8.7	109	22.9	5.4	375
5. Thin fully stocked poletimber, sapling, or seedling stand (removals 5+ cords/acre)	513	7.3	129	24.7	3.4	312
6. Thin fully stocked poletimber, sapling, or seedling stand (removals <5 cords/acre)	1,088	6.8	106	17.2	2.3	188
7. Regenerate understocked sawtimber stand that will not reach full stocking in 10 years	1,030	10.9	67	13.7	3.7	267
8. Let grow understocked sawtimber stand that will reach full stocking in 10 years	1,297	9.7	94	20.4	5.3	419
9. Regenerate understocked poletimber, sapling, or seedling stand that will not reach full stocking in 10 years.	980	6.5	50	7.3	1.0	74
10. Let grow understocked poletimber, sapling, or seedling stand that will reach full stocking in 10 years	609	7.4	84	15.3	2.1	149
All areas	9,476	8.9	102	20.8	4.9	425

or shadow price) in the production of 4/4 (1-inch) lumber, allowing for the cost of conversion. They account for a tree's species, diameter, merchantable height, and tree grade (based on butt-log grade measures). For example, a 16-inch-diameter northern red oak (*Quercus rubra* L.) with a grade 2 butt log and merchantable height of 2 logs was valued at $29. For trees other than hardwood sawtimber, merchantable height, d.b.h., and cull estimates were converted to net volumes and assigned value based on recent local stumpage price information. For example, pulpwood stumpage averages about $5 per cord.

PLENTY OF CHANCES FOR CUTTING

Some 3.1 million acres, about one-third of West Virginia's oak-hickory timberland, could use some thinning (opportunities 3 through 6). Another 2.1 million acres are in mature sawtimber stands that are ready for harvest (opportunities 1 and 2). More than 40 percent of the resource is inadequately stocked with acceptable growing stock, that is, trees of commercial species that are not rough or rotten. More than half of this understocked forest is not expected to reach an acceptable level of stocking in 10 years and should be regenerated (opportunities 7 and 9). Nearly 2 million acres of understocked forest that are projected to reach an acceptable stocking level during the next decade can be left to grow (opportunities 8 and 10). Stands representing every cutting opportunity are fairly well distributed in all regions of the state (Fig. 2).

As expected, stand conditions vary greatly for the 10 cutting opportunities. Per-acre statistics for opportunity 1 are most impressive: nearly 35 cords of total volume, including 11,000 board feet of sawtimber, with a total worth of more than $1,100. At the other extreme is opportunity 9: averaging only 7 cords of total volume, including 1,000 board feet of sawtimber, worth less than $75 per acre.

Species composition is no surprise. The oaks combined account for the largest share of the resource but other commercial species are abundant (Fig. 3). Yellow-poplar (*Liriodendron tulipifera* L.) and other high-value hardwoods (sugar maple--*Acer saccharum* Marsh., black cherry--*Prunus serotina* Ehrh., white ash--*Fraxinus americana* L., and walnut--*Juglans nigra* L.) combined make up one-fourth of the inventory. Hickory (*Carya* spp.), red maple (*Acer rubrum* L.), beech (*Fagus grandifolia* Ehrh.), and basswood (*Tilia americana* L.) also are well represented.

TOTAL CUT AMOUNTS TO 100 MILLION CORDS

The cut associated with all of the silvicultural opportunities totals 99.6 million cords (Table 2). That is a lot of wood, amounting to 60 times the current annual harvest of growing stock volume from the state. Included in this harvest is 25 billion board feet of sawtimber. On the stump, the conversion value of these removals amounts to $2.4 billion.

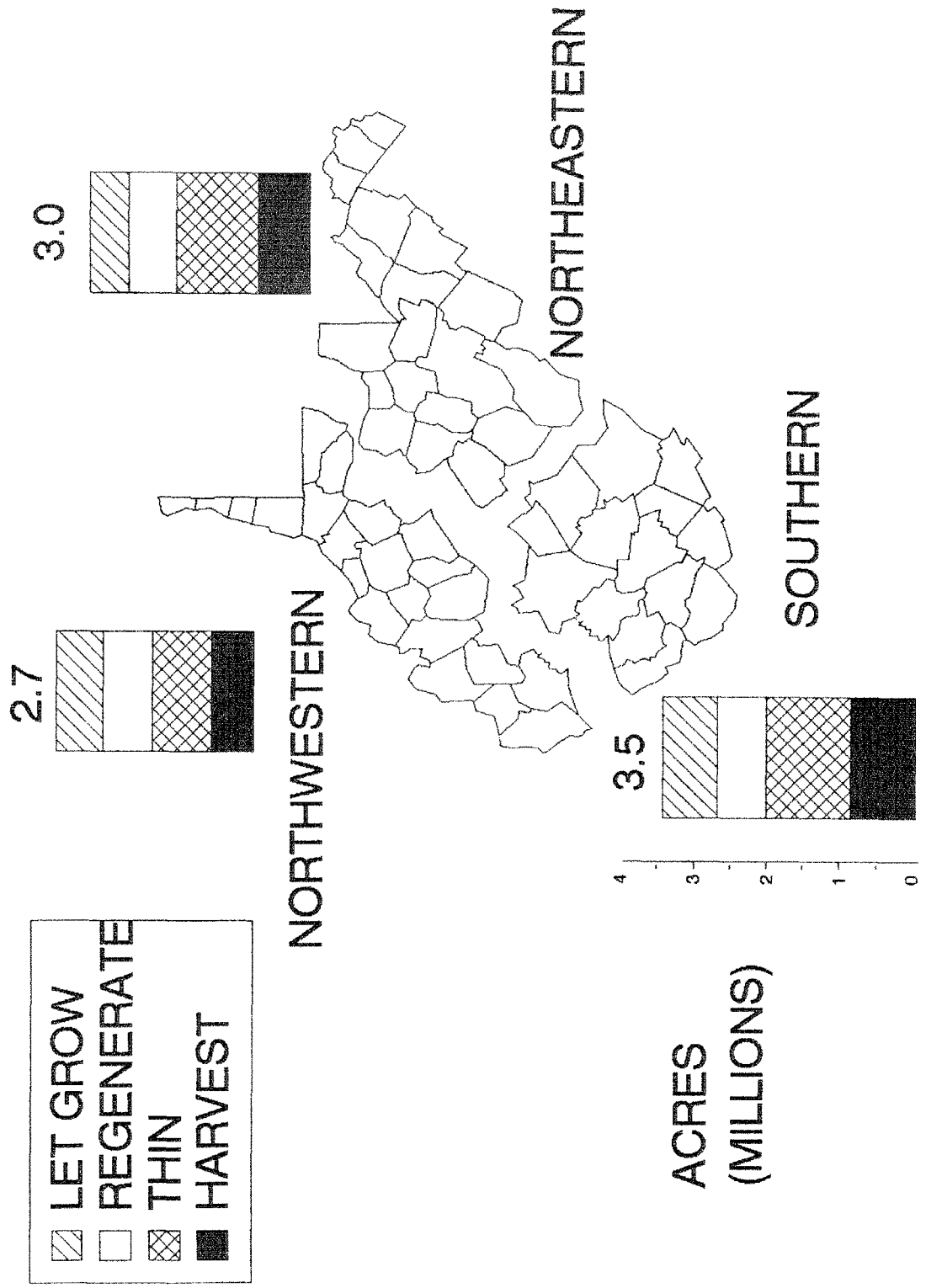

Figure 2. Geographic distribution of cutting opportunities in oak-hickory forests of West Virginia.

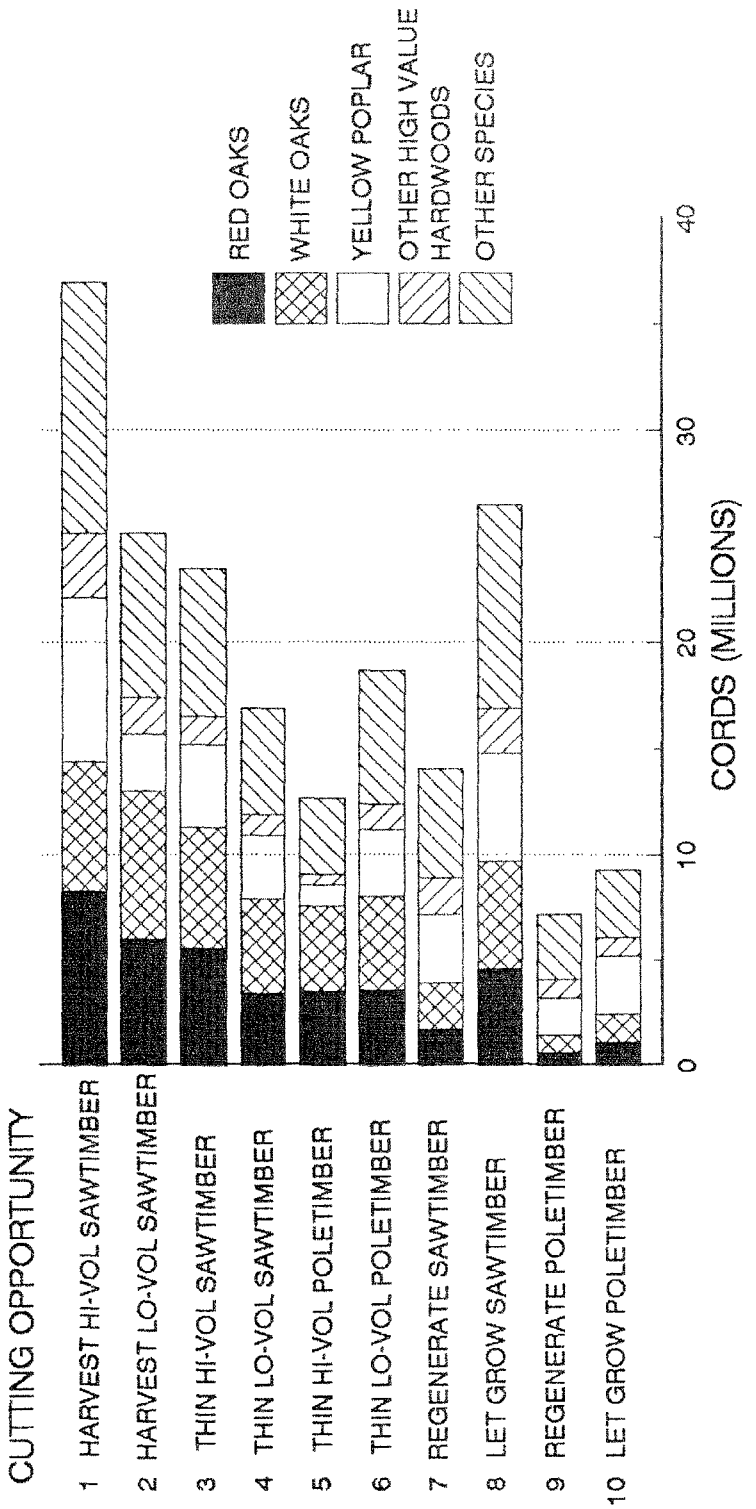

Figure 3. Distribution of inventory volume, by cutting opportunity and species group, oak-hickory forests of West Virginia.

Table 2.--Potential cut by opportunity in oak-hickory forests of West Virginia

Cutting opportunity	Per acre			All acres		
	Total volume	Sawtimber	Value	Total volume	Sawtimber	Value
	Cords	Mbf	Dollars	Million cords	Mmbf	Million dollars
1. Harvest fully stocked mature sawtimber stand (removals 8+ Mbf/acre)	34.7	10.9	1,139	36.9	11,651	1,214
2. Harvest fully stocked mature sawtimber stand (removals <8 Mbf/acre)	23.4	5.9	582	25.2	6,380	627
3. Thin fully stocked immature sawtimber stand (removals 5+ cords/acre)	9.3	1.9	115	7.2	1,479	89
4. Thin fully stocked immature sawtimber stand (removals <5 cords/acre)	2.5	0.6	35	1.9	390	26
5. Thin fully stocked poletimber, sapling, or seedling stand (removals 5+ cords/acre)	9.0	1.2	85	4.6	593	44
6. Thin fully stocked poletimber, sapling, or seedling stand. (removals <5 cords/acre)	2.4	0.3	22	2.5	345	24
7. Regenerate understocked sawtimber stand that will not reach full stocking in 10 years	13.7	3.7	267	14.1	3,774	275
9. Regenerate understocked poletimber, sapling, or seedling stand that will not reach full stocking in 10 years	7.3	1.0	74	7.2	1,005	73
All acres	10.9	2.9	258	99.6	25,617	2,372

From the standpoint of operability, the most lucrative options are harvesting opportunities 1 and 2 with cuts per acre exceeding 20 cords of total volume, including more than 5,000 board feet of sawtimber. The value of removals associated with the 2.1 million acres in opportunities 1 and 2 totals $1.8 billion. Other opportunities are reasonably attractive. For example, the regeneration of understocked sawtimber stands, opportunity 7, yields an average of nearly 14 cords per acre, including 3,700 board feet of sawtimber. By contrast, thinning opportunities 4 and 6 have per-acre cuts averaging fewer than 3 cords. While these thinning chances would be snubbed by most professional loggers, they might be of interest to the occasional fuelwood cutter with a chain saw and pick-up truck.

Oaks account for about 40 percent of the total volume (38 million cords) and 70 percent of the total value ($1.6 billion) included in the cutting prescriptions (Figs. 4-5). Northern red oak alone accounts for 25 percent of the value. Two-fifths of the sawtimber harvest is in trees with butt logs of grade 2 or better (Fig. 6). The quality of material taken in harvesting and regeneration operations is much better than that removed in thinnings where improvement cutting tends to leave the better trees in the woods.

CUTTING WOULD ENHANCE TIMBER PRODUCTIVITY

Dramatic improvements in timber productivity and quality would result from sound cutting practices. An individual-tree growth simulator was used to project gains in yield that might be expected over the next two decades from thinnings of similar forest stands in Pennsylvania (Gansner et al. 1987). Gains in timber yield (over no treatment) averaged nearly 4 percent. Poletimber, seedling, and sapling stands would net bigger gains in volume than sawtimber stands. But much more impressive than the gains in timber volume would be improvements in quality and value. Assuming prices remain constant, projected increases in timber value attributed to thinning averaged nearly 12 percent over 20 years. If these stands were left unthinned, their compound annual rates of value growth will average nearly 3 percent . If they were thinned, value growth rates on the residual stands would average more than 4 percent.

ROOM FOR INDUSTRIAL EXPANSION

The bottom line is that West Virginia's 9.2 million acres of oak-hickory forest represent a storehouse of economic opportunity. The potential cut from silvicultural thinning, regeneration, and harvest operations amounts to 100 million cords. Moreover, the good housekeeping associated with this environmentally sound cutting would result in significant improvements in timber productivity and quality. Obviously all of the cutting couldn't be done at once. The amount that might be undertaken remains a big question. At least one major flooring firm has taken advantage of the timber supply situation by establishing a new mill in the state. Further developments will require some tough decisions based on the interaction of a multitude of complex socioeconomic factors such as:

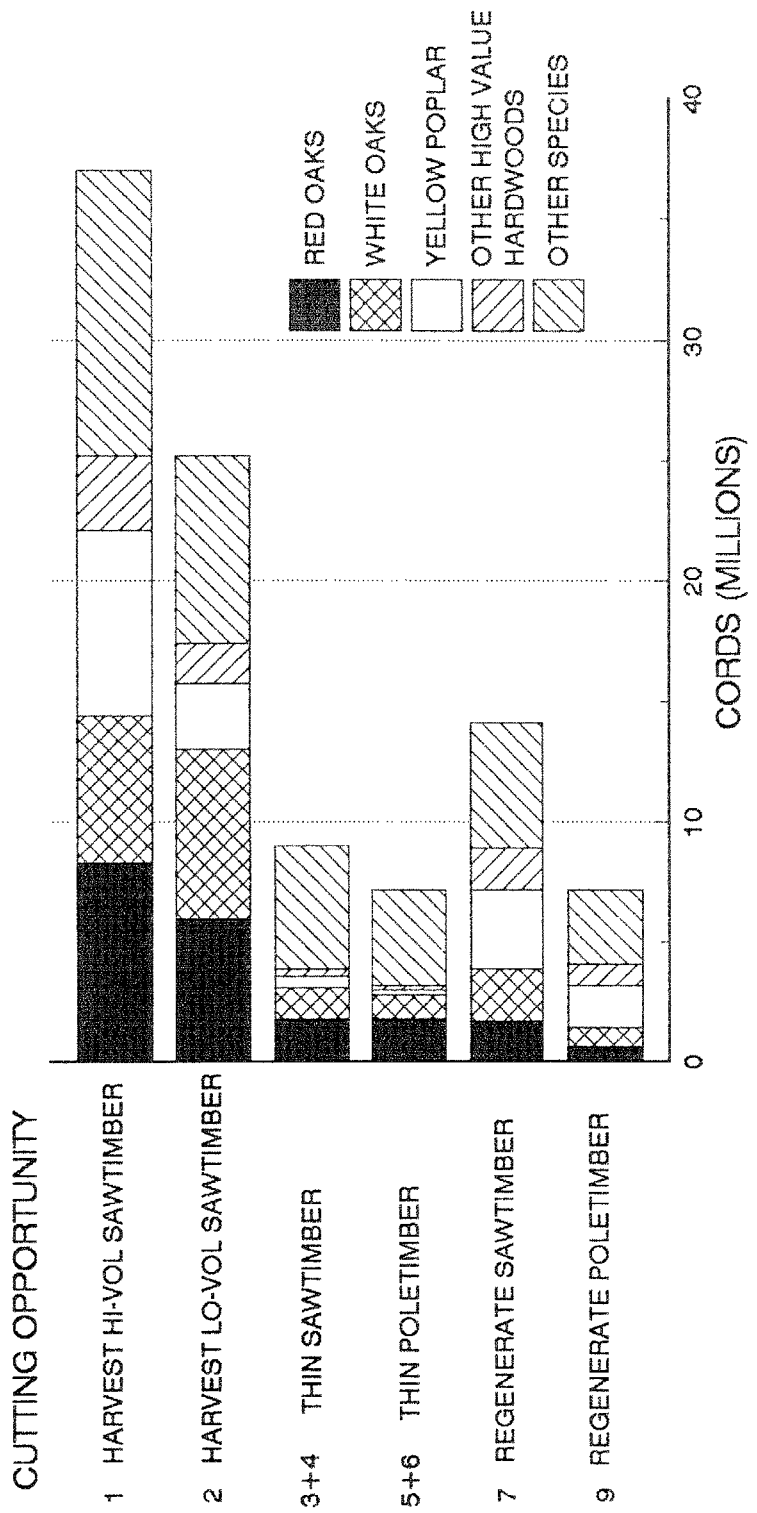

Figure 4. Potential cut of timber volume, by cutting opportunity and species group, oak-hickory forests of West Virginia.

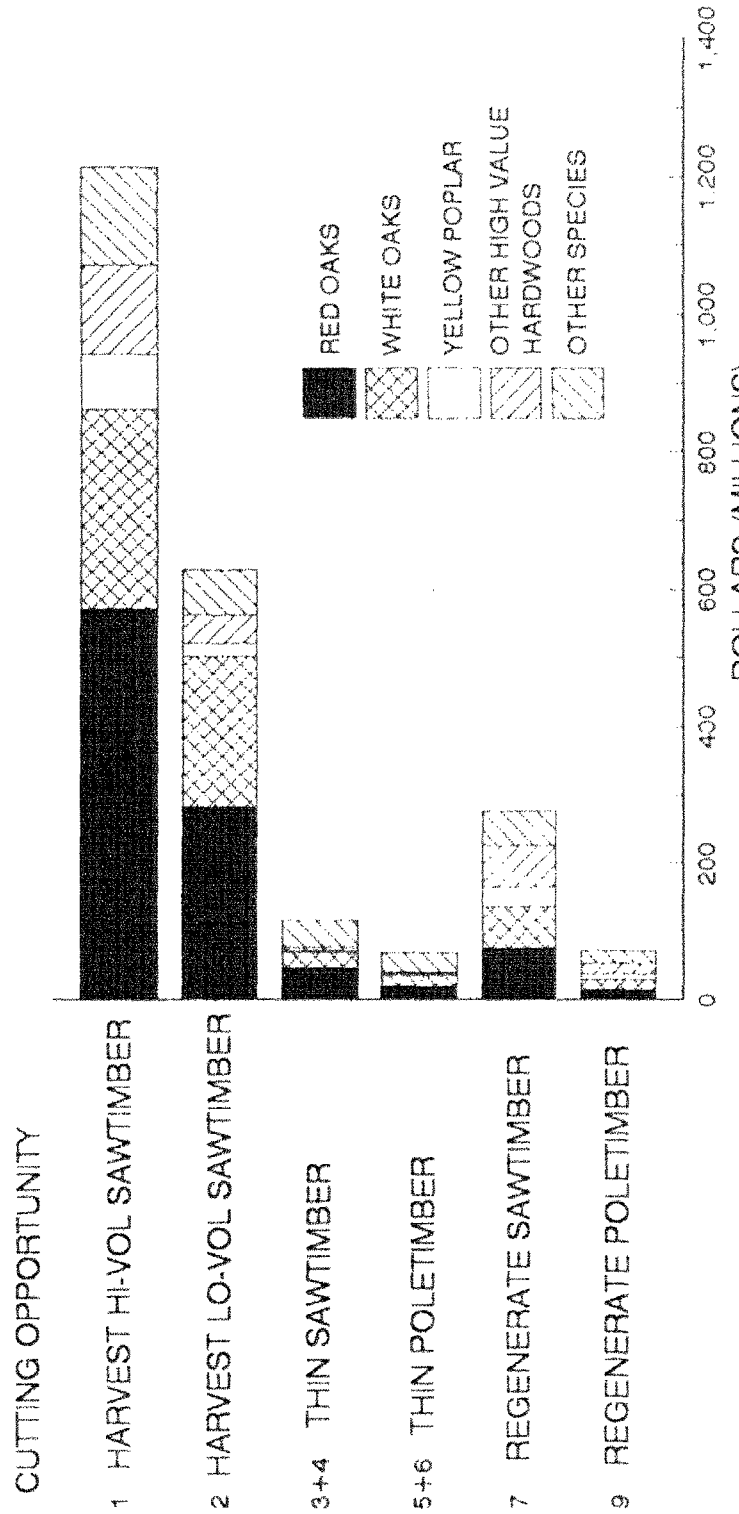

Figure 5. Conversion value of potential cut, by cutting opportunity and species group, oak-hickory forests of West Virginia.

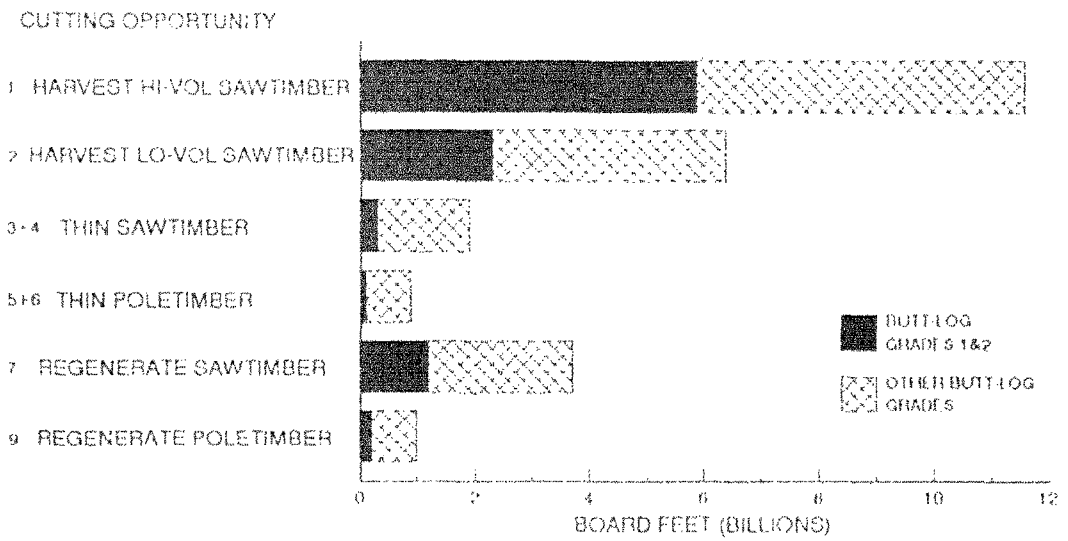

Figure 6. Potential cut of sawtimber volume, by cutting opportunity and tree grade, oak-hickory forests of West Virginia.

* Changes in timber demand, utilization, and operability.

* Attractiveness of local business climates to an expanding timber industry.

* Attitudes of woodland owners and other citizenry toward increased timber cutting.

* Desires to maintain a balanced distribution of age classes and sustainable flow of quality timber.

* Continued use of traditional cutting practices such as diameter-limit cutting and clearcutting of immature stands in place of recommended silviculture.

* Inadequate regeneration, especially where deer populations are high.

Given today's conditions, major increases in silvicultural cutting would have to be spread over the next several years. Only time will tell how this works out. At any rate, there is no denying that physical supplies of timber reveal a potential opportunity for significant expansion in wood use.

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INCIDENCE OF TWOLINED CHESTNUT BORER AND *HYPOXYLON ATROPUNCTATUM* ON DEAD OAKS ALONG AN ACIDIC DEPOSITION GRADIENT FROM ARKANSAS TO OHIO

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Abstract: The incidence of twolined chestnut borer (TLCB), *Agrilus bilineatus* (Weber), and the canker fungus *Hypoxylon atropunctatum* (Schw. ex Fr.) Cke. was recorded on dead oak (*Quercus*) trees ≥7 cm diameter at breast height (DBH) along an acidic deposition gradient from Arkansas to Ohio in 1989 and 1990. Approximately, one to three hectares of oak-hickory forests were inspected at each of seven study sites: one site in Arkansas, two in Illinois, two in Indiana, and two in Ohio. All sites were broadly analogous with respect to geology, soil, slope, aspect, and forest cover type. Proportionally, more trees in the red oak group had died than trees in the white oak group at the Illinois, Indiana, and Ohio sites. Mean DBH of dead red oaks was greater than that of dead white oaks at all sites. Evidence of TLCB and *H. atropunctatum* attack was observed at all sites on several red oak species (scarlet, blackjack, northern red, and black oak) and white oak species (white, chestnut, and post oak). TLCB attack was generally more common than *H. atropunctatum* on both red oaks and white oaks. Moreover, incidence of both pests tended to be (a) higher on red oaks than on white oaks, and (b) higher in Illinois, Indiana, and Ohio than in Arkansas.

INTRODUCTION

The Ohio Corridor Study is focused on the possible effects of acidic deposition on oak-hickory forests in the lower midwestern United States (LeBlanc et al. 1988, Loucks et al. 1991). This geographic gradient study was one of several forestry-related studies funded in the 1980's as part of the Forest Response Program of the National Acid Precipitation Assessment Program; see Schroeder and Kiester (1989) for program details. The Ohio Corridor Study was originally designed to test the hypothesis that, for analogous stand conditions and soil types, differences in growth responses of oak and hickory along the gradient could be explained by differences in pollutant dose. Seven study sites were selected within or near four national

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Table 1.--Site location data, median stand age of dominant and co-dominant trees, percent of basal area consisting of *Quercus* and *Carya* species (trees ≥10 cm DBH), mean annual precipitation at or near the site (1955-1986), and estimated annual total (wet + dry) sulfate deposition for two time spans (details in Loucks et al. 1991).

	Sites						
Parameter	ARK	DIX	TON	CSF	HNF	EOA	WNF
State	Arkansas	Illinois	Illinois	Indiana	Indiana	Ohio	Ohio
County	Franklin	Pope	Jackson	Scott	Jackson	Adams	Perry
Latitude	35°45′	37°25′	37°38′	38°30′	39°03′	38°40′	39°35′
Longitude	93°47′	88°40′	89°11′	85°50′	86°12′	83°27′	82°03′
Elevation (m)	685	87	121	97	86	101	123
Age (yr)	61	74	105	93	88	99	121
% *Quercus*	98	88	77	86	98	96	87
% *Carya*	1	9	20	6	>1	1	10
% *Q* + *C*	99	97	97	92	99	97	98
Precip (cm)	120.4	118.1	120.3	108.5	112.6	106.2	104.8
Estimated total annual sulfate deposition ($g/m^2/yr$)							
1900-1985	5.51	8.64	7.66	8.68	8.80	9.99	9.89
1955-1986	3.85	6.73	5.97	6.14	6.23	7.16	7.08

forests along a gradient from northwest Arkansas through southern Illinois and Indiana to south central Ohio. Within the United States, the Ohio River Valley has consistently been a region of high sulfur oxide emissions during the 1900's (Gschwandtner et al. 1986). Estimates of total sulfate deposition (wet + dry) during the 1900's show nearly a two-fold increase from Arkansas to Ohio (Table 1; Loucks et al. 1991), with sulfate concentrations decreasing in more recent years. In addition, the Ohio River Valley is recognized as an area of high ozone concentrations within the United States (Lefohn and Pinkerton 1988); however, no major ozone gradient was detected in the present study (Loucks et al. 1991). All study sites were selected to be south of the maximum glacial advance and north of areas where soils have high sulfate absorption capacities. Soils were primarily of the sandy loam types, with low cation capacity (Guillemette 1989, Loucks et al. 1991).

Although the Ohio Corridor Study sites were selected to be highly analogous, subsequent detailed soil and stand-structure studies indicated that the Arkansas site, and some of the Illinois and Ohio plots would have to be withdrawn from analyses when considering only the most narrowly analogous sites (Loucks et al. 1991). Nevertheless, in the present study, we present results from all seven sites.

Aspects of oak decline and mortality were investigated by several researchers in the Ohio Corridor Study (Loucks et al. 1991). Two pests that were commonly associated with dead oaks along the gradient were the twolined chestnut borer (TLCB), *Agrilus bilineatus* (Weber) (Coleoptera: Buprestidae), and the canker fungus *Hypoxylon atropunctatum* (Schw. ex Fr) Cke. These two pests are commonly associated with stressed oaks, especially drought-stressed oaks (Bassett and Fenn 1984, Haack and Benjamin 1982, Lewis 1981, Mistretta et al. 1981, Tainter et al. 1983). The TLCB is recognized as the principal insect mortality agent of stressed oaks in the eastern United States (Haack and Acciavatti 1991). The virulence of *H. atropunctatum* is less well documented; it is recognized as a saprophyte,

but it may be a weak parasite on severely stressed trees. No other above-ground pests were commonly found on recently dead and dying oaks across the gradient.

The objective of the present study was to categorize the dead oaks at each of the seven Ohio Corridor Study sites with regard to tree species or sub-genus, DBH (diameter at breast height), trunk condition and orientation, and incidence of TLCB and *H. atropunctatum* attack.

METHODS

Study Sites

Detailed information on study site selection and baseline information for all permanent plots is found in Guillemette (1989), LeBlanc et al. (1988) and Loucks et al. (1991). Briefly, seven study sites were selected that had similar vegetation, soils, and geology. These oak-hickory sites were selected to have broadly analogous environments, except for the acidic dose. Sites and their abbreviations are Ozark National Forest in Arkansas (ARK), Dixon Springs (DIX) and Touch of Nature (TON) in Illinois, Clark State Forest (CSF) and Hoosier National Forest (HNF) in Indiana, and Wayne National Forest (WNF) and Edge of Appalachia (EOA) in Ohio; administratively, HNF and WNF have been combined and are now known as the Wayne-Hoosier National Forest. Additional location and site data are presented in Table 1. At each site, approved sampling areas (sample elements) were located on upper slopes with southerly aspects in mature oak-hickory stands that showed no evidence of recent fire damage or logging. Eight 0.04-ha permanent plots were established at each site at randomly chosen points within the sample elements. Across the gradient, tree species composition was complex; about 30 different species were encountered on the 56 permanent plots (LeBlanc et al. 1988). The oak and hickory components of each site are presented in Table 2.

During summer 1989, we inspected all dead oaks for TLCB and *H. atropunctatum* on each permanent plot. That procedure, however, provided fewer than 10 suitable dead oaks per site at four of seven sites. To increase the sample size of dead oaks, we revisited all sites in spring 1990 and marked off large sections of practically all approved sample elements at each site for further inspection; approximately 1-3 ha per site.

Tree Measurements

We first determined whether individual dead trees were oaks by using characters such as bark, branching pattern, buds, wilted foliage, distinctive genus-specific beetle galleries, and wood grain. Then, if possible, oaks were assigned to a species or sub-genus group, i.e., the red oak group (ROG) *Erythrobalanus* or the white oak group (WOG) *Lepidobalanus*. Such assignments were usually not done with oaks that had lost all bark and/or were in advanced

Table 2.--Mean basal area (m^2/ha) of hickory (*Carya*) and oak (*Quercus*) species by site for trees ≥10 cm DBH, based on eight 0.04-ha plots per site (LeBlanc et al. 1988).

	Basal area						
Tree species	ARK	DIX	TON	CSF	HNF	WNF	EOA
Hickory species							
Bitternut, *C. cordiformis*	-	-	-	0.49	-	-	-
Pignut, *C. glabra*	-	0.67	1.97	1.15	0.11	-	3.57
Red, *C. ovalis*	0.22	0.46	1.49	-	-	-	0.31
Shagbark, *C. ovata*	-	0.76	0.11	-	-	0.25	0.17
Mockernut, *C. tomentosa*	-	-	-	-	-	0.08	-
Oak species							
White, *Q. alba* L *	7.23	5.24	2.85	2.20	0.83	10.11	0.95
Scarlet, *Q. coccinea* L	-	-	-	0.55	4.77	0.83	-
Southern red, *Q. falcata* E	-	0.50	-	-	-	-	-
Blackjack, *Q. marilandica* E	-	0.06	0.06	-	-	-	-
Chestnut, *Q. prinus* L	-	-	-	19.21	18.71	8.96	19.16
Northern red, *Q. rubra* E	9.97	1.07	1.05	-	-	0.79	1.81
Post, *Q. stellata* L	-	6.18	6.21	-	-	0.32	0.51
Black, *Q. velutina* E	0.26	4.70	2.71	0.68	0.98	5.33	4.08
Red oak group	10.23	6.33	3.82	1.23	5.75	6.95	5.89
White oak group	7.23	11.42	9.06	21.41	19.54	19.39	20.86
All oaks	17.46	17.75	12.88	22.64	25.29	26.34	26.75
All hickories	0.22	1.89	3.57	1.64	0.11	0.33	4.05
All other species	0.18	0.54	0.42	2.05	0.33	0.62	1.11
All species combined	17.86	20.18	16.87	26.33	25.73	27.55	31.67

* L = white oak group *Lepidobalanus* of genus *Quercus*, E = the red oak group *Erythrobalanus*.

stages of decay. Bark was the principal character used for species or sug-genus designation among dead oaks.

Several parameters were recorded for all dead oaks ≥7 cm DBH, using methods modified from McCune et al. (1988). DBH was recorded to the nearest 1 cm with no correction made for bark loss. At times, DBH had to be estimated, especially for stumps and decadent trees. Precision, as indicated by remeasurement of DBH, was within 0-3% of the original values.

Broad categories of tree condition were recorded to allow inference about the timing of death. Dead oaks that could be identified to species or sub-genus were assigned to one of five categories as given in McCune et al. (1988): 1 = small twigs intact, 2 = main trunk solid, small branches gone, 3 = main trunk soft but shape mostly intact, 4 = main trunk deeply rotted, collapsed, and 5 = main trunk gone, only fragments of tree base remaining. Dead oaks that could not be identified to species or sub-genus because of lack of bark or being in an advanced stage of decay were assigned to category 6.

We estimated percent of bark lost from the main trunk using 10% intervals, with remeasurements never exceeding ±1 interval. In addition, we recorded orientation of the main trunk as either standing, leaning but not touching the ground, fallen on the ground, or only remains of the stump existed.

Definitive signs of TLCB and *H. atropunctatum* were used to designate a dead oak as having been definitely attacked. For TLCB, the distinctive meandering larval galleries on the sapwood surface or D-shaped adult exit holes on the bark surface were used as positive evidence of TLCB attack (Haack 1989, Haack and Acciavatti 1991). In trees that had died the previous growing season (1989), TLCB larvae and pupae were often found because the 1990 surveys took place before adults emerged.

We designated trees as having *H. atropunctatum* infection if we observed one or more stromata on the main trunk as illustrated in Fenn and Holland (1984), Thompson (1963), and Van Arsdel (1972). We recognize that this method underestimates the actual level of *H. atropunctatum* because some infections may not yet have developed stromata, and others may never develop stromata.

On standing trees, the lower 2 m of trunk were always inspected for both pests; upper portions of the main trunk were examined from the ground for *H. atropunctatum* stromata. On leaning trees and those on the ground, nearly the entire trunk was inspected. Typically, incidence of TLCB and *H. atropunctatum* on oaks assigned to trunk conditions 4-6 could not be assessed with high accuracy due to lack of bark and to advanced stages of decay. Although standing trees had the smallest percentage of their trunk area inspected at close range, we consider the TLCB data reliable because this beetle attacks to ground level in the year of tree death (Haack and Benjamin 1982).

RESULTS

Characteristics of Dead Oak Trees

We inspected a total of 1384 dead oaks (≥7 cm DBH) on the seven sites (Table 3). Of the eight oak species found on the study plots, dead individuals of seven species were found: white (*Q. alba* L.), scarlet (*Q. coccinea* Muenchh.), blackjack (*Q. marilandica* Muenchh.), chestnut (*Q. prinus* L.), northern red (*Q. rubra* L.), post (*Q. stellata* Wangenh.), and black oak (*Q. velutina* Lam.) (Table 2). No dead southern red oak (*Q. falcata* Michx.) were found; however, this species was recorded at only one site (DIX; Table 2).

DBH of dead oaks ranged from 7 to 75 cm; mean DBH for red oaks exceeding that of white oaks at all sites (Fig. 1). The 10- to 19-cm DBH class was the most heavily represented at each site. Mean DBH for all dead oaks combined was smallest in ARK and greatest in EOA; mean DBH was positively correlated with median stand age (r^2=0.61, P<0.038, N=7 sites).

In general, dead oaks in trunk-condition categories 3 and 6 were the most frequently assigned (Table 3). Trunk condition patterns were broadly similar between red oaks and white oaks (data not shown). Based on examination by others of dead oaks ≥20 cm DBH on these same sites, oaks in trunk-condition categories 1 and 2 had died in the past 10 years, and those in categories 3 to 5 had died more than 10 years ago (Loucks et al. 1991).

Table 3.--Number or percent of dead oak trees ≥7 cm DBH in various categories by site.

	Site							
Category *	All	ARK	DIX	TON	CSF	HNF	WNF	EOA
Number of dead oaks in all trunk orientation categories (N=1384 trees total)								
All, conditions 1-6	1384	235	309	176	123	285	130	128
All, conditions 1-3	698	139	207	110	51	100	33	58
ROG, conditions 1-3	268	63	61	45	17	33	19	30
WOG, conditions 1-3	430	76	146	65	34	67	14	28
Number of standing or leaning dead oaks (N=647 trees total)								
All, conditions 1-6	647	156	183	63	52	115	33	45
All, conditions 1-3	493	113	157	56	40	75	15	37
ROG, conditions 1-3	189	50	55	23	14	21	9	17
WOG, conditions 1-3	304	63	102	33	26	54	6	20
Percent of all dead oaks (N=1384) by trunk condition (%)								
Condition 1	4	9	4	5	4	4	2	3
Condition 2	10	14	9	4	6	10	3	19
Condition 3	37	36	54	53	32	23	21	23
Condition 4	15	32	10	6	25	12	17	9
Condition 5	4	7	1	2	4	5	9	2
Condition 6	30	2	22	30	30	50	49	44
Percent of all dead oaks (N=1384) by percent bark lost (%)								
0 - 5 %	23	33	37	28	14	14	3	17
10 - 20 %	15	23	21	19	11	8	6	10
30 - 70 %	15	20	10	13	15	16	14	13
80 - 90 %	13	19	8	8	23	10	19	12
95 -100 %	34	5	24	32	37	52	58	47
Percent of all dead oaks (N=1384) by trunk orientation (%)								
Standing	43	62	56	33	43	37	20	30
Leaning	3	4	3	3	0	4	5	5
Fallen on the ground	51	34	41	64	56	57	61	53
Stump only	3	0	0	0	1	2	14	12

* ALL = all red oaks, white oaks, and oaks of unknown species combined; ROG = red oak group; WOG = white oak group.

Percent of bark lost from the main trunk of dead oaks is given in Table 3. Overall, most dead oaks in Arkansas and Illinois had lost relatively little bark (0-20%), while most dead oaks in Indiana and Ohio had lost most of their bark (80-100%). Patterns of percent bark lost were generally similar between red oaks and white oaks (data not shown). There was a positive correlation between percent bark lost and trunk condition category (r^2=0.66, P<0.001, N=1384 trees).

Percent of dead oaks in each trunk-orientation category is presented in Table 3. The ARK and DIX sites had the highest percentage of dead oaks in the standing position, whereas most were on the ground at the other five sites. Trees in the leaning category accounted for 0-5% of the dead oaks at any one site. Decayed stumps (with no obvious associated trunk) were found only at the Indiana and Ohio sites, suggesting some prior logging.

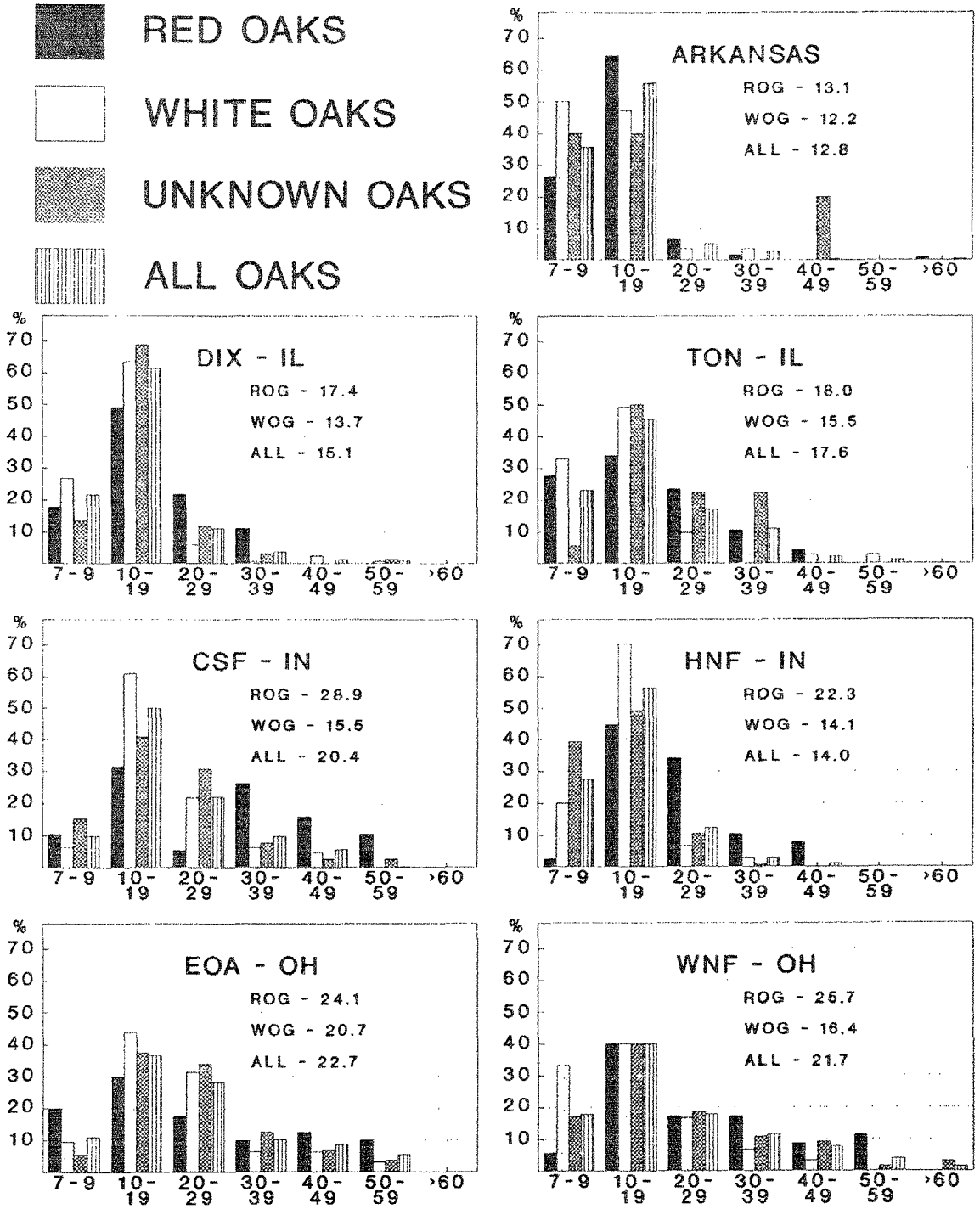

Figure 1. Percent of dead oaks for each site in various groupings by DBH (cm); N values given in Table 3. Unknown oaks are those in trunk-condition category 6 for which species determination was not made. Numbers within each box represent the mean DBH for all dead red oaks (ROG), all dead white oaks (WOG), and all dead oaks combined including those in trunk condition category 6 (ALL).

The above parameters were reanalyzed after restricting the data set to only oaks ≥10 cm DBH and again for oaks ≥20 cm DBH. In general, similar distributions were observed in trunk condition categories, percent bark lost, and trunk orientation (data not shown).

Proportions, on a basal-area basis, were calculated for living oaks in the red oak and white oak groups, using data presented in Table 2. Similarly, using DBH measurements of the dead oaks from the present study (trunk condition categories 1-3 only), basal area of red oaks and white oaks were determined for eact site and the proportions calculated. Comparisons of these two sets of proportions (Fig. 2), indicated slightly increased white oak mortality in ARK, slightly increased red oak mortality at DIX in Illinois, and greatly increased red oak mortality at the remaining five sites, especially CSF in Indiana.

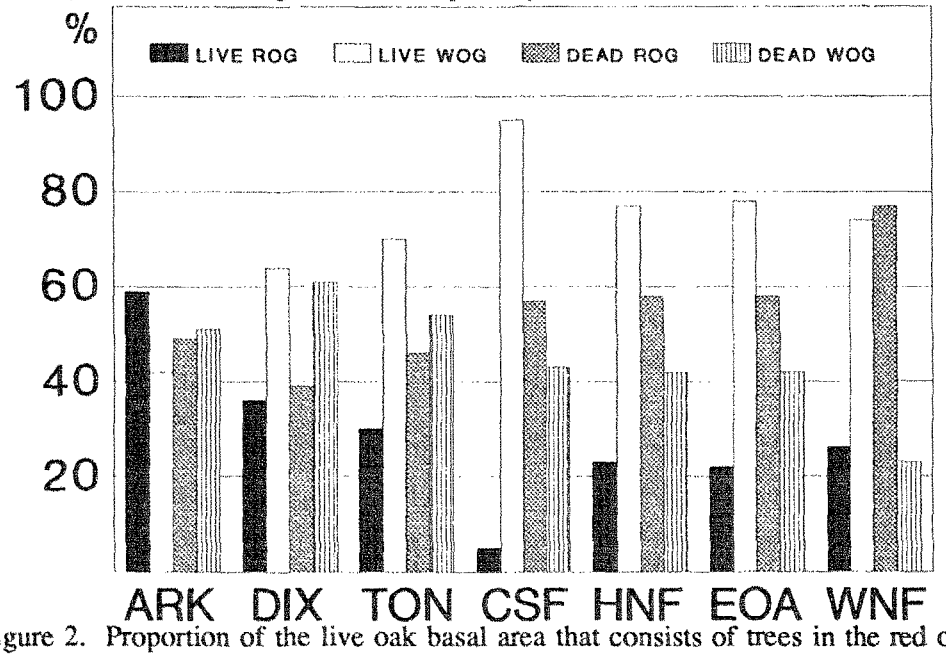

Figure 2. Proportion of the live oak basal area that consists of trees in the red oak group (ROG) compared with those in the white oak group (WOG) (as given in Table 2), and similarly for the proportion of dead oak basal area (from the present study).

Borer and *H. atropunctatum* Infestation Patterns

Both TLCB and *H. atropunctatum* were commonly associated with the dead oaks at all sites. Signs of both pest organisms were noted on individual white, scarlet, blackjack, chestnut, northern red, post, and black oaks at each site where those trees were found as listed in Table 2. For oaks ≥7 cm DBH in trunk- condition categories 1-3, for which signs of attack were most reliable, incidence of TLCB and *H. atropunctatum* attack was lowest in ARK and generally higher in Illinois, Indiana, and Ohio (Fig. 3). In general, more dead red oaks had been attacked by TLCB and *H. atropunctatum* compared with white oaks (Fig. 3). Evidence of attack by both TLCB and *H. atropunctatum* was found on several individual trees, especially red oaks (Fig. 3). The number of dead oaks lacking evidence of attack by either pest declined from west to east (Fig 3).

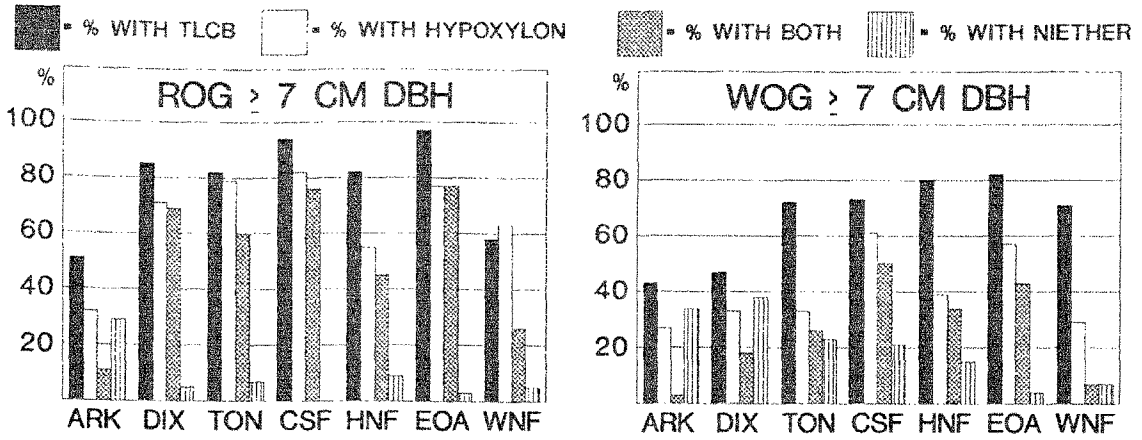

Figure 3. For each site, percent of dead oaks with evidence of TLCB and *H. atropunctatum* attack; based on oaks in trunk-condition categories 1-3 and all trunk orientations (N values given in Table 3).

DISCUSSION

Results of this study indicate that (a) oak mortality occurred at all study sites, (b) that red oaks suffered proportionally greater losses than white oaks at six of the seven sites, and (c) that TLCB and *H. atropunctatum* were commonly associated with dead oaks. Many others have reported episodes of oak decline in the 1980's, especially after drought (Law and Gott 1987, Mistretta et al. 1981, Stringer et al. 1989, Tainter et al. 1983). In the Ohio Corridor Study, historical weather data (1900-1987) indicated similar growing season climate at all sites (including incidence and duration of droughts), although much year-to-year variation did occur (Loucks et al. 1991).

Other Recent Reports of Oak Decline

Several local and regional reports of oak decline have appeared in recent years, and the occurrence of TLCB and *H. atropunctatum* has been mentioned in most; see Kessler (1989) and Millers et al. (1989) for more detailed reviews. For example, in Arkansas, Mistretta et al. (1981) reported widespread oak mortality following the 1980 drought. Both red oaks and white oaks were affected. Of 215 dead oaks examined, *H. atropunctatum* was evident on 49% of the red oaks and 32% of the white oaks: TLCB was not specifically recorded. Of 215 living oaks examined, only 3 had obvious *H. atropunctatum* stromata.

In Missouri, severe oak mortality was recorded by Law and Gott (1987) after the droughts of 1980 and 1983. Red oaks suffered the greatest mortality, especially scarlet and black oaks. TLCB and *H. atropunctatum* were commonly observed on the dead oaks but not quantified.

In addition, Pallardy et al. (1988) have reported increased red oak mortality in central Missouri during the period 1968-1982.

In Kentucky, Stringer et al. (1989) reported widespread oak mortality associated with droughts. Again, red oaks suffered the greatest mortality, mostly scarlet and black oak. Mortality was greatest on xeric sites, on mid- and upper slopes. TLCB was found on 100% of the dead and dying oaks inspected; *H. atropunctatum* was not recorded.

Tainter et al. (1983) reported increased oak mortality in South Carolina after the 1978 and 1980 droughts. Red oaks were the most commonly affected. *Hypoxylon atropunctatum* was evident on practically all dead oaks and on several declining but still living oaks as well.

In a southwide study by Starkey and Oak (1989), oak mortality was associated with sites characterized by shallow rocky soils, upper slopes, and a predominance of red oak species, especially black and scarlet oak. Red oaks suffered more mortality than white oaks; TLCB and *H. atropunctatum* were commonly observed on dead oaks but not quantified.

Incidence of TLCB and *H. atropunctatum*

TLCB and *H. atropunctatum* were commonly associated with dead oaks in our study. TLCB has been documented as a principal mortality agent of stressed oaks, especially those affected by drought and defoliation (Cote and Allen 1980, Dunbar and Stephens 1976, Dunn et al. 1986, Haack and Benjamin 1982). In contrast, the role of *H. atropunctatum* is less clear. Although *H. atropunctatum* fruiting bodies (stromata) are commonly found on recently dead oaks (Karasevicz et al. 1984, Lewis 1981, Thompson 1963, Van Arsdel 1972), they are rare on healthy-appearing or declining oaks. Except for Thompson (1963), most pathologists consider *H. atropunctatum* only a weak parasite, and primarily a secondary invader (Bassett and Fenn 1984).

Detailed work on the ecology of *H. atropunctatum* was conducted in Arkansas by Bassett and Fenn (1984). They isolated *H. atropunctatum* from branches of 57% and trunks of 11% of 300 healthy-appearing oaks, indicating that this fungus is well- positioned to colonize quickly. Moreover, isolation frequencies were similar between healthy-appearing red oaks and white oaks. After girdling of 196 healthy oaks, *H. atropunctatum* developed within 5 months on 77% of the red oaks and 70% of the white oaks.

In our study, several dead oaks had no obvious signs of TLCB or *H. atropunctatum* attack, especially many white oaks (Fig. 3). Some dead oaks were wind-blown, and a few others had been struck by lightning; such oaks would not be attractive to TLCB adults unless the trees were damaged close to or during the adult flight season. We did not examine root systems of the dead oaks, so we do not know the extent of colonization by *Armillaria* spp., another important complex of weak parasites that attack stressed trees. *Armillaria* often attacks root systems concurrently with TLCB (Wargo 1977). Moreover, we do not know what portion of

the observed mortality was the result of suppression or competition. For example, the high numbers of small-diameter dead oaks in Arkansas (Fig. 1), may reflect the lower median age of that site (Table 1), and that active "self-thinning" was occurring.

Greater Susceptibility of Red Oaks

Higher mortality rates of red oaks versus white oaks can be partially explained in terms of differences in xylem translocation. That is, conduction in the red oak group occurs primarily in the outermost annual ring, while conduction in white oaks occurs in the outer two to three annual rings (Kozlowski and Winget 1963, Kramer and Kozlowski 1979). As a result, red oaks are more susceptible to the girdling action of feeding borer larvae, because only the outer growth ring needs to be severed to effectively girdle and kill a branch or the entire tree. Repeated annual attacks may be necessary to kill part or all of a white oak.

Loucks et al. (1991) presented another theory to explain the greater mortality of red oaks, which is based on the apparent greater sensitivity of red oaks vs. white oaks to ozone (Reich et al. 1986, Loucks et al. 1991). Given the high ozone levels in the Ohio River Valley (Lefohn and Pinkerton 1988), this theory suggests that during periods of drought stress, it is the ozone- sensitive red oaks that succomb first to pest attack.

Pollutant Effects on Plant-Pest Interactions

Air pollution stress is known to induce a diverse array of biochemical, morphological, and physiological changes in trees (Kozlowski and Constantinidou 1986). The possibility that these changes could alter plant-pest interactions has been a topic of several reviews (Alstad et al. 1982, Baltensweiler 1985, Fuhrer 1985, Hain 1987, Heagle 1973, Hughes and Laurence 1984, Huttunen 1984, Lechowicz 1987, Mattson and Witter 1990). Moreover, several studies have shown increased insect populations with increased dose of various aerial pollutants (Bolsinger and Fluckiger 1987, Cobb et al. 1968, Dohmen 1988, Hughes and Voland 1988, Neuvonen and Lindgren 1987, Spencer et al. 1988, Stinner et al. 1988, Trumble et al. 1987).

Although TLCB is a common mortality agent of oaks stressed by drought and defoliation, there are no published reports of it attacking oaks stressed by pollutants or acidic deposition. Similarly, there are no reports linking *H. atropunctatum* attack to pollution stress. Our study, with only seven sites, was not robust enough to link pest attack to acidic deposition, or to any other pollutant. However, it is plausible that pollutants could stress oaks sufficiently to increase tree susceptibility to TLCB attack, especially during periods of drought.

ACKNOWLEDGMENTS

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BLACK WALNUT TREE GROWTH IN A MIXED SPECIES, UPLAND HARDWOOD STAND IN SOUTHERN INDIANA

Richard K. Myers and Burnell C. Fischer[1]

Abstract: A study was initiated in 1971 on Purdue University woodlands in southern Indiana to monitor the growth of black walnut trees in a natural, unmanaged evenaged stand. Objectives included documentation of walnut growth rates and survival in the absence of management, as well as establishing stand and tree development data baselines prior to initiation of management activities. Individual-tree periodic diameter growth rates were determined and analyzed in relation to tree crown class, stem diameter, and both overstory and understory stocking levels. Growth and survival data suggest that walnuts of intermediate or suppressed crown classes are of doubtful suitability as potential crop trees. Basal area measurements on .05-acre plots surrounding study trees were segregated into overstory and understory components. Results suggested the importance of concentrating timber stand improvement efforts on releasing crowns of walnut crop trees rather than controlling understory vegetation.

INTRODUCTION

The occurrence of black walnut (*Juglans nigra* L.) as a component of mixed-species upland hardwood forests has historically been an important aspect of forestry and a key factor in the wood products industry in the Central States Region. An unwavering demand for the wood of black walnut has kept it at the top of the hardwood market. Intensive procurement of walnut has resulted in a dwindling supply of naturally occurring trees of high quality. As a consequence, the number of acres of agricultural land being converted to black walnut plantations continues to increase. There is also a high degree of interest in managing natural hardwood stands to produce an improved supply of walnut timber.

A remarkable shortage of information exists concerning the growth of individual black walnut trees in natural stands and their subsequent response to silvicultural practices. This paper lends some insight into the growth characteristics of black walnut trees in unmanaged mixed stands based on observations of a population of walnut trees made over the past 19 years in southern Indiana. The intent is to provide foresters and landowners with information that will

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assist in making rational decisions relating to improving walnut growth in the mixed hardwood type.

METHODS AND ANALYSIS

In 1971, 92 black walnut trees were located and chosen for study in a mixed-species hardwood stand on the Southern Indiana Purdue Agricultural Center (SIPAC) in Dubois County, Indiana. These trees are situated on a moist, generally north-facing site, on middle to lower slope positions. Soils are of the Gilpin-Berks complex, have silt loam surface textures, are moderately deep to sandstone and shale parent material (20-36 inches), and are well drained (Wingard 1980). Slopes range from 20 to 50 percent. In 1989, the stand was fully stocked (Gingrich 1967), averaging 119 sq. ft. per acre basal area. Common associated overstory trees are hickories (*Carya* spp. Nutt.), yellow-poplar (*Liriodendron tulipifera* L.), sugar maple (*Acer saccharum* Marsh.), white ash (*Fraxinus americana* L.), red oak (*Quercus rubra* L.), white oak (*Q. alba* L.), and chinkapin oak (*Q. muehlenbergii* Engelm). The stand is evenaged, as indicated by observed stand structure. Site index for red oak is 80-85. Increment borings of 7 codominant trees from different parts of the stand gave ages ranging from 76 to 85 years in 1989. A strong component of sapling and pole-sized sugar maple is currently present in the understory.

In 1971, all black walnut study trees were assigned a permanent identification number and were measured for diameter at breast height (DBH) to the nearest 0.1 inch. Initial tree diameters for the 92 walnuts ranged from 6.8 to 19.5 inches. In 1982, DBH of surviving walnuts was remeasured, providing diameter growth information over twelve growing seasons. Diameter was the only tree characteristic recorded in both the initial and second measurements.

Following the 1989 growing season, another remeasurement was made of surviving study trees, providing a second, seven-year period of known growth rates. In this recent survey, a variety of tree characteristics and stand parameters were recorded. These included walnut DBH, individual tree crown class (dominant, codominant, intermediate, suppressed), basal area of all stems 3.0 inches or larger DBH on a .05-acre circular plot surrounding each walnut, basal area of overstory trees only (trees competing with walnuts for crown space) on the same .05-acre plots, a 10 BAF prism sample of basal area surrounding each walnut, and number of epicormic branches on merchantable stems of each study tree. Diameter growth rates of trees during this 19-year study period were analyzed using analysis of variance and regression techniques.

RESULTS AND DISCUSSION

Survival

After 19 years, 83 of the original study trees have survived. Original (1971) average DBH of the nine walnuts that died was only 8.7 inches, compared with 11.7 inches original average DBH for the 83 trees that currently remain. Since individual tree crown position was not described at study initiation, it is not possible to correlate initial crown class with 19-year survival or growth rates. However, it is reasonable to assume that in evenaged stands, intolerant tree species (such as black walnut) with relatively small stem diameters generally have small crowns, and are most likely to be individuals that are in the process of being overtopped. Such suppressed or weak-intermediate trees, in this case black walnuts, are most certainly the individuals that have died over the past 19 years. None of the surviving walnuts in 1989 had suppressed crowns, and only about one-fourth of the 83 survivors were intermediate in crown class. Considering the intolerance of black walnut to shading, it is to be expected that in this maturing and fully-stocked mixed species stand, small diameter/small crowned walnut trees are being crowded out. It is probable that additional weak-intermediate trees will die in this stand in the future.

Diameter Growth

The average annual DBH growth of the 83 surviving trees was 0.13 inches for the 19-year period. This rate compares favorably with results from regional growth summaries for black walnut for Indiana-Illinois, 0.13 (Smith and Shifley 1984), for Indiana, 0.12 (Kershaw and Fischer 1985) and Missouri, 0.11 (Shifley and Smith 1982).

Not surprisingly, black walnut trees with the larger stem diameters and the largest crowns in 1989 were those making the most rapid current diameter growth. Dominant trees grew at an average rate of 0.18 inch/year over the 19-year study period, compared to 0.13 and 0.08 inch/year, respectively, for codominant and intermediate trees (Table 1). Intermediate class walnut trees consistently had the smallest stem diameters and the slowest current (1983-89) growth rates. Phares and Williams (1971) found that unreleased, pole-sized walnuts with intermediate to codominant crown positions averaged only 0.06 inches annual DBH growth.

As shown in Table 2, walnuts with small initial diameters (8 to 10 inch DBH classes) in 1971 had much slower growth rates than did larger diameter trees (16 and 18 inches DBH classes). This trend held true for both measurement periods. Presently (1989) the smallest diameter trees are growing at only about half the annual increment (.08 inch/year) as are the largest study trees (0.16 inch/year). Such findings, in combination with the higher rate of mortality for small diameter trees as noted previously, illustrate why intermediate class and smaller-than-average-diameter walnut trees are usually poor candidates for selection as crop trees.

Table 1.--Black walnut diameter growth by crown class.

1989 Crown Class	Number trees per class	19-year average annual growth	Period 1 (1971-82) Annual Increment	Range	Period 2 (1983-89) Annual Increment	Range
		(in.)	(in.)	(in.)	(in.)	(in.)
Dominant	13	.18	.20 a[1]	.12-.29	.15 a	.10-.21
Codominant	48	.13	.14 b	.05-.28	.11 b	.01-.24
Intermediate	22	.08	.09 c	.03-.19	.07 c	.01-.18

[1] Column values followed by the same letter are not significantly different ($p < .05$), based on Duncan's New Multiple Range Test.

Table 2.--Black walnut diameter growth by DBH class for 2 measurement periods.

Initial DBH Class (1971)	Number trees per class	Period 1 (1971-82) Avg. Annual Growth	Range	Period 2 (1983-89) Avg. Annual Growth	Range
(in.)		(in.)	(in.)	(in.)	(in.)
8	15	0.11 a[1]	.05-.21	0.08 a	.01-.18
10	30	0.13 a	.03-.29	0.10 ab	.03-.18
12	14	0.15 ab	.05-.26	0.12 ab	.01-.24
14	15	0.14 a	.05-.22	0.11 ab	.01-.20
16	5	0.16 ab	.07-.24	0.14 b	.06-.21
18	4	0.21 b	.08-.28	0.16 b	.09-.21

[1] Column values followed by the same letter are not significantly different ($p < .05$), based on Duncan's New Multiple Range Test.

Diameter growth rates are decreasing for walnut trees in all crown classes (Table 1). For dominant trees, diameter increment averaged 0.20 inch per year for 1971-1982, but dropped to 0.15 inch per year during the 1983-1989 growing seasons. Codominant and intermediate DBH growth averaged 0.14 and 0.09 inches per year, respectively, during 1971-1982, but was down to 0.11 and 0.07 inches per year for 1983-1989. Increases in stem circumference, increasing stand density, and drier-than-normal growing conditions during the latter growth period are likely contributing causes of this decline in DBH increment. It is apparent that some type of partial harvest or timber stand improvement (TSI) treatment would be appropriate in the near future if a management goal is to improve the growth of walnut trees in this stand.

Diameter of trees 3.0 inches DBH and greater was measured on .05-acre plots and on 10 BAF prism points around each walnut tree, and basal area was compared with tree diameter increment. It was hypothesized that total plot or point basal area (including both overstory and understory trees) might provide an easily obtainable competition index for predicting current diameter growth. However, correlation analysis showed no evidence of a relationship between walnut DBH growth and either total plot or point basal area. An attempt was also made in this study to identify some combination of observable factors in a mixed stand that may be used to predict walnut growth and survival. A multiple regression analysis showed that crown class, in combination with current DBH (relative to average stand diameter) was the most consistent predictor of diameter increment ($r^2 = 0.3516$, $F = 21.7$; $df = 82$), and was somewhat better than using crown class alone ($r^2 = 0.3096$). Although the relationship is not strong, this evidence does indicate that a refinement of a multi-variable growth prediction model for naturally-occurring walnut trees should certainly include some measure of crown competition. However, non-subjective methods for evaluating crown competition in natural, mixed species hardwood stands have yet to be developed.

Interestingly, the largest and fastest growing walnut trees (dominants) in this study also had the heaviest understory competition, as measured by basal area of suppressed and intermediate trees in the .05-acre plot around each walnut (Table 3). Such results strongly support the idea that the growth of black walnut and other intolerant species on good sites is influenced more by availability of light (crown space) than by any other factor. At any rate, faster diameter growth rates in this stand are clearly not associated with lower levels of understory competition.

Table 3.--Average basal area around walnut trees in three crown classes, as measured on 0.05-acre plots with individual trees as plot center.

1989 Crown Position	Total Basal Area 0.05-acre Plot	Per Acre	Understory Basal Area 0.05-acre Plot	Per Acre
	(ft^2)	(ft^2)	(ft^2)	(ft^2)
Dominant	4.80 a[1]	96.0	2.76 a	55.2
Codominant	5.20 a	104.0	1.77 b	35.4
Intermediate	5.29 a	105.8	1.45 b	28.9

[1] Column values followed by the same letter are not significantly different ($p < .05$), based on Duncan's New Multiple Range Test.

Correlation analysis (Figure 1) showed that diameter growth for the second measurement period is strongly dependent on diameter growth rate in the first period ($r^2 = 0.5570$). In other words, past growth predicts future growth in unmanaged/undisturbed stands. The implication is that periodic measurements may provide especially useful information for the management of woodlands containing high value trees. However, foresters rarely have such

information available and are understandably hesitant to obtain growth rate information by the increment coring of potentially high value trees.

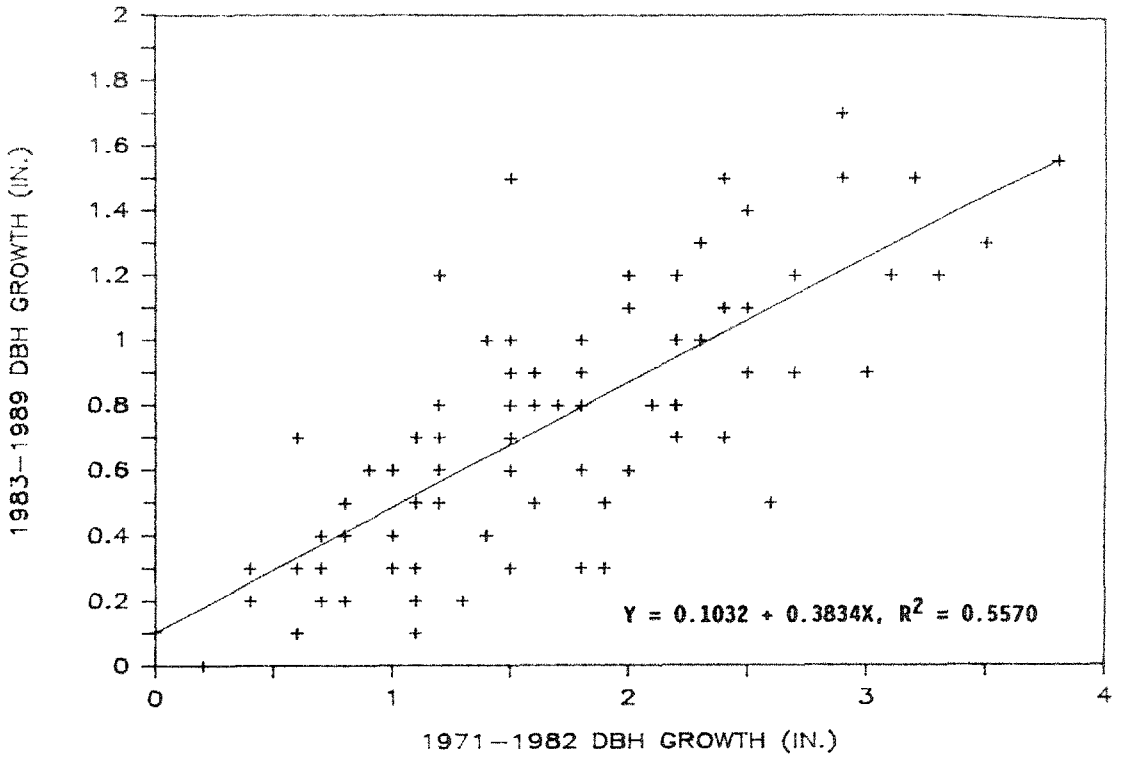

Figure 1. Diameter growth for 83 black walnut trees showing relationship of the first period rate (1971-82) to the second period (1983-89).

What then, is the best method for obtaining information concerning individual tree growth rates? One approach would be to implement continuous forest inventory (CFI) systems involving permanent re-measurement plots or mapped individual trees. Though intensive and time-consuming, systematic approaches for quantifying growth and yield should be considered as potentially useful management tools, especially for high-value hardwood stands with a substantial black walnut component.

SUMMARY

A goal of this investigation was to identify single factors or a combination of tree and stand attributes that can be used to give a consistent prediction of current individual walnut diameter growth rates. Such a system should aid in crop tree identification, assist in avoiding unnecessary TSI work, and improve timber marking decisions. Crown class, in combination

with tree diameter relative to the stand average, was found to be the best indicator of current DBH increment.

One of the measurements in this study included a separate tally of understory tree basal area. Such a description of stocking density can be used as an indirect expression of root competition, since understory trees in this study stand were in no way competing with walnuts for crown space. Since higher levels of understory stocking were not correlated with lower rates of walnut diameter increment, it may be inferred that walnut growth is not influenced nearly as strongly by competition for root space as it is for crown space. Therefore, TSI efforts should be concentrated on releasing black walnut crowns from low-value trees and grapevines, and not on removing understory trees. Research by Phares and Williams (1971) resulted in a similar conclusion.

Black walnut has been shown to be capable of responding to release, if trees have sufficiently full crowns and vigorous root systems (Phares and Williams 1971). However, the size and duration of the growth response must be large enough to offset the cost of the release in order to be considered a sound management decision. The ability to make such decisions depends on further study of walnut response to release in a combination of stand conditions, soil types, geographic locations, and economic situations.

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EFFECTIVENESS OF ELECTRIC DEER FENCES TO PROTECT PLANTED SEEDLINGS IN PENNSYLVANIA

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Abstract: Electric fences are used in Pennsylvania following a timber harvest to reduce deer browse on natural regeneration. In 1984, five-strand electric deer fences were constructed around two central Pennsylvania clearcuts. Northern red oak, white ash, white pine, and yellow-poplar seedlings were planted inside each fenced clearcut area in 1984 and 1985. One-half of the 1280 seedlings for each species were maintained free from herbaceous and woody vegetation competition with annual applications of glyphosate. Seedling survival, height and deer browsing in the growing season were recorded annually for four years. These data were analyzed to evaluate the effectiveness of electric deer fences to reduce deer browsing on planted seedlings with emphasis on (a) years from construction, (b) species, and (c) species specific height growth. The fences were effective in reducing deer browsing on the planted seedlings for the first two years after construction. After this time, browsing during growing season increased. Frequency of browsing was dependent on species and seedling height. White pine was the least frequently browsed and northern red oak was the most frequently browsed. Practices to enable the seedlings to grow >1.2 m in height in two or three years after fence construction will produced the most successful tree planting programs in Pennsylvania.

INTRODUCTION

Post-harvest artificial regeneration in mixed oak stands may be used when regeneration stocking is inadequate or the species composition of the regeneration is not desirable. When stands have abundant herbaceous vegetation and high deer populations, artificial regeneration programs should include steps to control competing vegetation and deer browsing. Effects of competing vegetation on species desirable in mixed oak stands have be reported for planted seedlings (Von Althen 1972, Farmer 1981, Johnson 1984, and Bowersox and McCormick 1987) and planted seeds (Kolb et al. 1990). The use of deer exclosures to reduce the incidence of deer browsing on natural regeneration is well documented (Jordan 1967, Marquis and Brenneman 1981 and Trumbull et al. 1989). Electric fences similar to those described by Brenneman (1982) are currently used to minimize deer browsing to seedlings from natural sources in Pennsylvania. However, the incidence of deer browse to planted seedlings inside

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an electric deer fence has not been well documented. Electric fence designs can vary but principle components are high tensile strength wire and energizers capable of charging the fence with at least 5500 volts. Effectiveness of the various designs may depend on local conditions. In Pennsylvania, properly constructed and maintained five-to-seven strand vertical fences have performed satisfactory.

This study reports on the effectiveness of electric fences to protect planted seedlings of four species (white pine (*Pinus strobus* L.), white ash (*Fraxinus americana* L.), northern red oak (*Quercus rubra* L.), and yellow-poplar (*Liriodendron tulipifera* L.)) from deer browsing in two central Pennsylvania clearcuts.

METHODS

Two mixed oak stands in the Ridge and Valley Provenience of central Pennsylvania were used as study sites. The two sites were located 14 km south of State College and within 1 km of each other. The sites were similar, except one had a southeastern aspect and the other had a northwestern aspect. Additional site information and soil chemical properties have been reported by Kolb et al. (1990). The stands had received shelterwood cuts to increase the quantity of desirable seedlings. Neither stand had acceptable stocking of seedlings 10 to 15 years after treatment. Red maple (*Acer rubrum* L.) dominated the average of 2050 to 5250 commercially important seedling per hectare for the two sites. Ground vegetation was dominated by hay-scented fern (*Dennstaedtia punctilobula* L.) and poverty oat grass (*Danthonia spicata* (L) Beauv.).

In the winter of 1983-84, approximately 6 ha of each stand were clearcut. A vertical five-strand, high tensile steel electric fence was constructed around 4 ha. Vertical arrangement of the wires were 20 cm above ground for the lowest wire, then spacings of 25, 30, 30 and 30 for a total fence height of 135 cm. Wires were attached to insulators installed on low value trees. Horizontal distance between insulators ranged 4 and 25 m, depending on topography and tree spacing. Electrical ground was established by four 1.22 m sections of copper coated rod. Deep cycle marine batteries were used to power Gallagher E-12 energizers. The batteries were changed once per month throughout the study.

In August 1983, four replications of four 80 m^2 plots were established in fern or grass dominated locations at each site. At this time, two plots per replication was treated with an application of 1.7 kg/ha of glyphosate to kill existing fern or grass vegetation. The remaining plots were maintained in the fern or grass condition. In May 1984, twenty bare root seedlings of each species were planted with a pointed planting bar at a 1.0 x 1.0 m spacing in each plot. Hardwood seedlings were 1-0 stock which were top-clipped at the time of planting to a height of 10 cm. The white pine seedlings were 2-0 stock and averaged 10 cm at planting time. Data for the fern and grass (Weedy) plots, and fern- and grass-free (Weed-free) plots were combined for this study. At each site, there was a total of 320 seedlings per species with 160 planted in Weedy plots and 160 planted in Weed-free plots. The 1984 planting methods and treatments were duplicated in 1985. Annual shielded applications of glyphosate

(1.7 kg/ha) were used to control competing vegetation on the weed-free plots. Seedling survival, height and deer browse on the terminal shoot during the growing season were recorded annually for four growing seasons (1984-1988). Deer densities for the area surrounding the study sites were estimated to be about 1 deer per 13 hectares.

RESULTS

Annual seedling survival values for both planting years and both sites were combined and are presented in Table 1. Survival one year after planting was generally above 80% and not strongly affected by herbaceous condition. As years after planting increased survival decreased, more on the Weedy plots than on the Weed-free plots. Survival of the hardwood species averaged 23 to 40% lower on the Weedy plots than on the Weed-free plots.

Table 1.--Average[1] survival for the four species by herbaceous condition and years after planting.

Species	Years After Planting			
Herbaceous Condition	1	2	3	4
	----------%----------			
White Pine				
Weedy	84	78	73	68
Weed-free	89	82	79	75
Northern Red Oak				
Weedy	94	74	61	58
Weed-free	94	89	82	81
White Ash				
Weedy	92	85	78	71
Weed-free	98	98	95	95
Yellow-poplar				
Weedy	76	53	41	38
Weed-free	87	82	80	78

[1]Values were averaged over planting years and sites, n= 640.

Differences in seedling height between the Weedy and Weed-free plots was species and time dependent (Table 2). The effect of herbaceous competition on height was moderate for white pine and northern red oak, and substantial for white ash and yellow-poplar. Average four years after planting height advantage of the Weed-free plots as compared to the Weedy plots was 1.2x for white pine, 1.3x for northern red oak, 2.2x for white ash and 1.7x for yellow-poplar.

Table 2.--Average[1] height of seedlings that were not browsed by deer for the four species by herbaceous condition and years after planting.

Species	Years After Planting			
Herbaceous Condition	1	2	3	4
	cm			
White Pine				
Weedy	22	44	66	97
Weed-free	22	42	77	115
Northern Red Oak				
Weedy	22	42	66	101
Weed-free	24	55	94	132
White Ash				
Weedy	29	55	87	121
Weed-free	39	99	178	265
Yellow-poplar				
Weedy	34	65	126	189
Weed-free	40	128	230	321

[1]Values were averaged over planting years and sites.

Deer tracks and feces inside the fence were rare during the first and second years after construction. Signs of deer inside the fence increased in the third and following years after construction. This observed pattern of deer penetration was also reflected in the frequency of browsing (Figure 1). The frequency of growing season browsing increased with increasing years after construction and varied among the four species. Northern red oak and yellow-poplar suffered the highest level of browsing. White pine and white ash were browsed less frequently. This browsing had a major impact on seedling height (Table 3). Over all treatments and conditions, browsed white pine, northern red oak, white ash and yellow-poplar seedlings averaged 51, 67, 76 and 74 cm four years after planting, respectively. These average species specific height values were considerably lower than the unbrowsed values.

DISCUSSION

Five strand vertical electric deer fences can be an effective tool in reducing the incidence of deer browse to planted seedlings. To maximize the effectiveness in protection, seedlings should be planted as soon after fence construction as possible and competing herbaceous vegetation should be controlled. In our study, deer penetrations of the fence were low in the first two years after fence construction. Initially, there were low frequencies of growing season browsing to the planted seedlings. Once the deer were frequently penetrating the

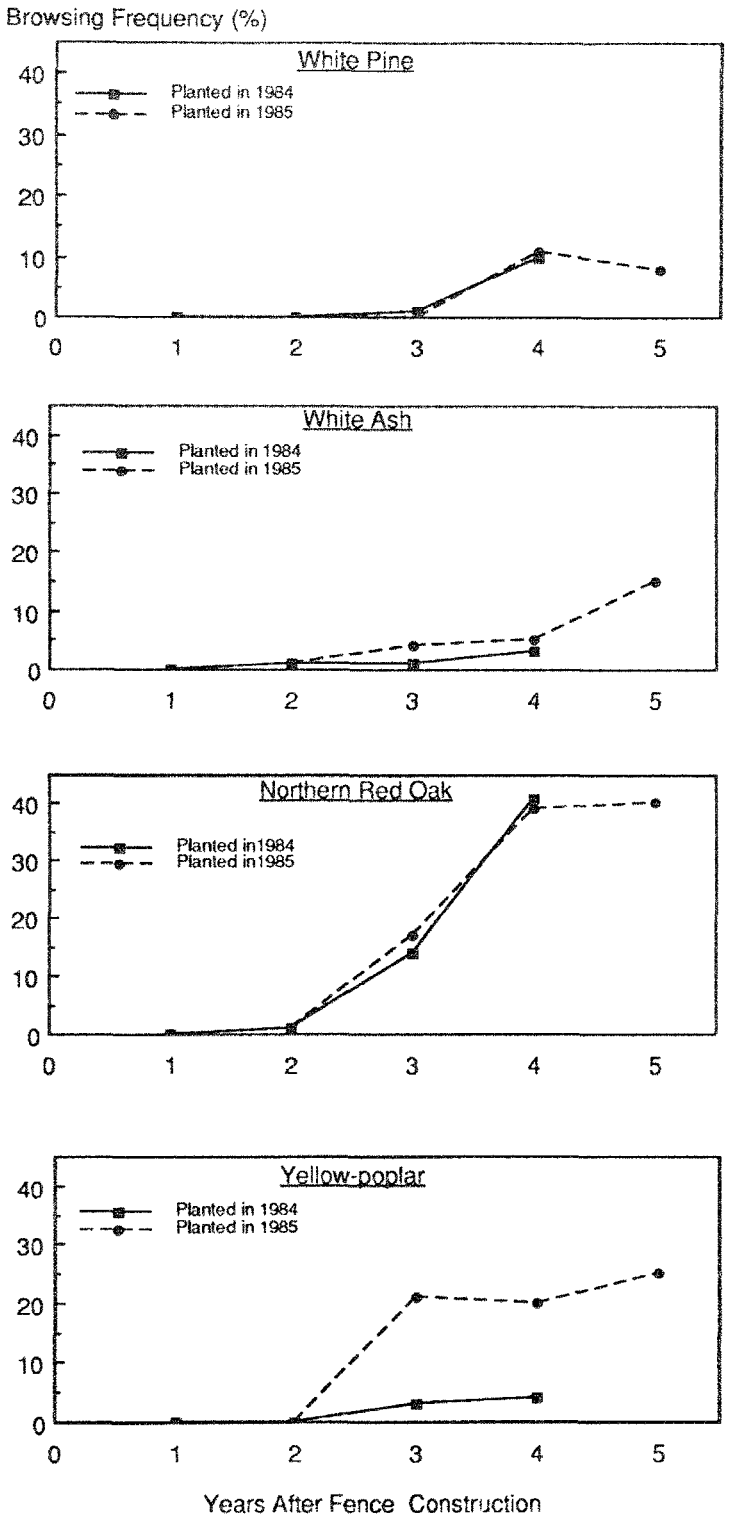

Figure 1. Frequency of deer browsing in the growing season for the four study species as a function of years after fence construction in 1984. Deer browsing activity was measured for four years after the 1984 and 1985 plantings.

Table 3.--Average[1] height of seedlings that were browsed by deer, by species.

Species	Years After Planting			
	1	2	3	4
	cm			
White Pine	--	15	39	51
Northern Red Oak	24	51	58	67
White Ash	30	81	71	76
Yellow-poplar	28	71	70	74

[1]Values were averaged over herbaceous condition, planting years and sites. N ranged from 0 for 1 year after planting to 72, 370, 94 and 81 for fours years after planting for white pine, northern red oak, white ash and yellow-poplar, respectively.

fence, browsing increased and most browsing was to seedling that were <1.2 m in height. Controlling the fern and grass vegetation enabled yellow-poplar and white ash to obtain an average height of >1.2 m in two and three growing seasons, respectively. White pine did not achieve an average height beyond the 1.2 m in four years for either herbaceous condition but it also was not frequently browsed. Northern red oak was frequently browsed by the deer, and its height growth was moderately responsive to reductions in herbaceous vegetation. Additional treatments should be explored to enable northern red oak seedlings to rapidly achieve heights that are beyond the terminal browsing height of deer. These treatments can be the use of larger stock, avoid top-clipping, and selecting seed sources or nursery practices which maximize juvenile growth.

We have maintained these and other fences in Pennsylvania. We have observed deer challenges to the fences and we will use this knowledge plus the experiences of others (PA Bureau of Forestry 1987 and deCalesta et al. 1989) to modify our future installations. Our observations have been that the deer first try to go under the fence. If this fails, they jump through the strands of wire before jumping over the fence. The increase in deer penetrations with time may be attributed to an acquired "knowledge" by deer, desire for favorable habitat inside the fence, and periods of low voltage or conductivity to ground. There were occasions when there was low or no voltage to the fence. These occasions usually followed high wind and electrical storms when downed trees or branches caused shorts in the fence or lighting caused overloads to the energizer. During dry soil conditions or periods of snow pack, resistance to ground was high and differential wire to ground voltage would drop below 3500 volts. An adjustment to minimize deer penetrations was to alternate the electrical charge to each successive strand of the fence. When all the strands are positively charged an airborne deer will not sense an electrical shock, since there is no ground to carry the electricity to the deer. At times we alternated positive and negative strands of the fence to try and negate this access route by deer. Other potential adjustments could include constructing a six or seven strand fence to minimize the distance between strands, frequent maintenance inspections, and using standard electrical service instead of batteries as the power source. However, once deer

penetrated the fence there was little incentive to leave the area due to the greater abundance of food and cover within the fenced area.

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RELEASING 75- TO 80-YEAR-OLD APPALACHIAN HARDWOOD SAWTIMBER TREES: 5-YEAR D.B.H. RESPONSE

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Abstract: Generally, mature trees on good growing sites are seldom thinned or released. Instead, at maturity the trees are harvested. Data were summarized from north-central West Virginia study areas (northern red oak site index 70 feet and above) where mature trees were released on all sides of the crown (full release). Five-year d.b.h. growth and rates of return information indicate that several species respond to release. Yellow-poplar and northern red oak were the fastest growing species, averaging 1.8 and 1.6 inches d.b.h. Thus, some mature trees will respond and it may be economical in some instances to retain mature trees for esthetics, seed production, and so on, while continuing to earn a good rate of return.

INTRODUCTION

All of us have wondered if a particularly large or "mature" sawtimber tree would respond to a thinning. Growth rings from freshly cut large stumps often indicate that an individual tree had periods of fast growth. There is little information about mature, larger hardwood trees responding to a thinning and this is expected. Simply, managed stands with mature trees usually are scheduled for a harvest cut such as some form of clearcutting, shelterwood, or diameter-limit.

A major problem in eastern hardwood stands is that many trees are about the same age due largely to activities in the past--especially logging and associated site or fire disturbance. These tree stands are now nearing maturity. Once the trees are mature and approach overmaturity they become more vulnerable to insect, disease, and climatic problems. One way to maintain tree-stand-forest health in maturing and mature trees is to try to stimulate growth through a thinning or release. Admittedly, these sawtimber trees often are economically mature since they may be growing, but earning less than an acceptable real rate of return. Also, some forest managers have an underlying belief that larger, mature trees do not respond to release.

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There are a number of concerns when releasing larger mature trees.

1. How much will trees in the dominant-codominant crown class position respond? With normally larger crowns, aren't these trees already growing as fast as possible?

2. Is the growth response for mature trees economical? A real rate of 4 percent is about the breaking point for an alternative investment.

3. How long are the desired species expected to live after release? Options for some current management plans are to grow trees up to 150 to 200 years (Sander and Smith 1989). Longer rotations may become reality due to landowner objectives or physical limitations, that is, too much land base for available personnel to manage.

4. What is the diameter breast height (d.b.h.) response of mature trees left for a short period (shelterwood concept), or two-age, or esthetic management where trees could remain from a short to an indefinite period?

The purpose of this paper is to report the 5-year d.b.h.-growth results of released, mature 75- to 80-year-old sawtimber Appalachian hardwood trees.

METHODS

This study was done on the Fernow Experimental Forest (USDA Forest Service research forest near Parsons, WV) and on the Monongahela National Forest in north central West Virginia. The study areas (four treated areas, plus three controls) were established on good-to-excellent growing sites with a site index for northern red oak (*Quercus rubra* L.) of 70 feet or higher. Annual precipitation ranges from about 55 to 60 inches. During the early 1900's, study areas were logged using forms of clearcutting and high grading.

There were two study treatments. Trees were released to a free-to-grow position, that is, tree crowns released on all sides: and tree crowns not released. Mature, dominant- and codominant-crown class Appalachian hardwood trees were selected as study trees. The average number of mature, released trees in the residual stands ranged from 12 to 20 trees per acre. Average residual basal area was about 20 ft^2/acre with one exception of 30 ft^2/acre. After logging, a stand with released trees resembled a seed-tree cut (Figure 1).

Growth of released trees was compared to similar trees in three uncut fully-stocked mature stands. The trees were in areas set aside for non-management (control areas), where cutting was not permitted and were the only available comparison areas. The three areas were on excellent growing sites--northern red oak site index 80. Also for comparison purposes, the overall growth rates should generally be higher on the control versus the released areas. Thus, any significant differences in results would be conservative. In general, study trees in

Figure 1. Stand with released dominant-codominant, mature 75- to 80-year-old hardwood trees.

the control area had larger initial d.b.h. than the released sample trees. This indicates that trees were growing on better sites and that some trees, such as sugar maple (*Acer saccharum* Marsh.), red maple (*Acer rubrum* L.), and beech (*Fagus grandifolia* Ehrh.), were older and more mature.

Five-year data were collected for 11 Appalachian hardwood species. Sawtimber trees treated included hickory (*Carya* spp.), beech, white oak (*Quercus alba* L.), chestnut oak (*Quercus prinus* L.), red oak, yellow-poplar (*Liriodendron tulipifera* L.), black cherry (*Prunus serotina* Ehrh.), sugar maple, red maple, basswood (*Tilia americana* L.), and white ash (*Fraxinus americana* L.). Initially, all trees 1.0 inch d.b.h. and larger were cut except the study trees. The d.b.h. growth was recorded at the same point on the trees using the Fernow Experimental Forest tree-identification wiring technique as indicated in Figure 2 (Lamson and Rosier 1984).

Figure 2. Permanent tree identification and d.b.h. measuring point using Fernow Experimental Forest technique.

Data were collected before release and 5 years later for treated and untreated trees. Data were analyzed using Analysis of Variance techniques with significance tested at the 1- or 5-percent level, and graphics were developed using SYSTAT software.

RESULTS

Average initial d.b.h. for the 742 released trees was 16.5 inches while the 268 non-released trees had an average d.b.h. of 19.8 inches (Table 1). Overall 5-year d.b.h. growth for the 742 released trees averaged 1.6 inches while similar growth for the 268 non-released trees was 1.0 inch d.b.h.--a difference of 60 percent. If the current growth rates continue, within 10 years after initial treatment periodic growth of released trees will exceed that of non-released trees by more than 1.0 inch, 3.2 inches compared to 2.0 inches.

Five-Year Growth.

The faster growing species for the 5-year period were yellow-poplar and red oak. A surprise was beech, a noted slow grower (Trimble 1969). However, we had only a few sample beech trees.

Five-year results are summarized for individual species in Table 1. For the 742 released trees, 38 percent (281) were yellow-poplar and 31 percent (232) were red oak. Yellow-poplar grew 1.8 inches d.b.h. in 5 years with red oak at 1.6 inches. Beech grew about 1.5 inches d.b.h. Red maple, basswood, and white oak were grouped around 1.4 inches while black cherry and sugar maple grew 1.0 to 1.2 inches d.b.h. Chestnut oak, hickory, and white ash were in the group with the lowest 5-year d.b.h., with a growth response between 0.8 and 0.9 inches d.b.h.

For the non-released trees, the fastest growing species were black cherry (1.2 inches d.b.h.) with red maple, red oak, yellow-poplar, and white ash averaging about 1.0 inch. The slowest growing trees were hickories.

The released trees had significantly greater d.b.h. growth response than non-released trees for the following species--yellow-poplar, red oak, beech, basswood, and hickory. Though released white oak trees grew significantly faster than non-released trees, we had only a three-tree sample for non-released trees. This sample size was definitely too small to make any meaningful comparisons between treatments. However, a number of species did not indicate a significant d.b.h. growth-response difference between released and non-released trees. These species were red maple, chestnut oak, sugar maple, black cherry, and white ash. Also, in two instances (black cherry and white ash), the average d.b.h. growth response for non-released trees was higher than that for released trees, though not significantly higher ($p > 0.05$).

Table 1.--Five-year d.b.h. growth and rate of return for released and non-released, sawtimber-size hardwood trees.

Species	No. trees	Initial d.b.h. (in.)	D.b.h. growth (in.)	Rate of return (%)	No. years before RR (<4%)
			Released		
Yellow-poplar	281	17.6	1.8**	12.8	20+
Red oak	232	17.1	1.6**	5.6	20+
Beech	7	18.2	1.5**	17.9	20+
Red maple	10	13.5	1.4NS	6.1	20+
Basswood	20	15.7	1.4**	9.6	20+
White oak	59	14.6	1.4*	17.6[a]	20+
Black cherry	91	14.8	1.2NS	11.1[a]	0-10
Sugar maple	8	12.8	1.0NS	7.9	0-10
Chestnut oak	12	14.4	0.9NS	4.2	0-10
Hickory	6	13.2	0.9**	14.2	20+
White ash	16	13.1	0.8NS	4.1	0-10
Totals/mean	742	16.5	1.6		
			Non-Released		
Yellow-poplar	46	18.3	1.0	6.5	20+
Red oak	65	21.1	1.1	3.2	0-10
Beech	7	25.9	0.7	3.2	20+
Red maple	11	15.5	1.1	5.4	0-10
Basswood	9	19.4	0.8	3.9	0-10
White oak	3	26.9	0.9	2.4	0-10
Black cherry	52	18.0	1.2	3.8	0-10
Sugar maple	28	25.9	0.7	2.0	0-10
Chestnut oak	6	18.0	0.8	2.4	0-10
Hickory	11	17.4	0.5	3.4	0-10
White ash	30	17.8	1.0	3.3	0-10
Totals/mean	268	19.8	1.0		

*;** Indicate average growth for released tree species significantly different from non-released species at 5 percent (*) or 1 percent (**) level of testing.
[a]Improved from grade 2 to grade 1 in 5 years.
+ More than 20 years
RR=Rate of return

Table 2.--Differences in 5-year average d.b.h. growth among released mature Appalachian hardwood tree species.

Species	5-year growth*
Yellow-poplar	1.8b
Red oak	1.6b
Beech	1.5ab
Red maple	1.4a
Basswood	1.4a
White oak	1.4a
Black cherry	1.2a
Sugar maple	1.0a
Chestnut oak	0.9a
Hickory	0.9a
White ash	0.8a

*Columns with means having same letter are not significantly different. Significance tested at the 1 percent level.

Species growth differences.

Using ANOVA techniques and the Tukey HSD for multiple comparisons, differences in 5-year growth rates were evaluated among the released species. Results indicated d.b.h. growth rates were significantly different among the following species or species groups (Table 2). Yellow-poplar, red oak, and beech grew significantly faster in d.b.h. than the other species, but growth response was not significantly different among the three species. Also, growth for beech was not significantly different from any evaluated species. Differences were not detected among any other species.

Predicted 10-year growth.

Often it is easier relating 10-year growth response than 5-year (Table 3, Figure 3) and we assumed the 10-year growth was twice as much as the 5-year growth. At 5 years, released trees remained in a free-to-grow crown position. As indicated, released yellow-poplar, red oak, and beech grew 3 or more inches in 10 years while released white ash, hickory, and chestnut oak grew less than 2.0 inches d.b.h. for the same period. Overall the released trees averaged 3.1 inches d.b.h. growth and the non-released trees 2.0 inches growth, a 56 percent increase.

Comparing d.b.h. growth of larger trees.

In general, trees from the non-released areas were larger in d.b.h. than trees from the released areas. Smaller and sometimes younger trees have a tendency to grow faster than larger and perhaps older trees. For this reason, the data were divided into two d.b.h. classes, trees $\leq$22.9 inches and $\geq$23.0 inches d.b.h. Five-year d.b.h. growth for the released and non-released large trees (d.b.h. $\geq$23.0 inches) averaged 1.9 and 0.9 inches, respectively. For small trees ($\leq$22.9 inches d.b.h.), the released trees grew 1.5 inches while the non-released trees averaged 1.0 inches d.b.h. Red oak and yellow-poplar were the only species having enough samples to make comparisons. For red oak, it was apparent that when released, the larger trees grew more than the smaller (2.0 compared to 1.5 inches d.b.h.). However, the larger yellow-poplar trees grew the same as the smaller sawtimber trees (1.8 inches d.b.h. in 5 years).

For the non-released tree species, red oak and sugar maple had adequate samples in the diameter-class categories. There was little difference in d.b.h. growth among the two d.b.h. categories.

Table 3.--Ten-year predicted d.b.h. growth for released and non-released sawtimber hardwoods.

	Released		Nonreleased		
Species	No. trees	D.b.h. growth (in.)	No. trees	D.b.h. growth (in.)	Difference (%)
Yellow-poplar	281	3.6	46	2.0	82.8
Red oak	232	3.1	65	2.2	43.5
Beech	7	3.0	7	1.3	138.8
Red maple	10	2.9	11	2.2	31.8
Basswood	20	2.8	9	1.6	71.6
White oak	59	2.7	3	1.8	51.1
Black cherry	91	2.3	52	2.4	- 3.3
Sugar maple	8	2.1	28	1.5	41.1
Chestnut oak	12	1.9	6	1.5	20.8
Hickory	6	1.8	11	1.0	91.7
White ash	16	1.7	30	2.0	-16.2

RATE OF RETURN

Real rates of return (net of inflation) were determined for both released and non-released trees (Table 1). Individual tree values were determined using updated tree- value conversion

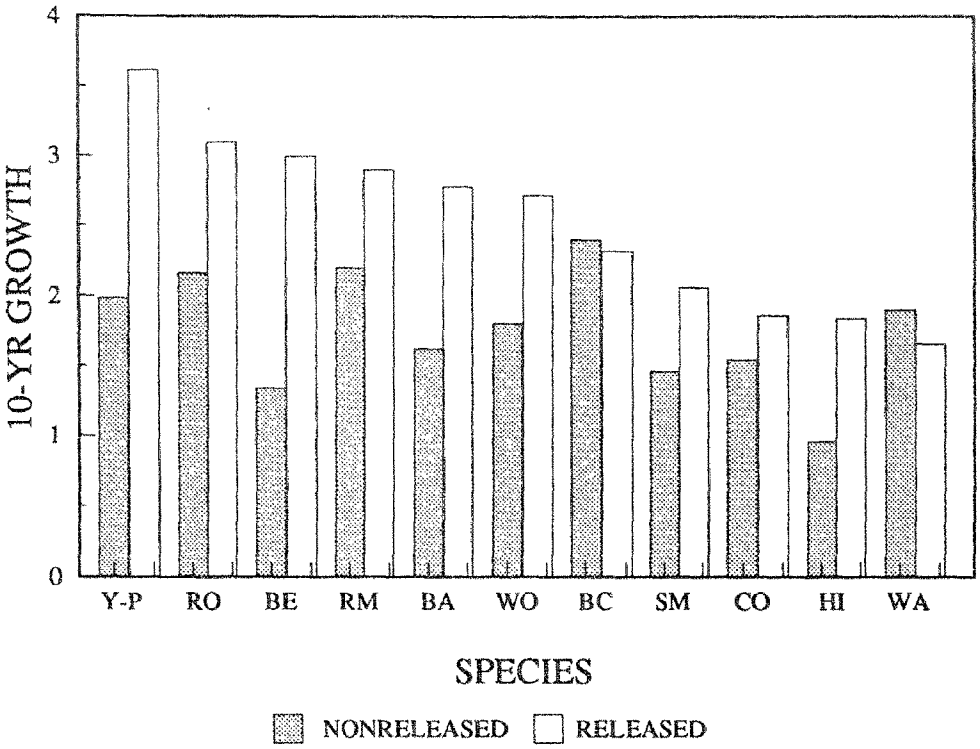

Figure 3. Anticipated 10-year growth information for species of released compared to non-released mature, Appalachian hardwood tree species.

standards, whereby tree values are derived from the value of lumber contained in a particular size and quality tree (DeBald and Dale 1990). Rate of return over the 5-year study period was based on observed growth, initial d.b.h., and merchantable height, assuming trees qualified for the highest possible grade in their size class. Projected rate of return was based on assuming that the observed d.b.h. growth would continue in the future; maximum merchantable height was fixed at 2.5 16-foot logs and trees qualified for grade 1 beyond 16 inches d.b.h.

In general, released trees earned a competitive rate of return over the 5-year period, and we expect many of them to earn at least a 4 percent return for more than 20 years in the future (Table 1). Most non-released trees earned less than 4 percent over the study period. It is clear that release improved the earning power of individual trees, but growth rates must continue for more than 5 years to make release of mature trees a desirable practice from a financial point of view.

If observed d.b.h. growth continues, several species have the potential to earn competitive rates of return for more than 20 years following release. Among released trees, black cherry, chestnut oak, sugar maple, and white ash will earn at least 4 percent for about 10 years after release. All other species will earn at least 4 percent for 20 years or more after release.

Among non-released trees, yellow-poplar and red maple will earn at least 4 percent for 20 years or more. Other species will earn less than 4 percent if not released.

The initial size of released trees influences potential rate of return following release. Rate of return decreases as d.b.h. increases, even though returns can remain positive for large trees. Returns were projected for each species using the observed 5-year d.b.h. growth, assuming individual trees were 18 inches d.b.h., with butt-log grade 1 and merchantable height of 2.5 logs at the time of release. By projecting value increases for trees of similar initial size and quality, we were able to isolate the effect of d.b.h. growth response to evaluate individual species as candidates for release.

Black cherry, sugar maple, chestnut oak, and white ash do not appear to provide an acceptable rate of return for more than 10 years following release. Other species studied will earn at least a 4 percent rate of return for 20 years or more following release. Without release, only yellow-poplar and beech promise competitive earnings for more than 20 years.

DISCUSSION AND CONCLUSIONS

What does this information mean to the forest manager? The bottom line is that some dominant and codominant sawtimber-size tree species on good growing sites will respond to a free-to-grow crown release. For yellow-poplar, the growth response is expected to be more than 3.5 inches 10 years after release. Similarly, northern red oak, red maple, and perhaps beech may grow about 3.0 inches d.b.h. Though all sides of the mature tree crown were released, we do not know the response when releasing two or three sides of the crown. However, in small sawtimber- and pole-size stands dominant and codominant tree crowns should be released on at least three sides for a significant growth response (Lamson and others 1990).

Recommended stand rotation lengths in the Appalachians are often 80 to 120 years based on site index, but in reality, the actual rotations may be 150 to 200. Also, butt-log quality on large mature trees is not influenced by release (Smith and others 1989). In a sample of more than 300 large trees, 20 trees (less than 7 percent) had a loss of quality in the butt log due to epicormic branching. Ten of these trees had epicormic branches on the tree bole before release and most of the individual trees were basswood.

The butt log is the most valuable log in the tree and at this time, 5 years after release, there is little reason to be concerned with the loss of butt log value due to epicormic branching, particularly if the tree boles do not have any epicormic branches before release. Also, a release that is heavy enough to stimulate butt- or second-log epicormic branching on codominant trees would also stimulate the establishment of reproduction--as in a shelterwood. Five years after a heavy release, the reproduction in most hardwood stands provides shade on much of the butt log, and within 10 years after release the crowns of the taller regeneration should shade most of the second log (Smith and others 1989).

Though the number of trees released in the study averaged 12 to 20 per acre, we know that for mature, fully-stocked, sawtimber-size Appalachian hardwood stands, we could expect to release about 20 to 25 good quality timber trees per acre. Most of these trees would be released on at least three sides of their tree crowns. Thinning mature hardwood stands could become more significant in the future as stands continue to mature and then become overmature, that is, trees are maturing faster than buyers are willing to harvest them (Arner and others, this proceedings).

A very heavy thinning in a mature stand where at least three and preferably four sides of the tree crown are released will most likely stimulate a worthwhile diameter-growth increase. Released trees can earn 4 percent or more for up to 10 years following release. If the observed d.b.h. growth continues (an unknown at this time), most species evaluated in this study will earn in excess of 4 percent for 20 years or more. Black cherry, sugar maple, chestnut oak, and white ash may not earn competitive returns beyond 10 years after release. For the cherry and oak trees, 5-year d.b.h.-growth data indicated non-released trees grew faster than released trees. Since study trees were codominant and the released trees were free to grow, it is quite possible these 75- to 80-year-old black cherry and chestnut oak trees will not respond to release.

Normally, fully stocked, even-aged stands on good Appalachian sites with overstory trees at least 75 to 80 years old and pole-sawtimber trees averaging 16 inches d.b.h. can be considered mature and ready for a regeneration harvest cut such as clearcutting. However, clearcutting may not be acceptable to the landowner. Besides partial cuts such as single-tree selection, diameter-limits, shelterwoods, or perhaps no cutting, the forest manager and landowner may have another option on good hardwood growing sites. If an economic cut is possible, consider giving the most desirable dominant and codominant sawtimber trees in the stand room to grow. The residual stand has a shelterwood or seed-tree look but these trees would not be harvested for several years. Many large trees will respond and become more valuable as a result of the release. Even if these trees can be released only on two or three sides of the crown and none of the understory is removed, there should be a d.b.h. response without loss of butt-log value due to the release. Tree vigor and perhaps seed production would increase too. There are site limitations to consider when applying this practice such as shallow soils or soils with fragipans. Also, at the higher elevations trees may become susceptible to glaze-snow damage. All of these limitations could lead to possible blowdown and/or loss of stem quality/value. However, retaining some mature hardwood trees for timber, esthetics and/or sources of seed for wildlife food or the regeneration of difficult species such as oak, is an option that could be acceptable to some landowners. This option could become even more acceptable, if continuing to earn a desirable rate of return is possible.

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A STAND DENSITY MANAGEMENT DIAGRAM

FOR SAWTIMBER-SIZED MIXED UPLAND CENTRAL HARDWOODS

John A. Kershaw, Jr. and Burnell C. Fischer[1]

ABSTRACT: Data from 190 CFI plots located in southern and west-central Indiana are used to develop a stand density diagram for sawtimber-sized mixed upland hardwoods in the Central States. The stand density diagram utilizes the concepts of self-thinning to establish a maximum size-density curve, and the stocking standards of Gingrich (1967) to formulate intermediate stocking levels. Like Gingrich's diagram, the stand density diagram can be used to determine thinning needs and other intensive management operations. Additionally the diagram has the advantages of relating volume rather than basal area to stand density and is organized in such a manner as to allow stand development patterns to be followed and predicted. Simulation runs from the Central States version of TWIGS are used to compare stand development trajectories on the density management diagram versus the traditional stocking diagram.

INTRODUCTION

The determination of criterion for the expression of stand density or stocking has been a frequent subject of forestry research. The most widely used stocking standard in the Central States is the tree-area equation developed by Gingrich (1967). Gingrich developed stocking standards for upland hardwood forests by utilizing tree-area ratios (Chisman and Schumacher 1940, Krajicek et al. 1961) for trees grown in natural stands under competition, and grown in open conditions free from competition. The tree- area equations express growing space (i.e. - tree area) as a function of number of trees, sum of diameters, and sum of diameters squared. Gingrich presented his results in the form of stocking guides based on number of stems per acre, basal area per acre, and quadratic mean stand diameter (Fig. 1).

Gingrich's stocking guide, and others of similar format (Solomon and Leak 1969; Roach 1977; Tubbs 1977; Hibbs and Bentley 1983), are widely used by practicing foresters in the East as a basis for deciding thinning needs, residual basal areas, and intensive management practices in even-aged stands (Leak 1981). A major reason for the wide utility is that the standards are not considered to be significantly influenced by site quality, stand age, or stand structure (Gingrich 1967).

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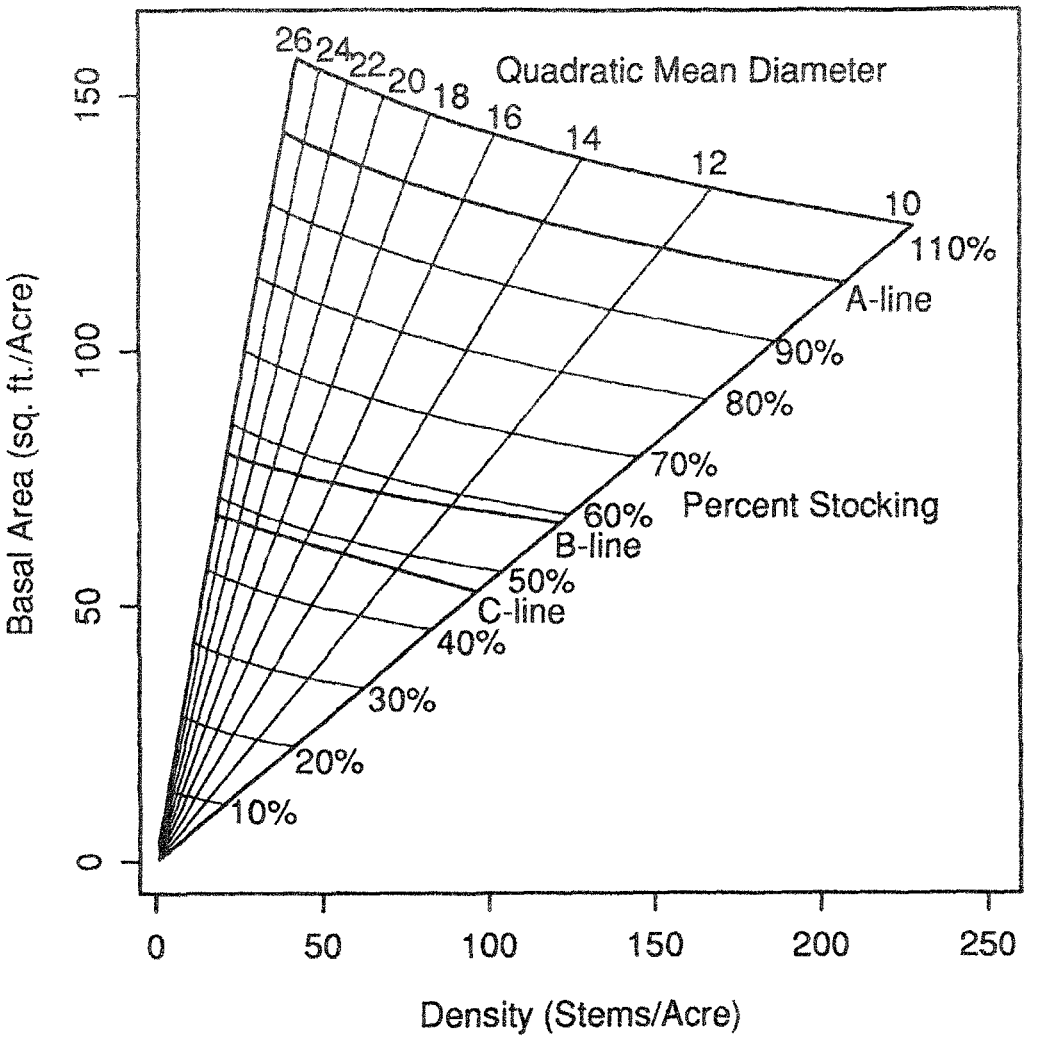

Figure 1. Gingrich's (1967) Upland Central Hardwood stocking guide.

In an alternative approach to the expression of optimum stand density and stocking Drew and Flewelling (1977) utilized concepts developed by Japanese scientists to determine size-density and yield-density relationships. By recognizing the relationship between a given density (stems per unit area) and the maximum mean tree size (weight or volume) a maximum size-density relationship utilizing the -3/2 power rule of self- thinning (Yoda et al. 1963) was developed. Further recognizing there are regions of both random and competition induced mortality, the zone of imminent competition mortality was identified (approximately .51 maximum size-density). Then locating the point of crown closure (.15 maximum size-density) Drew and Flewelling developed a density diagram for Radiata Pine based on density and mean tree volume (cubic feet), thus providing foresters with a simple biological model relating stand density and yield at any stage of stand development. This concept of stand density management has also been applied to Douglas-fir (Drew and Flewelling 1979),

western hemlock (Flewelling, Wiley, and Drew 1980), western redcedar (Smith 1989), and to natural mixed deciduous forests in Japan (Kikuzawa 1982).

Like the stocking guides developed in the East the stand density diagrams developed in the West apply to all stages of stand development (Drew and Flewelling 1977), and have the additional advantage, through the use of volume, of providing a forester with a simple biological model relating density and stand development to yield (Drew and Flewelling 1977). In this paper we develop a stand density diagram for sawtimber-sized mixed upland hardwoods in the Central States and use simulations from the Central States version of TWIGS to compare stand development trajectories on the traditional stocking diagram versus the density management diagram.

DATABASE

Data from 190 0.2-acre Continuous Forest Inventory (CFI) plots located throughout southern and west-central Indiana were utilized to formulate the density relationships. The woodlands are typical of the unmanaged or under- managed mixed species woodlands found throughout the Central States. In the early 1950's, when many of the CFI plots were established the woods were understocked, often the result of previous high-grading. Since then only limited improvement cutting or timber stand improvement (TSI) have been done.

The data collected on the CFI plots at each measurement include plot characteristics as well as tree characteristics. Trees are divided into two classes: sawtimber ($\geq$ 9.0 inches dbh) and poletimber (3.0 inches dbh to 8.9 inches dbh). The poletimber data were not collected during all measurement periods and therefore are not used in this study (thus restricting the scope of this paper to sawtimber-sized stands). The span of measurement ranges from 9 to 30 years. The measurement intervals range between 3 and 14 years with an average of 5 years. A total of 919 plot measurements are utilized in this study. For a complete description of data collection and the woodlands see Schroering and Fischer (1982), Fischer and Kershaw (1985), and Fischer (1986).

The species composition of these plots was fairly typical of central hardwood stands (Table 1). White oak (*Quercus alba* L.) average 15% of the stems per plot. Yellow poplar (*Liriodendron tulipifera* L.) averaged 12%. American beech (*Fagus grandifolia* Ehrh.), sugar maple (*Acer saccharum* Marsh.), and hickory (*Carya* spp.) each represented an average of 11% of the stems. Black oak (*Quercus nigra* L.), and northern red oak (*Quercus rubra* L.) represented 10% and 8% respectively. White ash (*Fraxinus americana* L.) averaged 5% abd black walnut (*Juglans nigra* L.) averaged 3%. The remaining species included American basswood (*Tilia americana* L.), eastern cottonwood (*Populus deltoides* Bartr. ex Marsh.), black cherry (*Prunus serotina* Ehrh.), elm (*Ulmus* spp.), black locust (*Robinia pseudoacacia* L.), chinquapin oak (*Quercus muhlenbergii* Engelm.), pin oak (*Quercus palustris* Muenchh.), sassafras (*Sassafras albidum* (Nutt.) Nees), and red maple (*Acer rubrum* L.). All nomenclature follows Kartesz and Kartesz (1980).

Table 1.--Average percent distribution of stems/plot by species and diameter class for mixed upland central hardwood CFI plots located in southern and west-central Indiana.

Species	Diameter Class										
	10	12	14	16	18	20	22	24	26	28+	Total
White Ash	1.95	1.56	0.79	0.28	0.20	0.18	0.18	0.02	0.06		5.23
Am Beech	1.50	1.38	1.22	0.89	1.20	1.60	0.75	0.77	0.67	0.99	10.97
Hickory	3.88	3.22	2.23	1.01	0.54	0.43	0.06	0.06	0.02		11.45
Su. Maple	2.84	2.72	1.56	0.97	0.79	0.57	0.73	0.30	0.12		10.60
N Red Oak	2.13	1.52	1.20	0.89	0.51	0.65	0.36	0.28	0.10	0.16	7.80
Black Oak	1.60	2.78	2.09	0.97	0.49	0.73	0.39	0.32	0.24	0.44	10.05
White Oak	2.37	2.53	2.55	1.82	1.40	1.16	0.51	0.59	0.36	0.88	14.19
Y. Poplar	3.75	3.63	2.09	1.16	0.71	0.30	0.26	0.06	0.06	0.12	12.14
Bl. Walnut	1.03	0.81	0.41	0.53	0.12	0.14	0.08			0.02	3.14
Misc.	3.64	3.47	2.85	1.09	0.68	0.36	0.10	0.04	0.04	0.04	14.41
Total	25.68	24.63	17.01	9.63	6.65	6.12	3.43	2.49	1.68	2.67	100.00

DERIVATION OF THE RELATIVE DENSITY INDEX

As stated above the maximum size-density relationship utilizes the -3/2 power law of self-thinning to identify the maximum average tree size obtainable at a given density (Drew and Flewelling 1977). The maximum size- density relationship is defined as the natural log-log relationship between mean tree volume and trees per acre:

$$\ln(\overline{V_{max}}) = \ln(C) - \frac{3}{2} * \ln(N) \qquad (1)$$

where,

_ ln = natural log,

V_{max} = Maximum mean tree volume,

C = a constant,

and N = Number of trees per acre.

By solving (1) for ln(N) the following is obtained:

$$\ln(N) = \frac{2}{3} * \ln(C) - \frac{2}{3} * \ln(V_{max}) \qquad (2)$$

or (by taking the antilog):

$$N = C^{\frac{2}{3}} * \overline{V_{max}}^{-\frac{2}{3}} \qquad (3)$$

By substituting the current mean tree volume, V, into (3) an expression for the maximum number of trees that can support the current mean tree volume is thus obtained. The relative

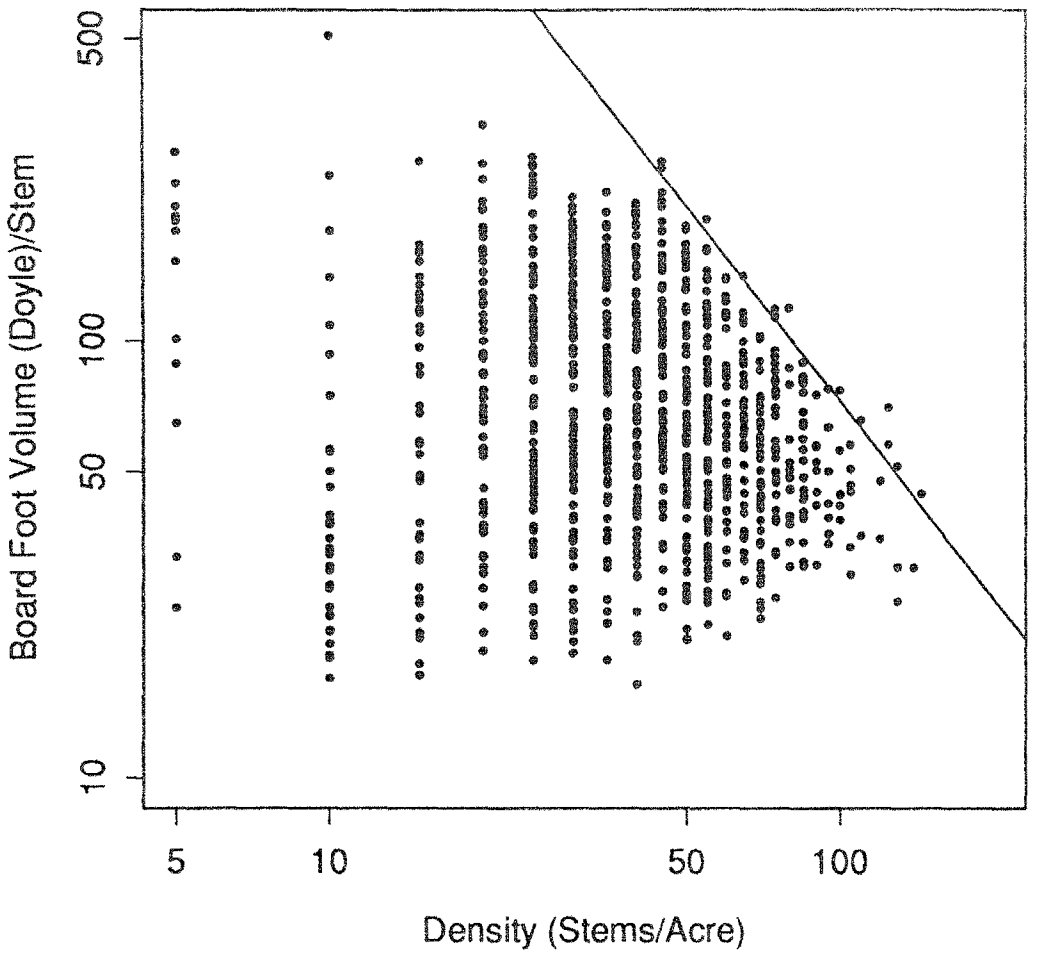

Figure 2. Natural log-log plot of board foot volume (Doyle)/stem over sensity (stems/acre) showing the location of the maximum size-density line. Based on 190 CFI plots located in southern and central Indiana.

density index (RDI) is calculated as the ratio of current number of trees per acre, N, to the maximum number of trees per acre, N_{max}, that can support the current mean tree volume:

$$RDI = \frac{N}{N_{max}}. \qquad (4)$$

Since mean tree volume, V, is simply V/N, where V is total volume per acre, (3) can be substituted into (4) and simplified to obtain:

$$RDI=\left(\frac{V}{C}\right)^{\frac{2}{3}}*N^{\frac{1}{3}}. \quad (5)$$

For convenience RDI can be multiplied by 100 so that relative density is expressed as a percentage of maximum density rather than a fraction. In the diagram developed here RDI is expressed in this manner.

Since there is no statistical procedure to estimate maximum relationships, the constant, C, is typically found by placing (1) across the observed maxima on a natural log-log graph of mean tree size (volume or weight) over number of trees per acre, and interpolating (Drew and Flewelling 1977). For each plot, mean board foot volume over number of trees per acre was plotted on a natural log-log scale (Fig. 2). As can be seen from figure 2 there appears to be a maximum mean tree size (board foot volume Doyle) obtainable for a given density (number of trees/acre). Quantification of the maximum size-density relationship was accomplished by constructing lines with slopes of -3/2 at various intercepts until it appeared to represent the observed maximum (Fig. 2). The line placed across this maximum was interpreted to be:

$$\ln(\overline{V_{max}})=11.2-\frac{3}{2}*\ln(N). \quad (6)$$

The line selected was thought to be a more obvious maximum because of the developmental pattern of the plots rather than across the highest point as done in previous studies (Drew and Flewelling 1977, 1979; Flewelling, Wiley, and Drew 1980). Placing the maximum size-density line to allow stands to exceed the maximum size-density relationship temporarily, and thus becoming "overstocked" reflects the thinking of Gingrich (1967) and appears reasonable.

The coefficients in (6) can be rearranged as before to obtain expressions for maximum density (N_{max}) and relative stand density (RDI). The expression for maximum density (3) becomes,

$$N_{max}=(73130)^{\frac{2}{3}}*(V)^{-\frac{2}{3}}, \quad (7)$$

and,

$$RDI=\left(\frac{V}{73130}\right)^{\frac{2}{3}}*(N)^{\frac{1}{3}}. \quad (8)$$

DEVELOPMENT OF THE DENSITY MANAGEMENT DIAGRAM

A relative density measure such as RDI is not very useful unless it is presented diagrammatically relation to easily measured stand parameters. The relationship between

mean tree volume, density, and either basal area or quadratic mean diameter was examined in a variety of equation forms, transformations, and weighting schemes. The equations were compared on the basis of Furnival's Index (1961) and residual analyses. The following equation was selected as "best" based on the above criteria:

$$V = b_0 * N^{b_1} * BA^{b_2} \quad (9)$$

where,

V, N are as defined above,
BA = Basal Area (sq. ft./acre),
and b_is are regression parameters.

The parameter estimates, standard errors, and approximate t values are given in table 2. All parameter estimates were significant at the .01 level, the adjusted R^2 was .63 and the root MSE was 41 (bd. ft./stem). This equation will be subsequently used to establish quadratic mean diameter contours on the density management diagram.

Mortality trends were not always as obvious as they were in the data used by Drew and Flewelling (1977, 1979) primarily because of the initial under-stocking and subsequent partial cutting of many of the plots; therefore, another set of relative density criteria needed to be utilized. The stocking standards of Gingrich (1967) was thought to be the most logical criteria to examine.

Table 2.--Parameter estimates, standard errors, and approximate t values for equation 9.

Parameter	Estimate	Standard Error	t-value
b_0	28.69	3.42	8.38
b_1	-1.42	.038	-37.77
b_2	1.52	.044	34.51

Gingrich's stocking standards were translated onto the maximum size- density relationship utilizing the tree-area equations developed by Gingrich and equation (9). Because Gingrich did not provide an equation for the C- line, the equation was derived by interpolating points from the stocking diagram and fitting a simple quadratic equation. The resulting equation was:

$$BA = 72.00 - 0.224 * N + 0.000254 * N^2. \quad (10)$$

The R^2 was .97 and the root MSE was 4.5 (sq. ft.). Figure 3 shows the relationship between the maximum size-density curve and the stocking standards of Gingrich. Based on the equations developed here the maximum size-density curve and the A-line are almost equivalent over the range of data in which the size-density relationship is most evident (45 - 100 trees/acre). As a result of this relationship the density management diagram and the stocking guide are essentially equivalent merely representing a transformation. The final density management diagram is shown in figure 4. The A-line was not included because of

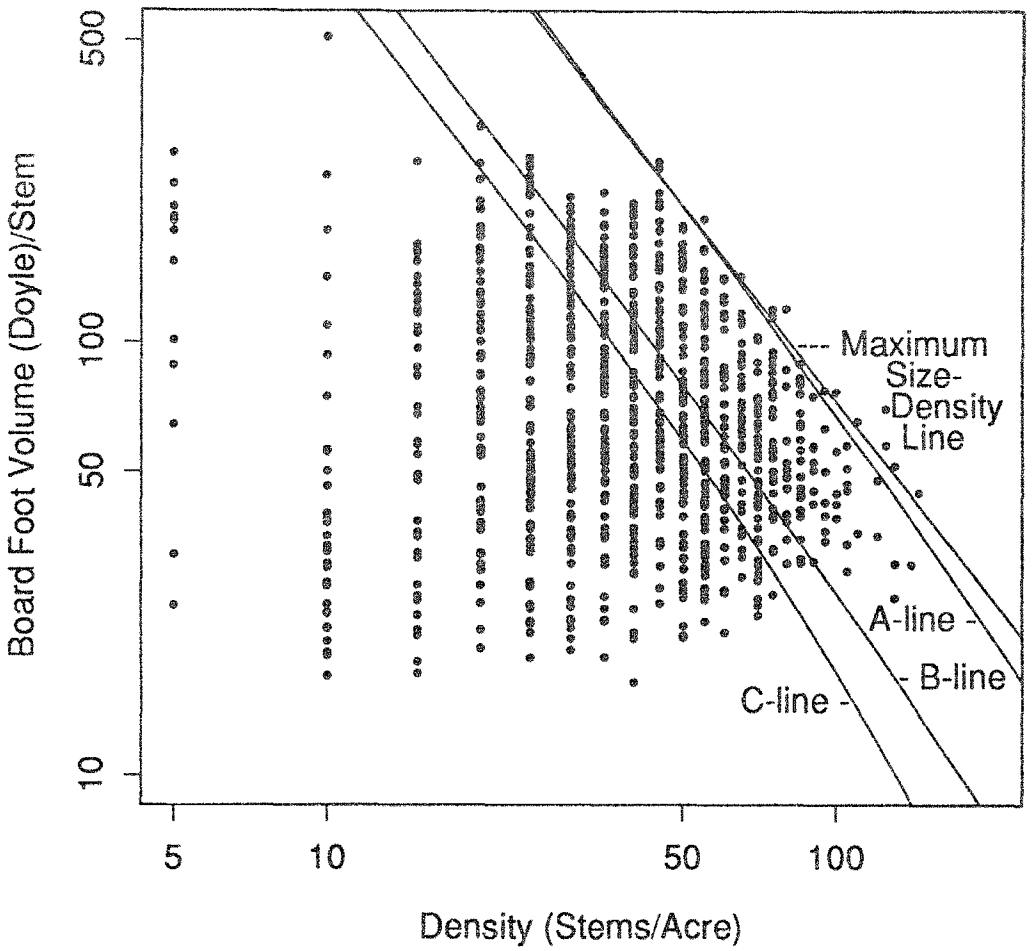

Figure 3. Density management diagram for mixed upland hardwood sawtimber- sized stands (An 8.5 X 11" copy of this diagram is available upon request from the Authors).

it's equivalence to the maximum size-density line (100% relative density line).

APPLICATIONS OF THE DENSITY MANAGEMENT DIAGRAM

TWIGS (The Woodsman's Ideal Growth Simulator) was used to develop a series of examples with which to compare the density management diagram with the stocking guide in relationship to stand development patterns. A stand of average composition was developed from the Feldun Purdue Agricultural Center (FELPAC) CFI database (Fischer et al. 1984). Three initial stand density levels were selected: low - 25 trees per acre; average - 50 trees per acre; and high - 100 trees per acre. The low and high densities represent the range for most of the CFI plots.

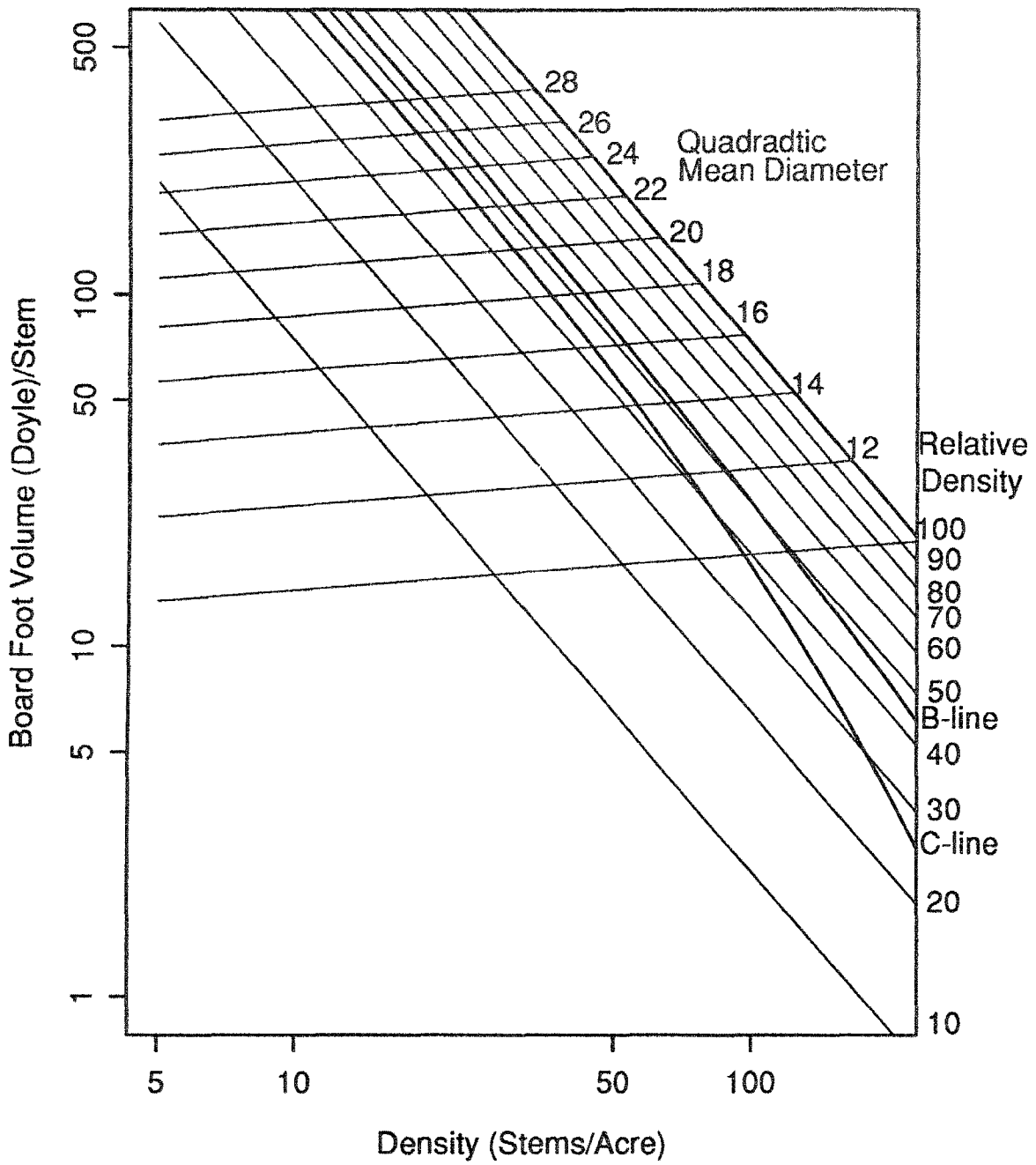

Figure 4. Plot of the maximum size-density relationship showing the location of the stocking criteria of Gingrich (1967).

In the first set of growth simulations (Fig. 5) the stands were allowed to develop without the influence of ingrowth. As can be seen from figure 5a the development of the low density stand is somewhat erratic, while the development of the high density stand is a rather smooth trajectory along the maximum size-density curve. This agrees with the theories of Drew and

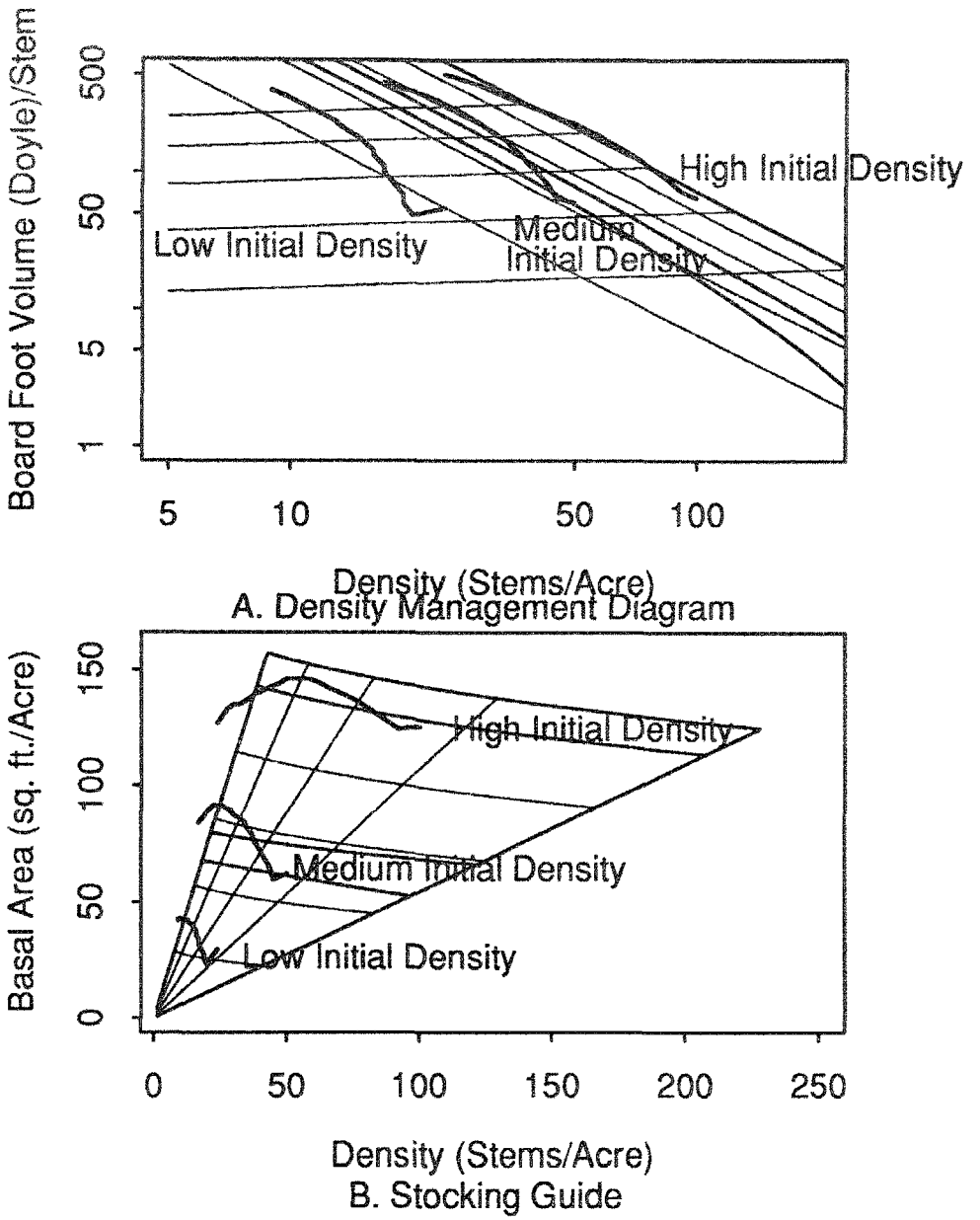

Figure 5. Comparisons of stand development trajectories on the stocking guide versus the density management diagram using simulation results from TWIGS and not accounting for ingrowth.

Flewelling (1977) in which stands below the B-line are subject to "random" mortality, and, therefore, have more erratic development pattern; while stands above the B-line experience "competition-induced" mortality, and have more predictable patterns. Comparing the same data plotted on the stocking guide (Fig. 5b) the trajectories are not nearly as obvious and it is

very difficult to discern exactly what stand development processes are occurring especially with the high density stand.

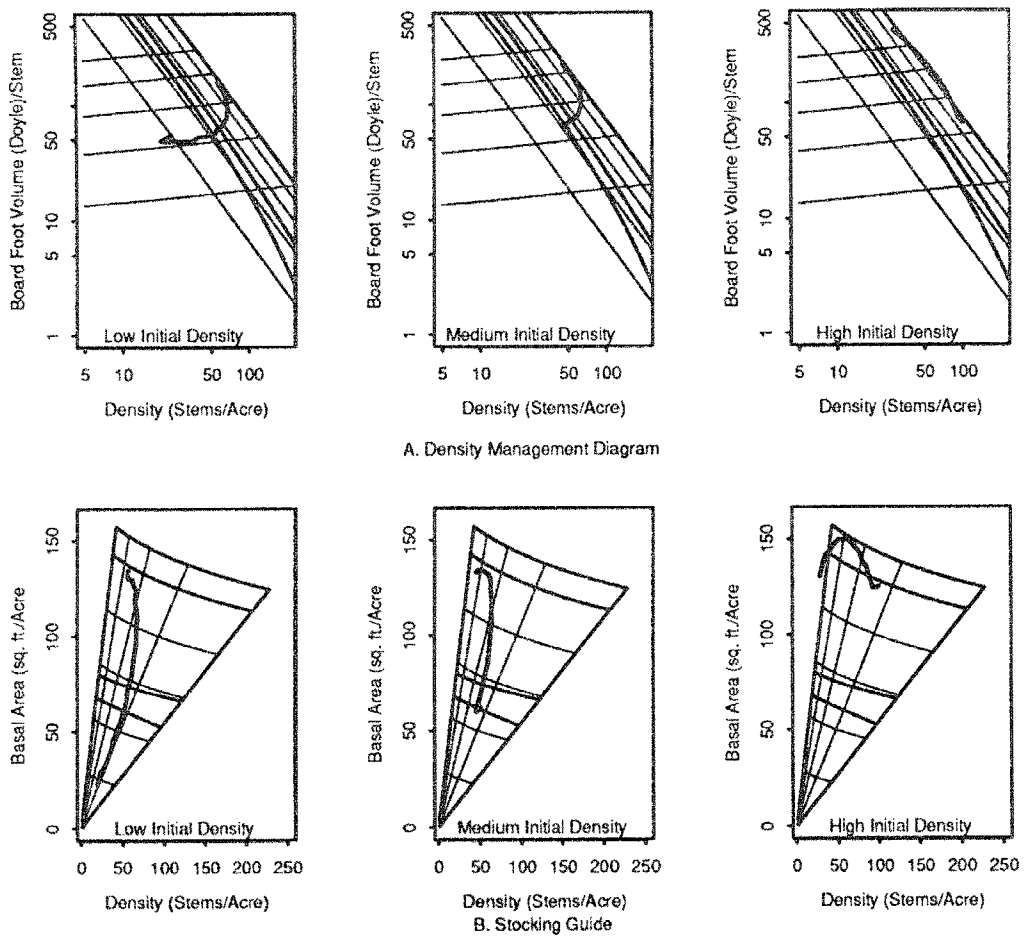

Figure 6. Comparisons of stand development trajectories on the stocking guide versus the density management diagram using simulation results from TWIGS adding ingrowth at an average rate by species and density.

In the second set of simulations (Fig. 6) ingrowth was allowed to influence stand development. Ingrowth was added at an average rate (percentage) by species and density level as computed from the FELPAC database (Fischer et al. 1984). In this set of simulations the stand development processes are again more clearly reflected in the density management trajectories. The stocking guide trajectories for the low and average initial densities do make sense; however, on the density management diagram the process of self-thinning is more evident. Above a relative density of 80 self-thinning is the major stand development process occurring in these simulated stands. On the density management diagram the results of self-thinning are illustrated by the "bend" in trajectory and the movement along the maximum

size-density curve. On the stocking guide the "bend" occurs but is not as pronounced and the stand development processes are not as easily interpreted.

Finally, the last set of simulations introduce partial harvesting into the stand development history. Using the high density stand a series of 1, 2, or 3 partial harvests are simulated to illustrate the use of the diagrams for making management decisions. Cuts are made initial and at 25 year intervals. All harvests attempt to reduce the relative density to the B-line. In this set of simulations both diagrams do an excellent job at depicting the stand development processes and management activities (Fig. 7). In this case the major advantage that the density management diagram has over the stocking guide is the depiction of relative density in terms of volume and stems/acre. Since forest managers typically manage for volume being able to view management decisions and stand development in terms of volume is extremely advantageous.

DISCUSSION AND CONCLUSIONS

The relative density diagram presented in figure 4 provides practicing foresters with a valuable management tool relating volume yield per tree to stand density. The significance of this work to the problem of forest stocking evaluation cannot be underestimated. Results of intermediate operations can now be examined in the units of interest to foresters managing timber: volume and trees per acre rather than in basal area.

The density management diagram integrates relative stocking and stand development theory providing foresters with a tool that not only allows point estimation of stocking but also serves as a stand monitoring system in which stand development and treatment can be traced throughout the stand management history. As the landbase available for commodity production continues to decrease foresters are going to need to intensify management efforts on the remaining acreage. This effort is going to require the development and implementation of innovative management techniques and plans. Utilizing this diagram as a diagnostic and monitoring tool should enable foresters to better evaluate management activities and develop a more adaptive approach to stand management.

The relative density measures presented here do not depart from the measures developed by Gingrich (1967) but are a transformation of Gingrich's standards and an incorporation of the ideas of self-thinning and maximum size-density. The density management diagram is a simple biological model relating yield and density at any stage of stand development, and, although the theoretical constancy of the self-thinning slope (-3/2) has come under criticism (Weller 1987, Zeide 1987), the utility of these diagrams for monitoring stand development and making management decisions should not be overlooked (Smith 1989). Additionally, the criticisms do not reject the concept of self-thinning, but rather question whether the slope of the maximum size-density curve should be constant for all species.

A potential shortcoming of this diagram is the lack of information about trees less than 9.0 inches dbh. It needs to be emphasized that this diagram is for sawtimber-sized stands.

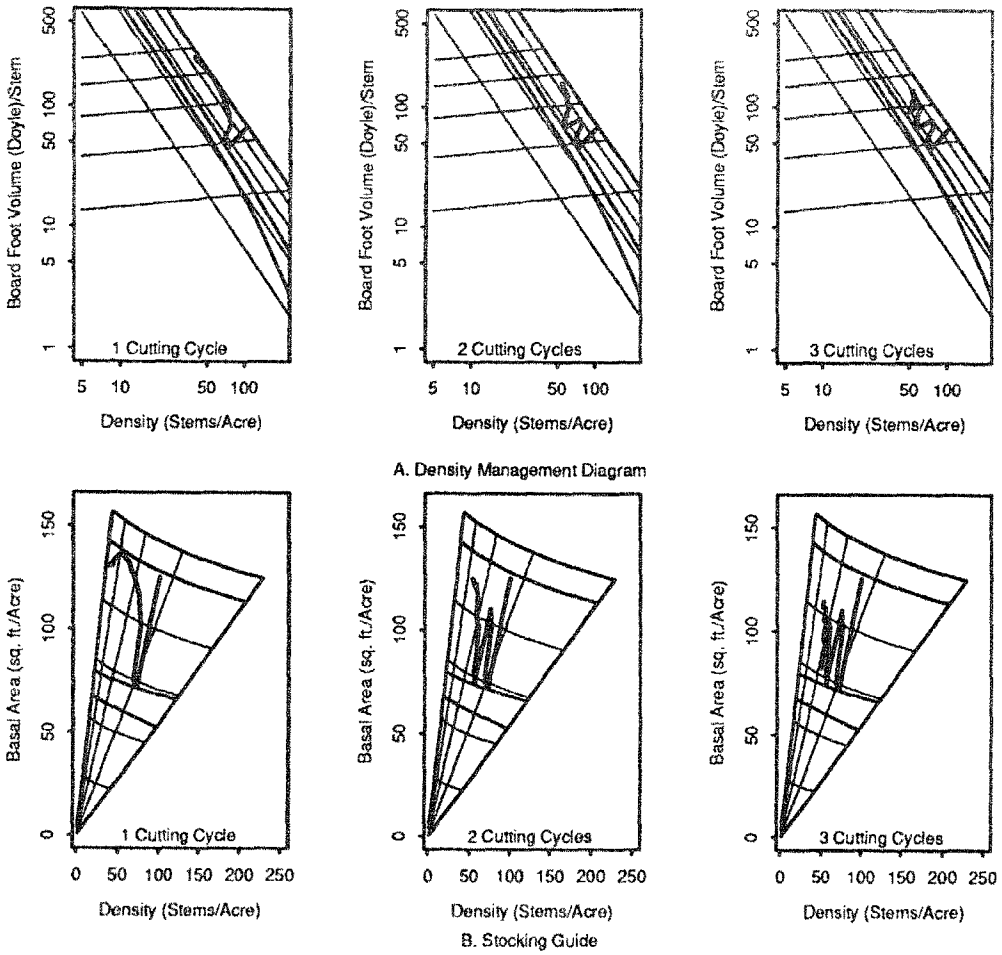

Figure 7. Comparisons of stand development trajectories on the stocking guide versus the density management diagram using simulation results from TWIGS illustrating the influence of management activities on stand development.

Stands which fall below the C-line are considered understocked in sawtimber-sized trees and, therefore, not sawtimber-sized stands. It should also be pointed out that Gingrich's (1967) stocking chart only utilizes trees within the main canopy (i.e. - dominant or codominant). So even though trees down to 2 inches dbh were utilized, very few would be contributing to the overall percent stocking in sawtimber-sized stands. Additionally, the density management diagram is based on merchantable volume; therefore, inclusion of trees below 9.0 inches dbh, which have little or no merchantable volume, would have little or no effect on relative density because mean tree volume will decrease proportionally as the number of trees with no volume increase. Management guidelines for non-sawtimber-sized stands are definitely a gap in our stand management knowledge in the central hardwoods.

Further development of the maximum size-density relationship presented here, including the incorporation of quality related information, will be important future improvements. Much

work continues to be needed in the area of optimal stand density and yield in mixed upland hardwoods. This work represents a first step in linking the two together.

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EVALUATION OF AN APPROACH TO IMPROVE ACORN PRODUCTION DURING THINNING

William E. Drake[1]

Abstract: Large poletimber size, mixed oak (*Quercus* spp.) stands in Centre County, Pennsylvania were thinned to determine whether acorn production could be improved by retaining the best acorn producing oaks as compared with conventional thinning practices. Sound acorn production averaged 291 and 339 kg/ha in the acorn production and conventionally thinned stands, respectively, prior to thinning. Average yields declined by 79 and 129 kg/ha in the acorn production and conventionally thinned stands, respectively, following thinning. Although declines were less in stands thinned for acorn production, they were not significantly different ($P>0.25$) from those in conventionally thinned stands. Crown dominance was an important factor affecting acorn production in this study. Ninety-six and 76 percent of the dominant and co-dominant oaks produced acorns. Conversely, only 40 and 8 percent of the intermediate and suppressed oaks were productive. Results of this study indicate that improvements in acorn yields were not sufficient to justify the additional effort and cost of identifying and retaining to best acorn producing oaks prior to thinning.

INTRODUCTION

Factors affecting the acorn production of oaks have been intensively studied over the years because of the importance of acorns in regenerating oak stands and as a food source for many wildlife species. Vigorously growing oaks with well developed crowns are regarded as generally superior acorn producers (Downs and McQuilken 1944, Cypert 1951, and Sharp 1958). Numerous studies also indicate that some individual oaks are consistently good or poor acorn producers and suggest that this may be due to their inherent genetic potential for producing acorns (Downs and McQuilken 1944, Harlow and Eikum 1963, Sharp and Sprague 1967, Goodrum et al. 1971, and Christisen and Kearby 1984).

Harlow and Eikum (1963), Sharp and Sprague (1967), Shaw (1971) and Goodrum et al. (1971) recommended that good acorn producing oaks be retained during thinning to improve acorn yields relative to conventionally thinned stands. This study was undertaken to evaluate the effectiveness of such a recommendation.

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I would especially like to thank S. A. Liscinsky for initiation of this study as well as his guidance and support until its completion. Pennsylvania Game Commission wildlife technicians, biologists and foresters assisted with field work and data collections. R. C. Boyd, W. L. Palmer, W. K. Shope and W. M. Tzilkowski provided statistical assistance. The study was funded by the Pennsylvania Game Commission.

METHODS

Study Sites

Three mixed oak stands were selected as study sites (replications). Two of the stands were on State Game Lands No. 33 and the third one was on State Game Lands No. 60 near Philipsburg in Centre County, Pennsylvania. All 3 stands were within 3.2 km of each other. Three replications were in fully stocked large poletimber size, mixed oak stands ranging from 42 to 58 years of age. The basal area, mean d.b.h. and percentage of oak in the 3 replications are given in Table 1. Measurements of site index within and between replications were not taken.

Table 1.--Basal area, mean d.b.h. and percentage of oak in 3 replications.

Replication	Basal Area (m^2/ha)	Mean d.b.h. (cm)	% Oak*
1	24.2	19.6	69
2	19.9	23.9	66
3	21.7	20.1	75

*Includes red oak (*Quercus rubra*), black oak (*Q. velutina*), scarlet oak (*Q. coccinea*), white oak (*Q. alba*) and chestnut oak (*Q. prinus*).

Study Design

A 3 x 3 randomized block design was used with 3 treatments within each replication:

1. Acorn production thinning (APT) - trees were selected for retention during thinning according to their acorn production.
2. Conventional thinning (CT) - trees were selected for retention during thinning according to conventional thinning criteria.
3. Control (C) - unthinned.

Treatments were applied on adjacent 0.8 ha square blocks in each replication. Assignment of treatment to blocks within replications was random.

Treatments

All oaks in the 3-0.8 ha APT treatment blocks were tagged with aluminum labels. Their potential for acorn production was evaluated by inspection of branches in the crown with binoculars (Sharp 1958). Numbers of acorns on the 6 most heavily bearing branches were counted for each oak (1,318 trees) for 3 years prior to thinning (1974 thru 1976). Those oaks with the best acorn production for 3 years prior to thinning were retained in APT treatment blocks. All non-oaks were removed first during thinning to maximize acorn yields. Then all non-producing and a few of the poorest producing oaks were removed until residual basal area in the APT blocks was the same as that in the CT blocks. Also, each of the oaks in the APT blocks were visually inspected prior to thinning and placed in a dominant, co-dominant, intermediate or suppressed crown dominance category.

CT treatment blocks were thinned by Pennsylvania Game Commission foresters. In addition to conventional silvicultural considerations such as commercial value, spacing and crown dominance, den trees, snags and less common tree species and shrubs were retained for their value to wildlife. C treatment blocks were left untreated to compare their acorn yields with those in both thinning treatments.

Table 2.--Pre-thinning species composition (% of basel area) in APT and CT treatments for 3 replications - January, 1977.

Species	Replication #1		Replication #2		Replication #3	
	APT	CT	APT	CT	APT	CT
red oak	32	30	25	26	59	49
black oak	23	20	8	18	5	8
scarlet oak	10	6	10	11	3	3
white oak	4	2	16	9	3	1
chestnut oak	5	6	6	8	4	15
red maple	25	35	35	28	20	18
sassafras	1	trace	0	0	5	4
hickory spp.	trace	1	0	trace	1	2
black gum	0	0	0	0	trace	trace
aspen spp.	0	0	0	0	0	trace
Totals	100	100	100	100	100	100

In January, 1977, diameter measurements of all trees in all 3 replications of the APT and CT treatment blocks were conducted to determine pre-thinning species composition (Table 2), size class composition and basal area (Table 3). Prism plot cruises were used to determine basal area in the C blocks. Pre-treatment basal area means were 22.9, 23.9 and 20.7 m^2/ha in the APT, CT, and C treatment blocks, respectively .

Table 3.--Pre-thinning size class composition (% of basal area) in APT and CT treatments for 3 replications - January, 1977.

Size class (dbh-inches)	Replication #1 APT	CT	Replication #2 APT	CT	Replication #3 APT	CT
2	39	42	49	55	37	32
4	22	20	13	9	23	26
6	15	15	12	11	15	18
8	13	14	15	12	17	15
10	8	6	5	7	6	7
12	1	2	3	4	2	2
14	1	1	2	2	trace	trace
16	1	trace	1	trace	0	trace
18	trace	trace	trace	trace	trace	trace
20	trace	trace	trace	0	0	trace
22	0	0	0	0	0	0
24	0	0	0	trace	0	trace
BA(ft^2/acre)	99.0	103.0	94.3	104.6	105.7	105.3
BA(m^2/ha)	22.7	23.6	21.7	24.0	24.3	24.2

In March, 1977, the CT blocks were reduced by about 30 percent to 16.3 m^2/ha of basal area using established forestry and wildlife practices. The APT blocks were thinned to the same basal area by removal of all non-oaks as well as the non-producing and poorest acorn producing oaks. Post-thinning APT treatment species and size class composition for Replications #1, #2 and #3 are in Tables 4, 5 and 6, respectively. Post-thinning CT treatment species and size class composition for Replications #1, #2 and #3 are in Tables 7, 8 and 9, respectively.

Beginning in the 1980 growing season, the study area experienced 5 years of gypsy moth (*Lymantria dispar*) defoliation. Defoliation was moderate in 1980, nearly complete in 1981 and 1982, light in 1983 and very light in 1984. By 1984, there was significant oak mortality throughout all 3 replications. To insure equal stocking levels following mortality, the basal area of all live trees in the APT and CT blocks was measured in May of 1984 and June of 1985 and 1986. By 1984, basal area in the APT blocks had had declined by an average of 34 percent from the original thinning in 1977. CT blocks had consistently less mortality. Basal area in the CT blocks was the same in May, 1984 (16.1 m^2/ha) as that remaining following

Table 4.--Post-thinning species and size class composition (ft^2acre) in Replication #1 - APT treatment - March, 1977.

Size Class (dbh - inches)	Species: Red Oak	Black Oak	Scarlet Oak	White Oak	Chestnut Oak	TOTALS	%
2							0
4					0.2	0.2	trace
6	1.0	0.2	1.4		1.6	4.2	6
8	9.1	2.4	4.5	0.7	1.8	18.5	26
10	12.1	2.8	3.3	0.5		18.7	26
12	3.1	3.2	1.6			7.9	11
14	1.1	7.5		1.0		9.6	14
16	1.4	2.8				4.2	6
18		5.3				5.3	8
20		2.2				2.2	3
TOTALS	27.8	26.4	10.8	2.2	3.6	70.8*	
%	39	38	15	3	5		100

*BA = 16.3 m^2/ha

the initial thinning in 1977 - a result of compensating growth and mortality. Sufficient trees were removed in the CT blocks in June of 1984, 1985 and 1986 to equalize basal area between APT and CT treatments throughout the study. Residual basal area in the APT and CT treatments during the 1984, 1985 and 1986 growing seasons were less than one-half their pre-thinning levels (Table 10).

Prism cruise basal area measurements in the C blocks were only taken at the beginning and upon completion of the study. Mean basal area in the 3 C blocks had declined by 24 percent by June of 1986 from pre-thinning levels (Table 10).

Acorn Production Measurement

Pre- and post-thinning acorn production was sampled in 9-0.8 ha treatment blocks (3 replications of 3 treatment blocks each). Sampling was done on a 0.4 ha sampling area in each block surrounded by 12.2 m buffer strip to avoid an edge effect from adjacent treatments.

Sixty acorn traps were systematically located in each sampling area. Acorn traps were constructed with plastic bags with bottoms removed and tied and supported by wire hoops on posts (Liscinsky 1971). Each trap was 48.3 cm in diameter (0.13 m^2 sample area) resulting in

Table 5.--Post-thinning species and size class composition (ft^2/acre) in Replication #2 - APT treatment - March, 1977.

Size Class (dbh - inches)	Species: Red Oak	Black Oak	Scarlet Oak	White Oak	Chestnut Oak	TOTALS	%
2						0.0	0
4						0.0	0
6				0.6	0.8	1.4	2
8	1.8		2.1	5.2	3.1	12.2	17
10	8.8	2.2	3.3	7.2	1.6	23.1	33
12	8.7	0.8	3.1	2.4	0.8	15.8	23
14	5.4	1.1		2.1		8.6	12
16	5.6	1.4				7.0	10
18						0.0	0
20	2.2					2.2	3
TOTALS	32.5	5.5	8.5	17.5	6.3	70.3*	
%	46	8	12	25	9		100

*BA = 16.1 m^2/ha

7.8 m^2 being sampled in each sampling area. Four collections were made each fall. Sound acorns captured were weighed within 24 hours of collection. Weights were converted to estimates of sound acorn production in kg (fresh weight) per ha.

All 9 treatment blocks were sampled for 3 years (1974 thru 1976) to obtain estimates of mean pre-thinning acorn production. Each treatment block was then sampled for 10 years (1977 thru 1986) to determine post-thinning means.

Data Analysis

Friedman's randomized block analysis of variance test was used to test the H_o that changes in acorn yields following thinning were the same for all 3 treatments. Since mean pre-thinning acorn yields were not equal in all 3 treatments, comparisons of response to the 2 types of thinning were based on percentage changes in mean acorn yields following these thinnings. X^2 tables were used to determine the significance of Friedman's critical value (X^2r, P=0.05, 2 df, Zar 1974).

The Kruskal-Wallis single factor analysis of variance by ranks test was used to test the H_o that the percentage of oaks in the APT treatment blocks producing acorns was the same regardless of crown dominance ($H_{0.05,3,3,3,3}$, Zar 1974).

Table 6.--Post-thinning species and size class composition (ft^2/acre) in Replication #3 - APT treatment - March, 1977.

Size Class (dbh - inches)	Species: Red Oak	Black Oak	Scarlet Oak	White Oak	Chestnut Oak	TOTALS	%
2						0.0	0
4						0.0	0
6	3.2	0.4		0.2	0.8	4.6	6
8	21.0	1.4	1.7		2.1	26.2	36
10	23.7	2.2	1.1		0.5	27.5	38
12	8.7	1.6				10.3	14
14	1.0	1.1				2.1	3
16						0.0	0
18				1.8		1.8	3
TOTAL	57.6	6.7	2.8	2.0	3.4	72.5*	
%	79	9	4	3	5		100

*BA = 16.6 m^2/ha

RESULTS AND DISCUSSION

Annual Acorn Production Trends

Trends in mean acorn production in 3 treatments over 13 years are presented in Table 11. As in other studies (Downs and McQuilken 1944, Goodrum et al. 1971, and Christisen and Kearby 1984), acorn yields varied considerably between years. There were bumper crops (>700 kg/ha or > 600 pounds/acre) of acorns in 3 of 13 years. One (1976) was before and 2 (1979 and 1985) were after thinning (Figure 1). Only 1 other year (1984) had mean acorn yields in excess of 150 kg/ha. The acorn crops of 1980 thru 1984 were heavily affected by gypsy moth defoliation. Trends in annual acorn yields between treatments were fairly consistent throughout the study. All treatments had excellent yields in bumper years and vice versa in years of poor acorn production.

Acorn Production Thinning Versus Conventional Thinning

Mean pre-thinning acorn yields for APT and CT treatment blocks were 291 and 339 kg/ha, respectively. Mean acorn yield declined during the 10 years following thinning in both APT

Table 7.--Post-thinning species and size class composition (ft^2/acre) in Replication #1 - CT treatment - March, 1977.

Size Class (dbh - inches)	Species: Red Oak	Black Oak	Scarlet Oak	White Oak	Chestnut Oak	Others**	TOTALS	%
2		trace				trace	trace	trace
4					0.1	0.2	0.3	1
6	0.6	0.4	0.4	0.2	0.4		2.0	3
8	12.6	3.9	1.7		1.4		19.6	28
10	18.1	5.5	2.8	0.5		0.6	27.5	39
12	4.7	3.2					7.9	11
14		2.1	1.1		1.1		4.3	6
16		1.4	1.4				2.8	4
18		3.5					3.5	5
20		2.2					2.2	3
TOTALS	36.0	22.2	7.4	0.7	3.0	0.8	70.1*	
%	51	32	11	1	4	1		100

*BA = 16.1 m^2/ha
**Includes red maple, hickory spp. and sassafras.

and CT blocks to 217 and 210 kg/ha, respectively (Table 11). Post-thinning declines may have been partially due to gypsy moth defoliation. Acorn yields declined less following thinning in the APT blocks (-74 kg/ha) than in the CT blocks (-129 kg/ha). Friedman's test indicated that changes in acorn yields were not different (X^2r=1.962, P>0.25, 2 df) regardless of the thinning techniques used.

There could be several reasons why acorn yields were not improved significantly by retaining the best acorn producing oaks during thinning. Perhaps oaks with the best genetic potential for consistantly good acorn production were not well identified by counting acorns on the 6 best producing branches. However, this should be a practical phenotypic criteria for selecting oaks with the best genetic potential for acorn production (Sharp 1958). In addition, all 5 oak species (red, black, scarlet, white and chestnut) had at least 1 year of good acorn production during the 3 years when branches were inspected prior to thinning. All 5 oak species had at least fair acorn production during the bumper 1976 crop. If poor or superior acorn producing oaks are relatively consistant in this respect, they should have been easily identified.

Results of this study were heavily influenced by bumper acorn yields in 1979 and 1985. Perhaps continuation of the study would have given different results. However, if the acorn production potential of the oaks retained during thinning was a relatively consistant factor affecting acorn yields, it should have been demonstrated in these bumper years.

Table 8.--Post-thinning species and size class composition (ft²/acre) in Replication #2 - CT treatment - March, 1977.

Size Class (dbh - inches)	Species: Red Oak	Black Oak	Scarlet Oak	White Oak	Chestnut Oak	Others**	TOTALS	%
2	0.2	trace		trace		0.2	0.4	1
4			0.1			0.3	0.4	1
6				0.2	0.2	0.2	0.6	1
8	1.7	2.5	0.7	1.1	0.7		6.7	9
10	4.9	6.6	2.7	1.7	2.7	0.6	19.2	26
12	8.7	4.7	2.4	0.8	0.8		17.4	24
14	11.8	2.1	3.2				17.1	24
16	2.8	1.4	1.4				5.6	8
18				1.8			1.8	2
20							0.0	0
22							0.0	0
24	3.1						3.1	4
TOTALS	33.2	17.3	10.5	5.6	4.4	1.3	72.3*	
%	46	24	14	8	6	6	2	100

*BA = 16.6 m^2/ha
**Includes red maple and hickory spp.

Crown Dominance Versus Acorn Production

Studies by Downs and McQuilken (1944), Cypert (1951), Burns et al. (1954), Sharp and Sprague (1967) and Goodrum et al. (1971) have indicated the importance of crown dominance on acorn yields. The importance of crown dominance was also apparent in the study. Ninety-six and 76 percent of the dominant and co-dominant oaks produced acorns, respectively. Conversely, only 40 and 8 percent of the intermediate and suppressed oaks, respectively, were productive (Table 12). Crown dominance was an extremely important factor ($H=10.37$, $P<0.001$) influencing whether or not oaks in the APT treatment blocks produced acorns.

All the non-producing oaks as well as some of the poorest producers, were removed during thinning. Poorest producing oaks also tended to be suppressed and intermediates. Since many of the suppressed and intermediates were removed in the CT blocks, size class distributions of trees retained in the APT blocks were similar to those in the CT blocks (see Tables 4 through 9). Even the spacing of residual trees was observed to be similar in the

Table 9.--Post-thinning species and size class composition (ft²/acre) in Replication #3 - CT treatment - March, 1977.

Size Class (dbh - inches)	Species: Red Oak	Black Oak	Scarlet Oak	White Oak	Chestnut Oak	Others**	TOTALS	%
2						0.1	0.1	trace
4						0.3	0.3	1
6	2.4	0.4	0.2	0.2	0.4	1.0	4.6	6
8	14.0	1.8	0.3	0.4	4.5	1.1	22.1	31
10	19.8	2.7	1.7		2.2	0.5	26.9	38
12	8.7				0.8		9.5	14
14	1.0	1.1					2.1	3
16		1.4	1.4				2.8	4
18							0.0	0
20		2.2					2.2	3
TOTALS	45.9	9.6	3.6	0.6	7.9	3.0	70.6*	
%	65	14	5	1	11	4		100

*BA = 16.2 m²/ha
**Includes red maple, hickory spp., sassafras, aspen spp., and blackgum.

Table 10.--Mean basal area (m²/ha) in 3 treatments.

Date	Treatment: APT*	CT*	C**
	Prior to thinning		
January, 1977	22.9	23.9	20.7
	Following thinning		
March, 1977	16.3	16.3	?
	Following gypsy moth mortality		
May, 1984	10.6	16.1	?
June, 1984	10.6	10.6	?
June, 1985	10.3	10.3	?
June, 1986	11.3	11.3	15.6

* Based on diameter measurement of all trees in 3 replications.
**Based on 10 BAF-10 prism plots in all 3 replications.

Table 11.--Mean pre- and post-thinning acorn production for 3 treatments*.

Year	Treatment APT	CT	C
		Pre-thinning	
1974	44	39	44
1975	46	35	79
1976	783	944	658
Mean (3 yrs.)	291	339	260
		Post thinning	
1977	22	33	33
1978	5	2	7
1979	771	952	618
1980	93	62	68
1981	0	5	11
1982	0	1	0
1983	0	8	2
1984	63	293	122
1985	1081	680	734
1986	135	59	30
Mean (10 yrs.)	217	210	163
Change	-74	-129	-97
% change	-25.4	-38.1	-37.5

*Figures represent mean (for 3 replications) estimated sound acorn production in kg (fresh weight)/ha.

Table 12.--Percentage of producing oaks, by crown dominance category in 3 APT replications- 1974 thru 1976.

Replication	Crown Dominance Category Dominant	Co-Dominant	Intermediate	Suppressed
1	90.7	71.3	30.0	0.0
2	97.8	80.9	53.5	9.7
3	100.0	75.3	37.2	13.9
Mean	96.2	75.8	40.2	7.9

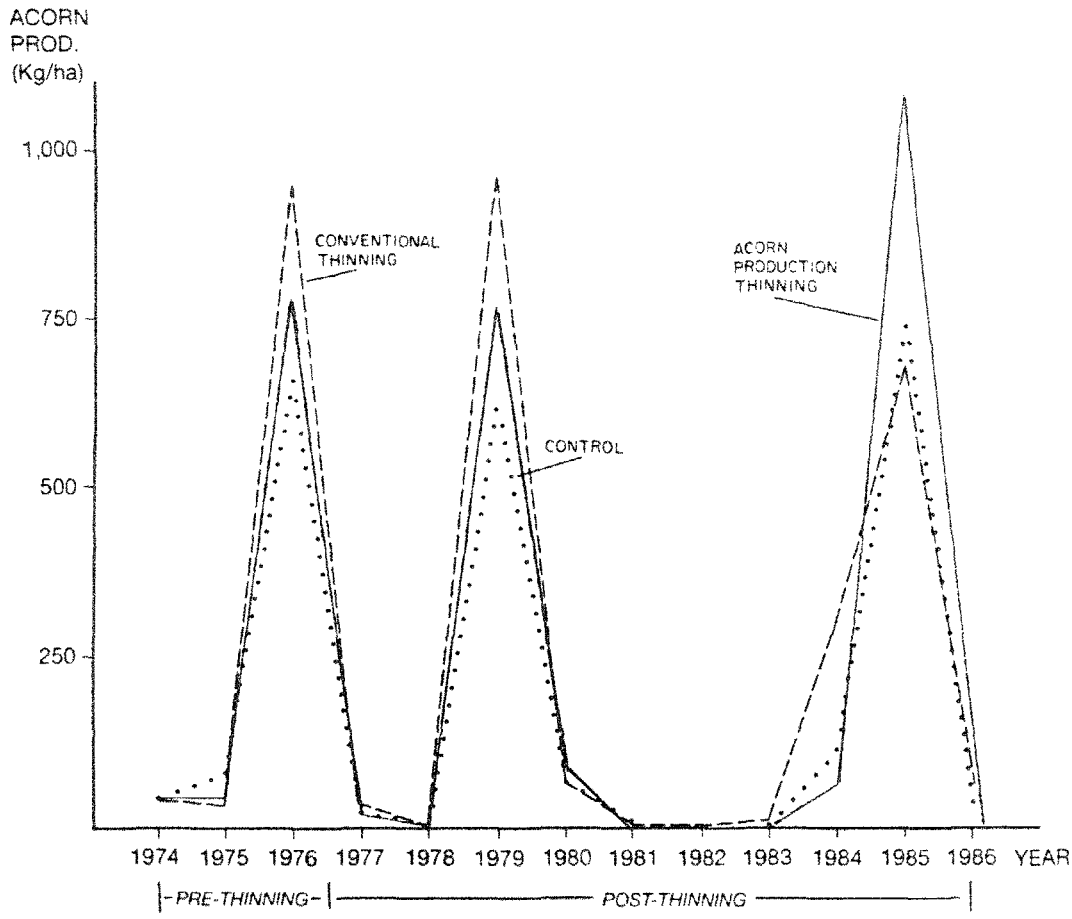

Figure 1. Mean pre- and post-thinning acorn production for three treatments.

APT and CT blocks. This may have been due to the majority of dominants and co-dominants being retained and the similarity of their spacing in both treatment blocks.

The importance of crown dominance may partially explain why acorn yields were not improved by retaining the best producers. Perhaps the suppressed and intermediate oaks with good genetic potential for acorn production did not display a phenotype expression of their potential (i.e. good acorn production) because of shading and were outproduced by dominants and co-dominants with moderate or even poor genetic potential whose crowns were exposed to higher intensities of sunlight. If so, it again reflects the importance of crown dominance relative to the selection of phenotypically superior acorn producers and points out the practical difficulty of improving acorn yields by retaining the best producers.

SUMMARY

Crown dominance was an important factor affecting the acorn production of individual oaks in this study. Conversely, acorn yields were not appreciably improved by retaining good acorn producing oaks during thinning relative to conventionally thinned stands. Results of this study indicate that improvements in acorn yields were not sufficient to justify the additional effort and cost of identifying and retaining the best acorn producing oaks prior to the thinning.

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INDEPENDENT EFFECTS AND INTERACTIONS OF STAND DIAMETER, TREE DIAMETER, CROWN CLASS, AND AGE ON TREE GROWTH IN MIXED-SPECIES, EVEN-AGED HARDWOOD STANDS

David A. Marquis[1]

Abstract: Many studies have shown that initial tree diameter is closely correlated with subsequent tree growth. But initial tree diameter is actually a confounded variable, incorporating both competitive position (crown class) and age. A study in hardwood stands in Pennsylvania has shown that the two latter variables were more reliable predictors of tree growth than initial diameter. These two variables lack the confounding of initial diameter, and are biologically more appropriate parameters for inclusion in growth simulators.

Surrogate variables calculated from typical cruise data were found to be nearly as well correlated with growth as the more difficult-to-measure crown class and age. Relative tree diameter (the ratio between actual tree diameter and stand diameter) provided a useful surrogate for crown class, and effective age (calculated from the average diameter of the major species groups present in each stand) provided a useful surrogate for actual age in these even-aged cherry-maple forests.

INTRODUCTION

Many studies have shown that initial tree diameter is closely correlated with subsequent tree growth (Hilt 1983, Hough and Taylor 1946, Marquis 1969, Trimble 1969). Often, other factors studied have added little to the correlation after initial tree diameter was fitted. As a result, initial tree diameter is a good predictor of future growth. It is often used as one of the major independent variables in tree growth-prediction equations (Hilt 1983, Miner and others 1988, Solomon and others 1987). This is probably unfortunate because it tends to mask the biological relationships involved. Initial tree diameter is a variable that actually expresses two more basic factors: competitive position and age.

Large trees in even-aged stands grow faster in large part because of their competitive advantage over their neighbors. In a single stand of trees of the same age, use of initial tree diameter to predict growth causes no problems, because diameter is an expression of competitive position in this case.

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But old trees grow slower than young trees of the same species and competitive position. Individual-tree-diameter growth peaks at an early age, and even trees that retain dominant crown positions decline in growth as they get older and, therefore, larger in diameter.

So, initial tree diameter is confounded as an indicator of future tree growth: large trees grow faster than small trees when comparing trees within an even-aged stand because tree size is a measure of competitive position. But large trees grow slower than small trees when trees of similar species and competitive position are compared across stands of different ages. In this situation, tree size is a measure of age.

To determine how important this confounding might be in growth predictions, and to test other parameters that express competitive position and age more directly, the long term growth records of a group of cherry-maple stands were examined in northwestern Pennsylvania; the records included direct measurements of age and competitive position (crown class). Because crown class and age are difficult to measure accurately and are seldom included in inventory data, several surrogates of these parameters that can be calculated from typical inventory data were tested. This is a report on the results of that investigation.

STUDY METHODS

Individual-tree growth records from three unrelated studies were used in this investigation. The three studies were:

1. Wolf Run Crop Tree Plots--consisted of individual-tree diameter records spanning 37 years, with remeasurements at approximately 5-yr intervals. Trees in this study were open-grown trees left after an overstory removal cut. Records included only d.b.h at each measurement period, plus age from ring counts of stumps at the time of harvest cut. These data are from a single stand on the former TG Forest Industries property adjacent to the Allegheny National Forest. The stand was 44 years old at the first measurement. There were 83 black cherry, 101 sugar maple, and 5 red maple trees available in the Wolf Run Plots. These data were used only for correlations of diameter growth and age.

2. Kane Weeding Study--consisted of stand and individual-tree-diameter records spanning a 35-year period with remeasurements every 5 years. Records included d.b.h. and crown class of each tree at each measurement, plus stand age derived from records of stand origin. Only data from the control plots were used. Each plot was 1/2-a in size. There were four separate stands in this study. Stand ages varied from 13 to 18 years at the start of the study, and from 48 to 53 years at the last measurement. All four stands were located on the Kane Experimental Forest, a part of the Allegheny National Forest.

Three of the seven growth periods available lacked data on crown class, so these three periods were omitted from investigations of the effect of crown class on diameter growth, and on tests of surrogate measures of crown class. In the summaries that follow, data from the four stands and four measurement periods on each stand are presented in groups based on stand age at the start of the period, as follows: 10-20 yr, 30-40 yr, and 40-50 yr. There were approximately 500 trees in this data set on which individual tree growth records were available, in four species: black cherry (*Prunus serotina* Ehrh.), sugar maple (*Acer saccharum* Marsh.), red maple (*Acer rubrum* L.), and American beech (*Fagus grandifolia* Ehrh).

All seven growth periods were used for investigation of the effect of age on diameter growth.

3. Fertilizer Study--consisted of stand and individual-tree diameter records spanning a 6-yr period, with remeasurements each year. Records included d.b.h. and crown class of each tree at each measurement, plus stand age derived from increment cores of ten dominant black cherry trees in each stand. There were six separate stands in this study. Stand ages ranged from 55 to 65 yr at the start of the study, and data from these stands are presented in the 55-65-yr age group in the summaries that follow. Only data from the control plots were used. Each plot was 1/2-a. All six stands were located on the Allegheny National Forest. There were approximately 2,000 trees in this data set on which individual growth records were available, in four species: black cherry, sugar maple, red maple, and American beech. These data were used for correlations of diameter growth with competitive position, and for testing of surrogate measures of crown class and age.

Descriptive data on stands from the Kane Weeding Study and Fertilizer Study are presented in Table 1. These data characterize the stands used for investigations of crown class, relative diameter, and tree growth and provide a summary of the distribution of trees into crown classes.

The study reported in this paper was conducted in several separate parts, each designed to test or illustrate a specific point. Investigation 1 illustrates the point that initial tree diameter expresses both stand age and the competitive position of individual trees within a stand, and that these two factors affect subsequent tree growth in opposite directions. Investigation 2 tested the hypothesis that competitive position (crown class) and age together provide better growth predictions than initial tree diameter alone when applied to stands that span a wide range of ages. Investigation 3 tests relative tree diameter as a surrogate measure of crown class or competitive position. And Investigation 4 tests effective age as a surrogate measure for actual age.

Table 1.--Characteristics of stands used in the investigation of the effect of crown class and relative diameter on tree growth.

Variable	Age class			
	10-20 yr	30-40 yr	40-50 yr	55-65 yr
	Entire Stand			
Age (yr)	14	36	44	58
Basal area (sq ft/acre)	54	110	133	147
Trees (no./acre)	3599	1569	1071	658
Relative density (%)	68	76	99	99
Medial diameter (in.)	2.7	6.3	8.0	9.5
Quadratic diameter (in.)	1.7	3.7	4.8	5.9
	Dominants and codominants			
% of no. trees	29	14	22	14
% of basal area	55	55	67	51
Average diameter (in)	2.4	7.0	8.6	11.6
	Dominants, codominants, intermediates			
% of no. trees	92	23	30	31
% of basal area	92	70	76	81
Average diameter (in)	2.0	6.2	7.9	9.7

The basic calculations were made as follows: diameter growth was calculated for each individual tree for each growth period; stand parameters (medial stand diameter, quadratic stand diameter, relative density or stocking, basal area/a, numbers of trees/a.) were calculated for each plot for each measurement period using the computer program SILVAH (Marquis 1986); then, diameter growth averages were calculated by crown and age classes.

In several investigations, simple and multiple regressions were run to relate individual-tree growth (by species) to various tree or stand parameters involved in the investigation. Only those regressions with an F-test that exceeded the 0.05 level were considered significant, and only signicant regressions are shown in this paper. Coefficients of determination (r^2) for the individual regressions are shown where appropriate. In other investigations, differences among crown class means were tested with analysis of variance. Only those F-tests that exceeded the 0.05 level were considered significant.

Relative diameter was calculated for each tree as a possible surrogate expression of crown class or competitive position. Relative diameter is simply the diameter of the individual tree divided by the average stand diameter. Thus, a 12-in tree in a stand with an average diameter of 12 in would have a relative diameter of 1.0. A 6-in tree in that same stand would have a relative diameter of 0.5. Using this expression, dominant trees in this study had a relative diameter of over 1.0, while suppressed trees had a relative diameter of 0.5 or less.

Codominant and intermediate trees had intermediate values. Thus, relative diameter is a continuous variable that can be related to the four discrete crown classes actually observed. In the calculation of relative diameter, both medial diameter (diameter of a tree at the mid-point of the basal area distribution) and the quadratic diameter (tree of average basal area) were used as measures of stand diameter.

Effective age was calculated as a possible surrogate for actual age. Age for each of two major species groups in cherry-maple stands was estimated from their medial diameters, using the average increase in medial diameter expected for that group. The two species groups are: a) fast-growing black cherry, white ash (*Fraxinus americana* L.), yellow-poplar (*Liriodendron tulipifera* L.), red maple, and northern red oak (*Quercus rubra* L.); and b) slower growing sugar maple and American beech. The average increase in medial diameter (herein called the growth factor) for these two species groups was derived from approximately 120 Allegheny hardwood stands in northwestern Pennsylvania (Marquis and others 1984). The growth factors are: a) .20 inches/yr for fast growing species group 1, and b) .15 inches/yr for slower growing species group 2). Thus, effective age provides an estimate of actual age based on the diameters of two major species groups. The equation is:

$$Effective\ age = \frac{\frac{(MD1 * BA1)}{GF1} + \frac{(MD2 * BA2)}{GF2}}{Total\ BA} \quad (1)$$

where:

BA = basal area in trees 1" dbh and larger
MD = medial stand diameter of trees 1" dbh and larger
GF = growth factor
1 = species group 1
2 = species group 2

RESULTS AND DISCUSSION

Investigation 1 -- Is initial dbh a reliable predictor of tree growth?

A common way to express the competitive position of a tree is by the use of crown class -- a subjective grouping of trees into dominant, codominant, intermediate, and suppressed classes. These crown classes reflect the tree's height relative to its competing neighbors in the crown canopy, and they also indicate the proportion of the tree's crown that receives direct sunlight for tree growth.

Data from both the Kane Weeding Study and the Fertilizer Study were used to calculate the average diameter growth for trees of various crown classes. Average initial dbh was also calculated for these same crown classes.

Differences among crown classes in both average initial dbh and average diameter growth rate were highly significant within any of the 10-year age ranges tested (Table 2). Thus, the dominant trees are the largest trees in their stands, and they grow faster than trees of lower crown class or smaller initial dbh. Within a crown class, older trees are also larger in dbh.

All trees in the Kane Weeding Study that remained in the dominant or codominant crown class throughout the 35-year period were selected for analysis of the effect of age on diameter growth rate. Average growth at various ages between 13 and 48 years were plotted. There were 124 black cherry and 41 sugar maple trees in this sample. There were too few trees of other species in the dominant and codominant classes to provide reliable results.

Table 2.--Average dbh and average diameter growth for trees of different crown class, by age ranges.

Crown class	Average initial dbh	Average diameter growth (in/5 yrs)
Ages 10-20 years (Kane Weeding Study)		
Dominant	2.7	1.24
Codominant	2.2	0.86
Intermediate	1.5	0.55
Suppressed	1.2	0.52
Ages 30-40 years (Kane Weeding Study)		
Dominant	8.4	1.02
Codominant	6.3	0.64
Intermediate	4.4	0.36
Suppressed	2.7	0.13
Ages 40-50 years (Kane Weeding Study)		
Dominant	10.7	0.73
Codominant	7.8	0.46
Intermediate	5.1	0.20
Suppressed	3.2	0.12
Ages 55-65 years (Fertilizer Study)		
Dominant	13.0	1.10
Codominant	10.7	0.67
Intermediate	8.2	0.36
Suppressed	2.9	0.07

Diameter growth rates of dominant and codominant black cherry trees had peaked by age 18. Sugar maple growth was erratic up to aproximately age 30, but it declined at a steady rate thereafter (Figure 1).

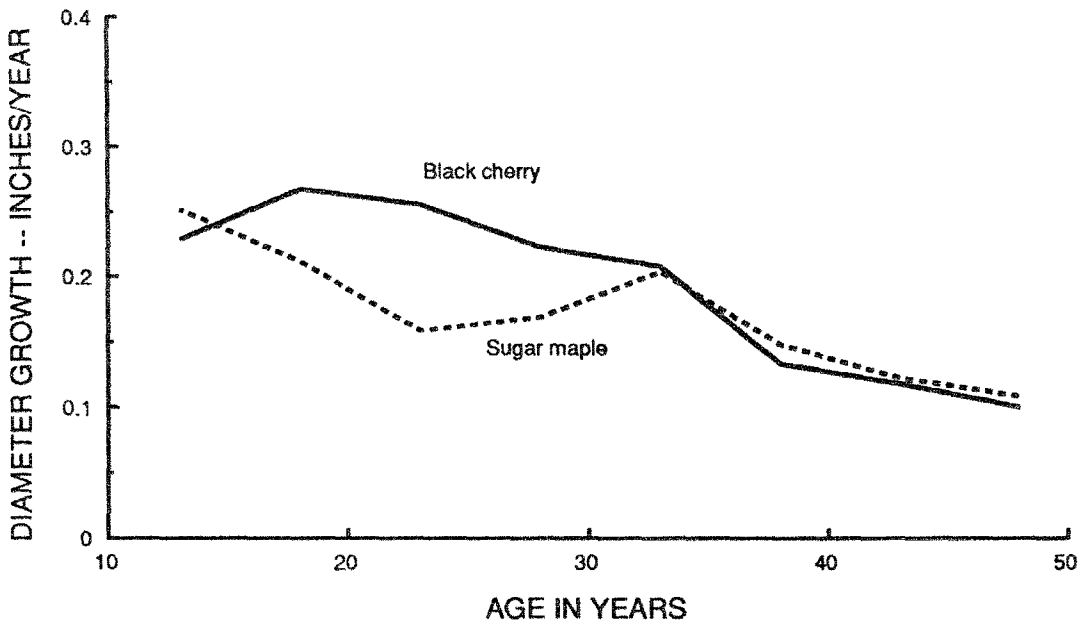

Figure 1. The effect of age on diameter growth (dbh) of individual trees (age 13 to 48).

Data from the Wolf Run plots provide data from older trees than available in the Kane Weeding Study. These data were analyzed in the same manner as above. Diameter growth rate of all three species (black cherry, sugar maple, and red maple) had peaked before the start of measurements (44 yr), and declined steadily throughout the 37-yr growth period (Figure 2).

These several sets of data illustrate that initial tree dbh affects individual tree diameter growth in two conflicting ways. Within stands of similar age, initial dbh is an indicator of competitive position, and large trees grow faster than smaller ones. But across a range of stand ages, initial dbh is an indication of age; large trees grow slower than small trees of the same crown class because the large trees are older. Thus, initial dbh is not a desirable predictor of individual tree growth when used across a range of stand ages and crown classes. Initial diameter is a confounded expression of two other variables that affect tree growth in different directions.

Investigation 2 -- Are crown class and age better predictors than initial dbh?

Using individual tree data from both the Kane Weeding Study and Fertilizer Study, regression equations were calculated to predict individual tree growth based either on: a) initial dbh, or

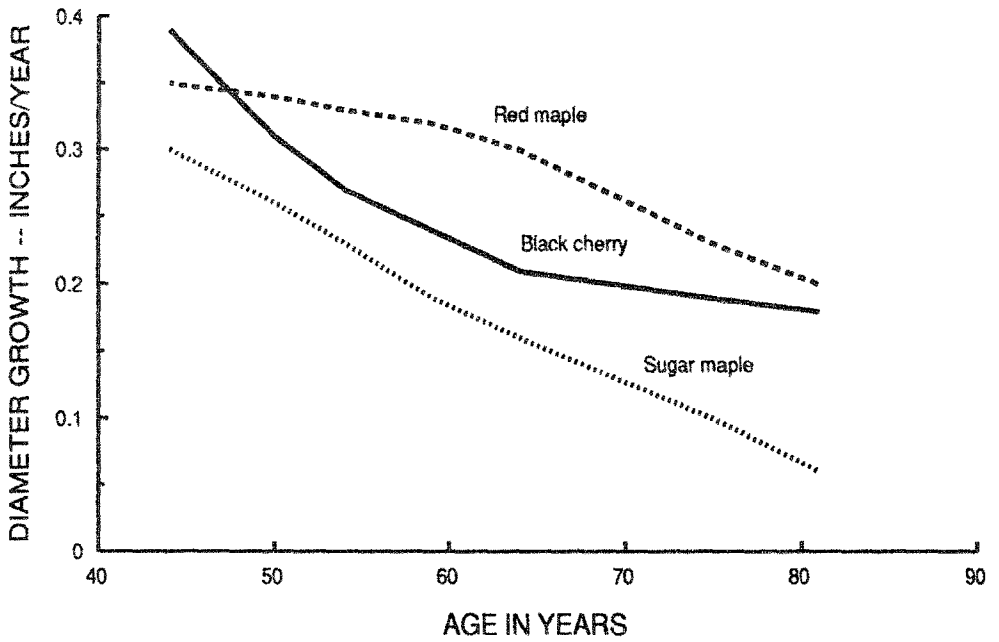

Figure 2. The effect of age on diameter growth (dbh) of individual trees (age 44 to 81).

b) crown class plus age. Crown class was entered into the equations as a set of dummy variables. Separate equations were calculated for black cherry and sugar maple.

Coefficients of determination showed that equations including two independent variables to express both competitive position and age were much better (had higher r^2 values) than equations including only initial dbh as an independent variable (Table 3). In fact, initial dbh was only poorly correlated with diameter growth across the range of ages included in these equations, and regressions with dbh were not statistically significant.

Table 3.--Coefficients of determination (r^2) between individual tree diameter (dbh) growth and either initial dbh or age plus crown class.

Species	Independent variable(s)	
	Initial dbh	Age + Crown Class
Black cherry	0.00	0.41
Sugar maple	0.08	0.62

Investigation 3 -- Relative diameter as a measure of competitive position

Crown class is a subjective measure of competitive position, and therefore not evaluated equally by all observers. It provides estimates of competitive position in discrete classes, and is therefore inconvenient to include in prediction equations. Furthermore, it is an observation not commonly included in inventories made on an operational basis. Therefore, crown class has limitations as an independent variable in growth prediction equations.

It would be very desirable to find a continuous variable that provides a measure of competitive position that can be objectively estimated from commonly available inventory data. Relative diameter (diameter of the tree relative to the average stand diameter) is a variable that expresses the size of a tree relative to its competitors in the same stand, and therefore appears promising as a measure of competitive position and a surrogate for crown class.

The Kane Weeding Study and Fertilizer Study data were used to calculate the average diameter growth of all species stratified into four crown classes and five relative-diameter classes. Both crown classes and relative-diameter classes had a strong influence on diameter growth, with a clear trend of best growth from trees in the better competitive positions (Table 4).

Table 4.--Diameter growth rates (inches/5 yrs) as affected by competitive position for stands of four age groups (all species together).

Variable	Age class			
	10-20 yr	30-40 yr	40-50 yr	55-65 yr
Crown class				
Dominant	1.24	1.02	0.73	1.10
Codominant	0.86	0.64	0.46	0.67
Intermediate	0.55	0.36	0.20	0.36
Suppressed	0.52	0.13	0.12	0.07
Relative diameter class (based on medial diameter)				
1.25+	1.45	0.97	0.72	0.92
1.00 - 1.25	1.15	0.78	0.59	0.63
0.75 - 1.00	0.92	0.53	0.39	0.38
0.50 - 0.75	0.67	0.29	0.25	0.18
0.00 - 0.50	0.43	0.01	0.07	0.05

When diameter growth is predicted using regressions of diameter growth as a function of relative diameter and compared to predictions of diameter growth based on crown class averages, the two measures perform about equally. There was a slight tendency for crown class to predict growth better than relative diameter, but the differences were minor (Table 5). This indicates that relative diameter can be used in place of crown class as a predictor of diameter growth.

Table 5.--Standard errors for diameter growth estimates based on crown class averages versus those based on regressions with relative diameter.

Age range	Crown class	Relative diameter
	30-40 years	
black cherry	.32	.32
sugar maple	.18	.18
	40-50 years	
black cherry	.22	.21
sugar maple	.13	.12
	55-65 years	
black cherry	.25	.26
sugar maple	.11	.08

Data from both the Kane Weeding Study and the Fertilizer Study were then used to calculate regressions of diameter growth as a function of initial diameter and as a function of two different relative diameters. Relative diameter was calculated using both the medial diameter and the quadratic diameter. The regressions were run within single stands (where age was constant), and across all stands in the data set (where age varied from 10 to 65 years).

The coefficients of determination (r^2) for three regressions of diameter growth on d.b.h., relative medial diameter, and relative quadratic diameter were identical within each stand. And correlations between d.b.h. and the two relative diameter measures were perfect -- r^2 of 1.00 (Table 6). This is to be expected since the two relative diameters are equivalent to d.b.h. divided by a constant. Within a single stand, where all the trees are the same age, all three measures provide identical results as expressions of competitive position.

However, when the same regressions are calculated across a group of stands of varying ages, r^2 for regressions containing relative diameter are much higher than those for regressions on initial d.b.h. (Table 6). In this situation, the two relative diameter measures continue to provide an expression of the competitive position of each tree's position that is unconfounded with age. But initial d.b.h. is now expressing both competitive position and age, two factors that affect diameter growth in opposite ways as demonstrated earlier. Thus, relative diameter appears promising as a measure of competitve position in place of crown class; and it is a measure that is not confounded by age as is initial dbh.

Table 6.--Coefficients of determination (r^2) for initial diameter and relative diameter (based upon medial stand diameter and quadratic stand diameter) as affected by age range in the data.

Age range	No. of stands	Dependent variables: Diameter Growth — Independent variables: Dbh[1]	RMD[2]	RQD[3]	D.b.h. — Independent variables: RMD	RQD
Black cherry						
Within a single stand*						
age 10-20	4	0.40	0.40	0.40	1.00	1.00
age 30-40	7	0.51	0.51	0.51	1.00	1.00
age 40-50	3	0.42	0.42	0.42	1.00	1.00
age 55-65	6	0.54	0.54	0.54	1.00	1.00
Across a wide range of stand ages*						
age 10-65	22	0.00	0.22	0.23	0.53	0.49
age 30-65	18	0.28	0.48	0.45	0.66	0.56
Sugar Maple						
Within a single stand*						
10-20	4	0.25	0.25	0.25	1.00	1.00
30-40	7	0.60	0.60	0.60	1.00	1.00
40-50	5	0.55	0.55	0.55	1.00	1.00
55-65	6	0.51	0.51	0.51	1.00	1.00
Across a wide range of stand ages*						
10-65	22	0.08	0.57	0.50	0.42	0.48
30-65	18	0.36	0.58	0.59	0.83	0.70

[1]Dbh = diameter at breast height at the beginning of the growth period
[2]RMD = relative diameter based upon medial stand diameter
[3]RQD = relative diameter based upon quadratic stand diameter

*Values shown within a single stand are the mean of the r^2 values for each individual stand in the age range shown. Values shown across a wide range of stand ages are the single r^2 value from a regression using all stands in the specified age range.

Differences between the two relative diameter measures were small. The one based on medial diameter gave slightly better results in most cases than the one based on quadratic diameter. The exception was in very young stands where results were erratic (Table 6).

Medial diameter has the added advantage that it provides a much more realistic estimate of tree size than quadratic diameter in these mixed-species hardwood stands. Quadratic diameter is heavily influenced by the large number of suppressed trees, so it gives an estimate of stand diameter that does not adequately reflect the size of the crop trees in the stand.

To illustrate, the quadratic stand diameter and the medial stand diameter are plotted against the arithmetic average diameter of the dominant plus codominant trees and against the arithmetic average diameter of the dominant, codominant, and intermediate trees in the Kane Weeding Study and Fertilizer Study data sets (Figure 3). Medial stand diameter closely approximates the average diameter of the dominants, codominants, and intermediates--the trees that make up the main crown canopy. Quadratic stand diameter is much lower, and does not adequately represent the diameter of the important trees in the stand.

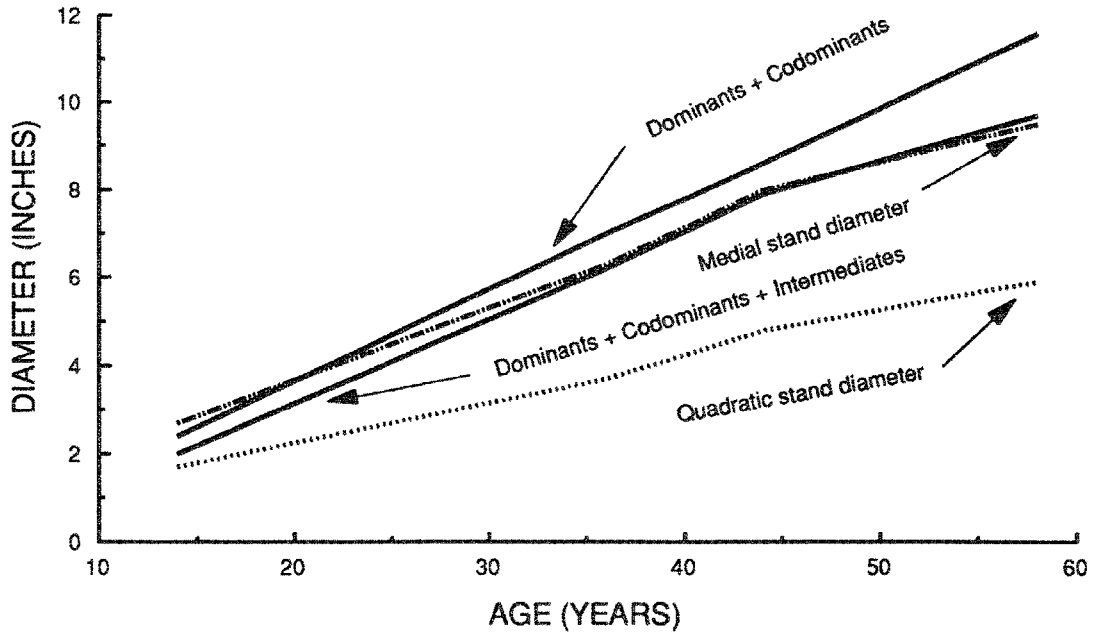

Figure 3. A comparison of medial stand diameter and quadratic stand diameter as expression of average tree dbh of various crown class groups in cherry-maple stands.

So, medial stand diameter clearly seems to be a better measure of stand size class, and is better correlated with diameter growth than quadratic stand diameter. Its use as an expression of average stand diameter is recommended.

Data from the Kane Weeding Study and Fertilizer Study were examined to determine whether or not relative diameter might be used to segregate trees into crown classes when direct measures of crown class are not available. The relative diameter breaking points used to separate one crown class from another were estimated by regressing the relative diameter limits from each age class over age (Figure 4). The results of segregations made on this basis were compared with actual crown class observations (Table 7).

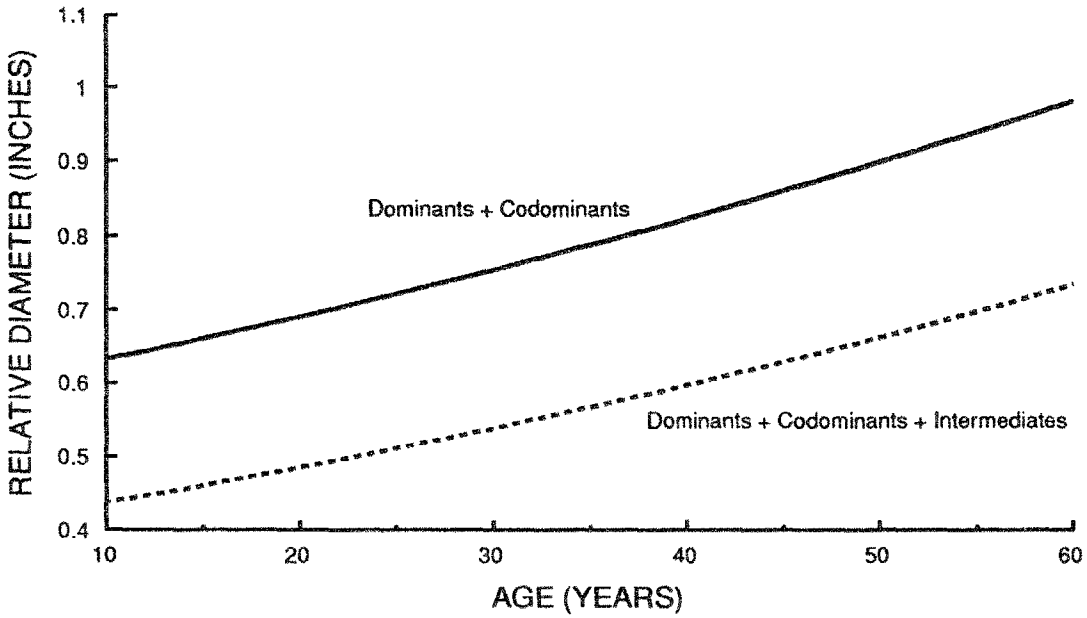

Figure 4. Relative diameter limits used to separate crown classes in cherry-maple stands, as a function of age.

These trials suggest that it is possible to select those trees in a stand which represent any crown class (or group of crown classes) by using relative diameter as a surrogate. The group of trees selected as representing a particular crown class will not correspond exactly to the actual crown classes, but will contain approximately the same number of trees and have approximately the same growth rate and average diameter as that crown class (Table 6). These trials also suggest that the relative diameter that separates one class from another is not a constant, but varies with both age and species. Thus, additional study would be needed to define the relative diameter breaking points appropriate to a wide range of stand compositions and ages. Nevertheless, relative diameter appears to be a useful surrogate for crown class.

Table 7.--Conformity among crown class and relative diameter in selection of the trees in the upper crown canopy over four age classes -- all species.

Competitive position*	Age class			
	10-20 yr	30-40 yr	40-50 yr	55-65 yr
	Number of trees/acre			
D & C crown classes	299	319	238	284
D & C via Relative dia.	302	325	234	273
D, C & I crown classes	481	449	294	619
D, C & I via Relative dia.	481	459	287	619
	Average diameter (dbh)			
D & C crown classes	2.4	7.0	8.6	11.6
D & C via Relative dia.	2.3	7.2	8.7	11.8
D, C & I crown classes	2.0	6.2	7.9	9.7
D, C & I via Relative dia.	2.0	6.4	8.1	9.8
	Diameter growth, inches/5 yrs			
D & C crown classes	0.98	0.76	0.53	0.80
D & C via Relative dia.	0.99	0.74	0.53	0.78
D, C & I crown classes	0.82	0.64	0.47	0.56
D, C & I via Relative dia.	0.82	0.63	0.49	0.56

*D = dominant crown class
*C = codominant crown class
*I = intermediate crown class

Investigation 4 -- Effective age as a measure of actual age

Like crown class, age is difficult to measure in the field, and is seldom available from inventory data. The effective age calculated by the SILVAH program, and described earlier, provides a possible surrogate for actual age.

To test the value of effective age in prediction equations, a series of multiple regressions that included relative diameter plus either actual age or effective age was run. Effective age had r^2 values nearly as high as actual age in most regressions, and slightly better than actual age in one regression. Thus, effective age appears to be a useful surrogate for actual age that can be used in growth prediction equations. The regressions also show that the combination of relative diameter and effective age is considerably better as a predictor of diameter growth than either variable alone (Table 8).

Table 8.--Coefficients of determination (r^2) for regressions of diameter growth (dbh) and various combinations of relative stand diameter, age, and effective age.

Independent variable	Black cherry	Sugar Maple
Relative diameter	0.22	0.57
Age	0.08	0.26
Effective age	0.07	0.23
Rel. dia. + Age	0.41	0.62
Rel. dia. + Eff. age	0.39	0.63

CONCLUSIONS

These investigations show that initial tree diameter may express either a tree's competitive position in stands of similar age, or a tree's age when viewed across stands of many ages. Since a large initial dbh produces fast growth in the former situation, and slow growth in the latter, initial tree dbh is a confounded variable that may provide inaccurate growth predictions when applied to trees of a wide range of ages and competitive positions. Separate measure of age and competitive position provide more accurate growth prediction than use of initial dbh alone.

Since neither age nor competitive position (crown class) are commonly included in the data from operational inventories, easily calculated surrogates of these variables are needed. Relative diameter provides a useful measure of competitive position, and effective age provides a useful measure of actual age in Allegheny hardwood stands. Both of these measures can be calculated from the species and diameter records commonly collected in forest inventories. Predictions of growth based on these surrogates provide estimates with accuracy similar to those based upon crown class and actual stand age.

Medial diameter is a better measure of average stand diameter in Allegheny hardwood stands than quadratic diameter. When used to calculate relative diameter, it also provides better correlation with tree growth than relative diameter calculated from quadratic stand diameter.

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RADIAL PATTERNS OF TREE-RING CHEMICAL ELEMENT CONCENTRATION IN TWO APPALACHIAN HARDWOOD STANDS

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Abstract: Radial patterns in tree-ring chemical element concentration in red oak (*Quercus rubra* L.) and black cherry (*Prunus serotina* Ehrh.) were analyzed to infer past environmental changes at two mature Appalachian forest sites. Multiple cores extracted from five trees of each species at each site were divided into 5-yr segments, measured for length, composited, and analyzed for 19 elements using plasma emission spectroscopy. Radial patterns of tree-ring chemical elements were categorized into three types: elements showing relatively constant radial concentration in an inner wood zone with increased concentrations in an outer wood zone near the cambium, elements showing relatively constant radial concentration distributions with no rise near the cambium and elements showing gradually increasing concentrations from pith to cambium. Piece-wise multiple regression with correction for serial correlation was used to develop models of these patterns. Significant effects on chemical element concentrations by basal area growth rates and the outer 15 years of growth were detected. With the possible exception of Ca and Sr, trends in chemical element concentrations in inner zone wood with tree-ring age did not indicate a response to the effects of timber cutting, chestnut blight or atmospheric deposition.

INTRODUCTION

Tree-ring chemistry has frequently been used to record changes in levels of air pollutants and, more recently, changes in the soil chemical environment. Long and Davis (1989) recently found that Sr concentrations in white oak (*Quercus alba* L.) in Pennsylvania showed a consistent pattern of higher Sr accumulation from fly-ash in xylem for periods when coal-fired emission stacks were lowest and at locations near power plants. Guyette et al. (1989) showed a decrease in heartwood molybdenum concentration in eastern redcedar (*Juniperus virginiana* L.) which was believed to be caused by increased atmospheric sulfur deposition. McClenahen et al. (1989) showed significantly increased chemical element content of tree-rings in yellow-poplar (*Liriodendron tulipifera* L.) in response to applications of N-P-K fertilizer and dolomitic limestone to the soil. Bondietti et al. (1989) used radial trends in the ratios of Al to base cations in red spruce (*Picea rubens* Sarg.) and eastern hemlock (*Tsuga canadensis* (L.) Carr.) wood to infer the impact of atmospheric deposition on

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soil in Tennessee and North Carolina. Sayre (1987) and DeWalle et al. (1990) both showed that the chemical element content of sapwood xylem in several Appalachian tree species varied with soil fertility. All of these papers indicate that tree-ring chemistry has potential to record time trends in environmental pollution.

Despite the successes in the application of tree-ring chemical analysis to assess environmental pollution, interpretation of results can be ambiguous. Lepp (1975) pointed to many uncertainties with regard to pathways of metal uptake, complexation, and lateral transport in trees which limits use of tree-ring chemical chronologies in studies of environmental pollution. For example, McClenahen et al. (1989) found evidence that P, S, K, Ca, and Zn were mobile in yellow-poplar wood. Thus, application of tree-ring chemistry is not an exact science.

This study was initiated to determine if the radial variation of tree-ring chemistry in two mature Northern Appalachian hardwood stands could be used to determine if changes have occurred in the forest chemical environment. Environmental stresses in these stands can be documented and have included early forest cutting, chestnut blight, and relatively high levels of acidic atmospheric deposition. The sites, Fork Mountain and Pea Vine Hill, have differing soil fertility levels (DeWalle et al. 1988) and any trends related to soil changes were emphasized in this paper. Tree species studied were red oak (*Quercus rubra* L.) and black cherry (*Prunus serotina* Ehrh.), both important commercial species.

STUDY AREAS

Trees studied were located on Fork Mountain at Fernow Experimental Forest in northcentral West Virginia (39°, 03'N; 79°, 41', 30" W) and Pea Vine Hill on Laurel Mountain in southeastern Pennsylvania (40°, 10', 45" N; 79°, 09' W). Fernow Experimental Forest is located near Parsons, WV and is managed by the U. S. Forest Service, Northeastern Forest Experiment Station. The Pea Vine Hill site is part of Rolling Rock Farms near Ligonier, PA. Both sites were gently sloping (<10% slope) ridge-top sites.

The Fork Mountain site was dominated by red oak, black cherry, and sugar maple (*Acer saccharum* Marsh.) trees with minor amounts of other hardwoods occurring in the overstory. Soils were derived from sandstone and siltstone from the Catskill and Chemung formations. Soils were Dekalb and Berks series loamy-skeletal, mixed, mesic, Typic Dystrochrepts. Elevation of this site was about 850 m. Mean annual precipitation at the Fernow Experimental Forest is 142 cm and mean annual air temperature is 8.9 degrees C.

At Fork Mountain heavy high-grade cutting occurred in 1910-15. In addition, residual American chestnut (*Castanea dentata* (Marsh.) Borkh.) trees began to die from chestnut blight in 1910 and by 1925 all mature trees were killed. Salvage logging of dead American chestnut occurred in this stand at about this time.

The Pea Vine Hill site consisted of red oak and black cherry trees almost exclusively. Sandstone and shale from the Pottsville and Mauch Chunk Formations, respectively, were found in soil pits at the site. Soils were Hazleton loamy-skeletal, mixed, mesic Typic Dystrochrepts and Leck Kill fine-loamy, mixed, mesic Typic Hapludults. Elevation of this site was about 880 m. Mean annual precipitation on top of Laurel Mountain near Pea Vine Hill is about 135 cm with 278 cm of annual snowfall depth. Mean annual air temperature is 7.2 degrees C. Forest cutting on Pea Vine Hill has been prohibited since the tract was purchased for Rolling Rock Farms on November 18, 1916. Some dead American chestnut was removed in the 1940-50 period and thus it is assumed that chestnut died in this stand beginning around 1910-15.

Soil at Fork Mountain showed lower acidity and higher exchangeable base cations than soil at Pea Vine Hill. Exchangeable calcium at Fork Mountain averaged 0.82 meq/100 g compared to 0.59 meq/100 g at Pea Vine Hill (DeWalle et al. 1988). Soil water at Pea Vine Hill exhibited significantly higher H, Mn, and Al and lower Ca and Mg concentrations than at Fork Mountain. More complete soil and soil water chemistry at these two sites is available elsewhere (DeWalle et al., 1988).

Atmospheric deposition is relatively acidic at both sites. Out of 82 wet deposition monitoring stations in the United States, the Leading Ridge, Pennsylvania station which is located 130 km northeast of the Pea Vine Hill site ranks 1st in deposition of H^+ and 6th in sulfate deposition (Knapp et al. 1988). The Parsons, West Virginia station within 20 km of Fork Mtn. ranks 9th in H^+ and 10th in sulfate deposition.

METHODS

Five red oak and five black cherry trees were sampled at both the Pea Vine Hill and Fork Mountain sites in 1985. Trees selected for coring were dominant and co-dominant overstory trees with relatively straight boles and healthy crowns within about 500 m of ridge-top soil leachate monitoring sites used in other research. No hollow trees were sampled. Some of the red oak trees sampled at both sites had pith ages over 100 years; these trees apparently survived the heavy cutting in 1910-15 at Fork Mtn. Other red oak and all black cherry trees sampled had pith ages of 85 years or less. Diameters at breast height of sampled trees at Fork Mountain averaged 57 cm for red oak and 48 cm for black cherry. Diameters at Pea Vine Hill averaged 44 cm for red oak and 41 cm for black cherry.

Wood cores were extracted from tree boles at breast height using a 4-mm diameter Teflon-coated increment borer. Borers and extractors were cleaned with acetone and deionized water prior to each field visit and rinsed with deionized water before each extraction. Four cores from bark to pith were extracted from each tree. Cores were extracted at approximately 90-degree angles from each other around the circumference of the trees. Samples included any reaction wood present. No cores with diseased tissue were analyzed. Plastic gloves were used whenever cores were handled. Cores were rinsed with deionized water after extraction in the field and transported from the field and frozen in plastic straws.

In the laboratory, cores were divided into five-year growth increments and the segments of the four cores from each 5 yr segment were composited for each tree. Cores were not cross-dated before compositing. Errors could exist due to missing or indistinct rings when comparing the ages of 5 yr segments among trees and sites. Any such errors are more likely in black cherry with diffuse-porous wood and relatively indistinct rings than in red oak with ring-porous wood and more distinct rings. Composite samples were used to reduce sample variability and provide sufficient mass for chemical analysis. Length of each core segment was measured with a calipers and averaged for each composite sample. Composite sample dry weights averaged 0.7 g with a range from 0.11 to 1.91 g. The division between sapwood and heartwood in the cores was not recorded.

Wood cores were analyzed for phosphorus, potassium, calcium, magnesium, iron, manganese, molybdenum, copper, zinc, sodium, aluminum, silica, cobalt, chromium, nickel, lead, cadmium, strontium, and barium at the University of Georgia, Institute of Ecology using a Jarrel-Ash plasma emission spectrometer. Cores were oven dried, weighed, ashed and digested in 20% nitric acid prior to analysis (Jones 1977).

Multiple regression analysis was employed to analyze trends in tree-ring chemistry data for each element, species, and site. Tree-ring chemical concentrations were used as dependent variables and independent variables were ring age in years, basal area increment in mm^2 per five years, and a piecewise regression term which is described later. Basal area increments were computed from the mean lengths of five-year tree core segments. Serial correlation of residuals from these models, as determined using the Durbin-Watson statistic, was eliminated using an iterative procedure involving differencing all variables over time and using a fitted autocorrelation coefficient (Neter et al. 1985). All statistical tests were conducted at a 95% confidence level.

RESULTS AND DISCUSSION

Basal Area Growth of Trees

Radial patterns of basal area growth for the trees showed peak basal area increments occurred at different times among sites and species (Figure 1). Older red oak trees at both sites experienced rapid diameter growth beginning in about 1910-20 with greatest basal area increment in the 1930-40 period. Release from competition by cutting and chestnut blight probably explains this growth pattern. Younger red oaks and black cherry showed peak basal area increment around 1960 or a gradual increase in basal area increment up to the time of sampling. These younger trees reached breast height after 1910-20 and many are still growing vigorously. As indicated in Figure 1 black cherry trees were generally younger than the red oaks and the youngest black cherry were found at Pea Vine Hill.

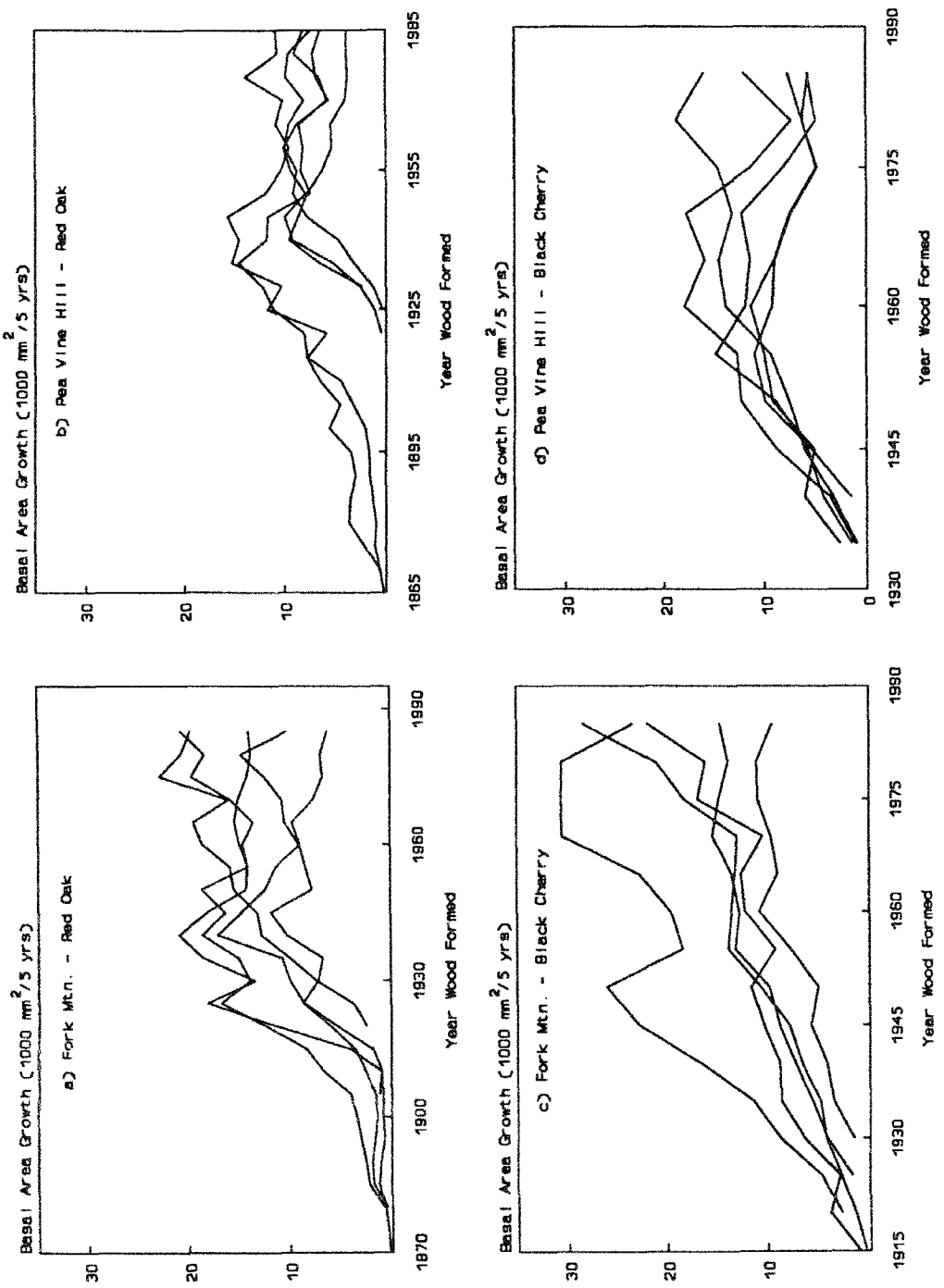

Figure 1. Basal area growth rates of (a) Fork Mtn. - red oak, (b) Pea Vine Hill - red oak, (c) Fork Mtn. - black cherry and (d) Pea Vine Hill - black cherry trees.

Distinct patterns of radial variations in the concentrations of chemical elements were found in tree-rings for both sites and species. Patterns observed varied with the element in question.

A pattern of radial variation in tree-ring element concentration was identified in which concentrations varied between an inner and outer zone. In the inner zone concentrations were relatively constant. In the outer zone concentrations increased sharply as the cambium was approached. This pattern of variation was designated Type 1. Designation of inner and outer zones does not necessarily represent heartwood and sapwood zones in these trees. Elements showing Type 1 variation were Ca, Mg, Sr, Ba, Mn, K, and P. Examples of this type of variation are given in Figure 2 for Ca in red oak and black cherry at both sites. Higher concentrations of Ca occurred near both the pith and the cambium in the older red oaks; the absolute maximum occurred near the cambium in the last increment in almost every case. Minimum concentrations in the older red oaks tended to occur during the 1910-50 period suggesting a growth rate effect on concentration for all alkaline earth metals including Ca. Potassium and phosphorus were also classed as Type 1 elements even though they are not alkaline earth metals.

Several features of the Type 1 variation suggest a growth rate effect on chemical element concentrations in tree-rings. Minimum concentrations occur at about the time of maximum basal area increments at least for the older oak trees. Concentrations also increase and basal area increments generally decrease as the cambium is approached. Both of these trends suggest an inverse relationship between concentration and basal area increment. The importance of this relationship was tested with regression analysis since growth rate effects must be removed to detect any trends in chemical element content over time.

The other extreme in radial pattern in tree-ring elements was designated Type 2 with extreme variability and general lack of any radial trend within trees. Elements which followed this Type 2 pattern include Cd, Pb, Cu, Co, Cr, Ni, and Al. Figure 3 illustrates this pattern for Pb in red oak and black cherry. Although trends in radial Pb are indicated for individual trees, no consistent trends are shown for all trees. This was typical of all the above trace metals. The concentrations of these trace metals did not appear to vary with growth rate or increase in the outer, near-cambium region.

Type 3 radial variation in tree-ring elements was intermediate between the other two types with variable, but gradually increasing, concentrations from pith to bark. No consistent steep increases occurred in the outer zone. Elements falling in this category include Na, Fe, Zn, Mo and Si. Examples of Type 3 radial pattern for Mo is given in Figure 4 for both species and sites. Again trends for some trees may look like Type 1 or 2 elements, but the trend was not consistent among trees or sites. Placement of the elements into one of the three patterns of radial variation was somewhat subjective and regression analysis was used to help quantify relationships.

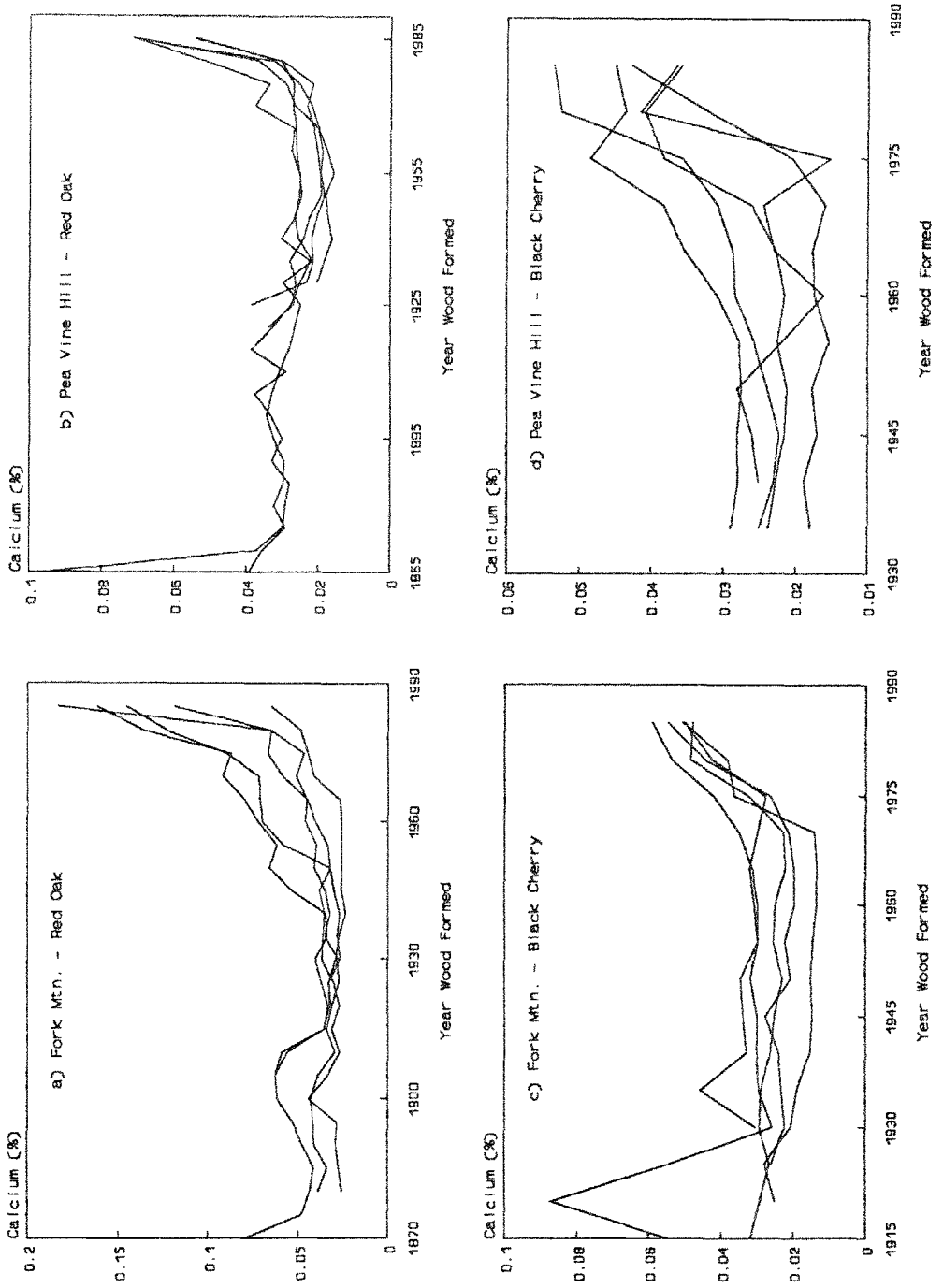

Figure 2. Radial variation of tree ring calcium content for (a) Fork Mtn - red oak, (b) Pea Vine Hill- red oak, (c) Fork Mtn.- black cherry and (d) Pea Vine Hill - black cherry. This pattern of variation was designated Type 1 with a marked increase in the sapwood.

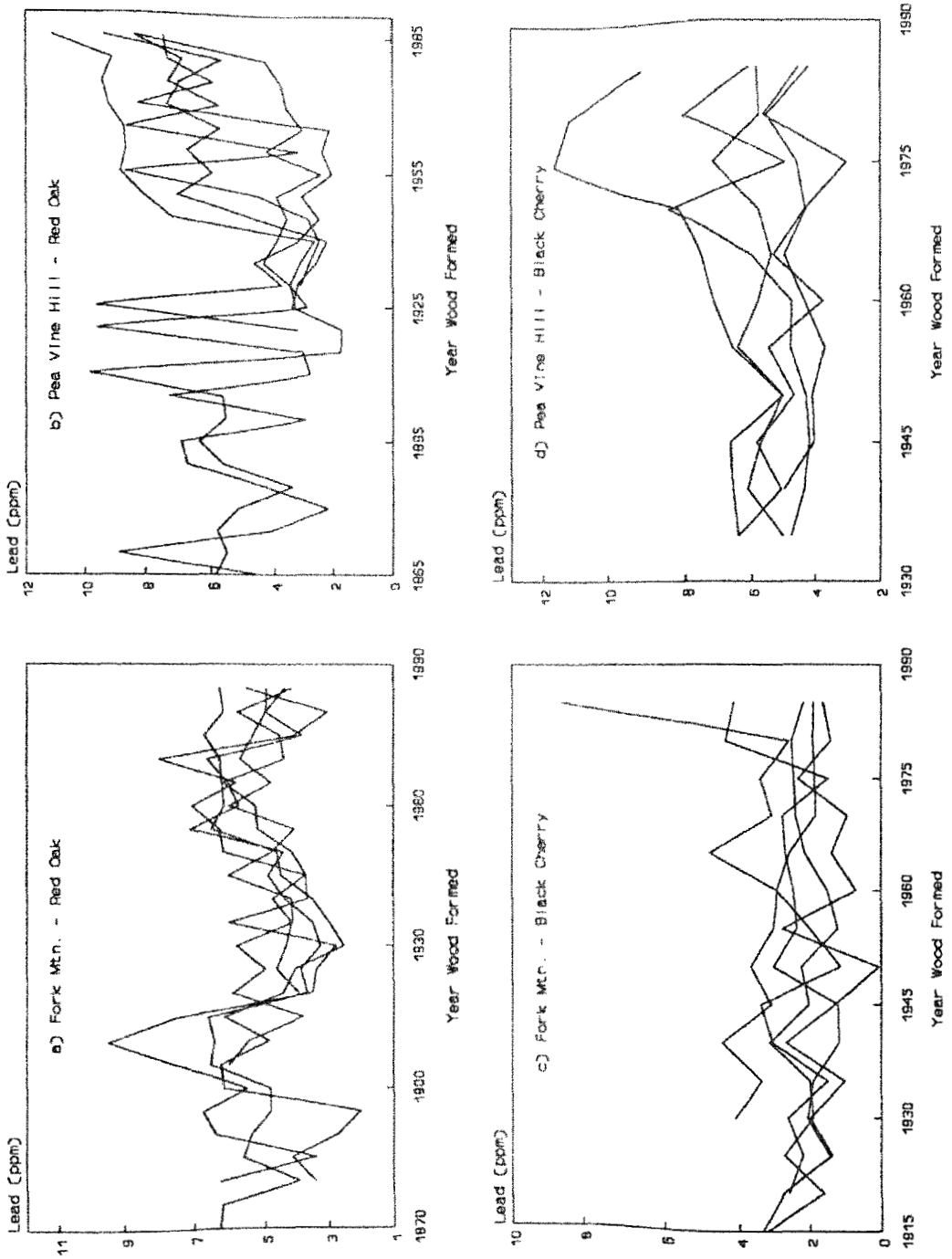

Figure 3. Radial variation of tree ring lead content for (a) Fork Mtn. - red oak, (b) Pea Vine Hill - red oak, (c) Fork Mtn. - black cherry and (d) Pea Vine Hill - black cherry. This pattern with great variation and little radial trend was designated Type 2.

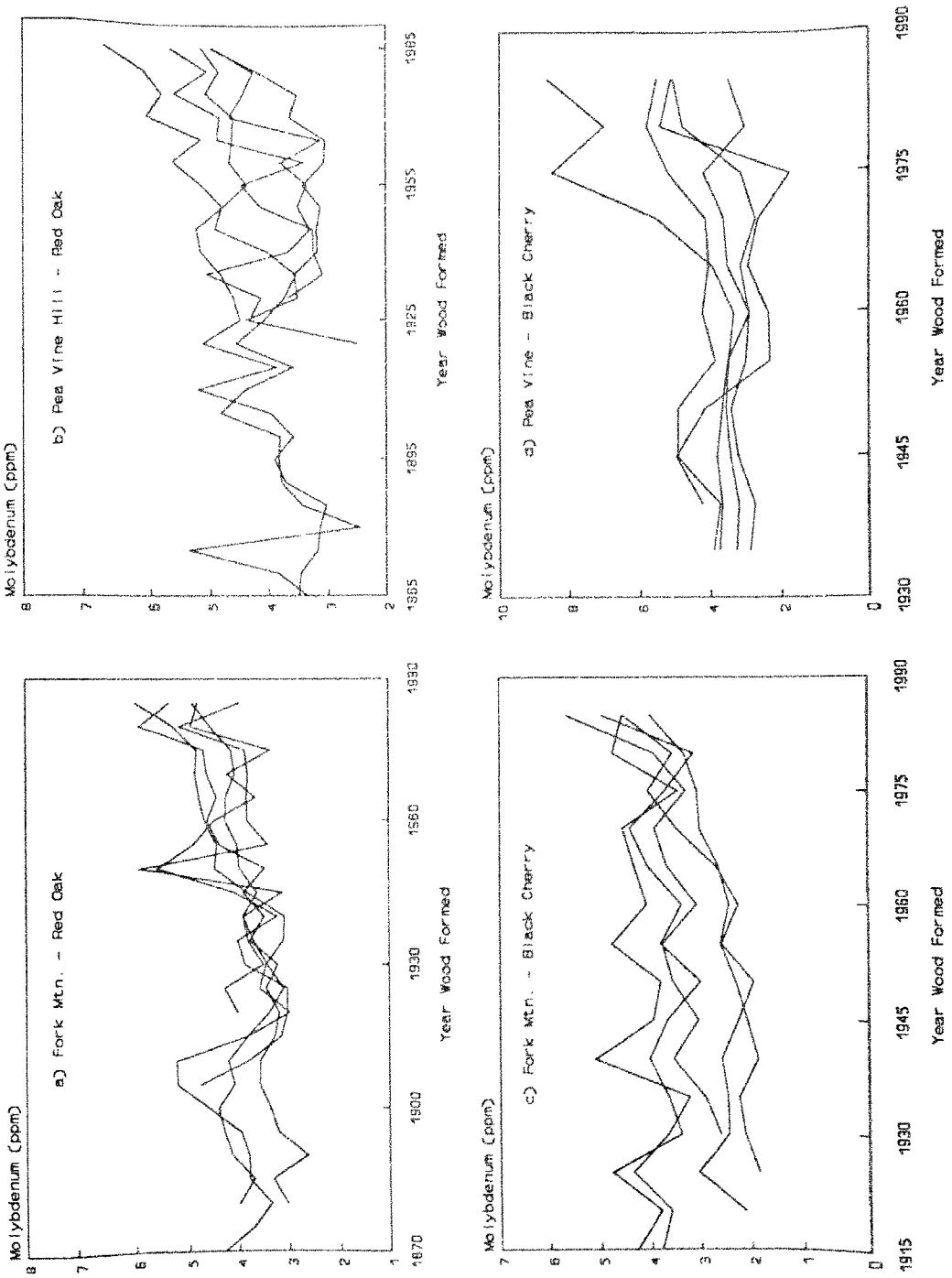

Figure 4. Radial variation of tree ring molybdenum content for (a) Fork Mtn. - red oak, (b) Pea Vine Hill - red oak, (c) Fork Mtn. - black cherry and (d) Pea Vine Hill - black cherry. This intermediate pattern of radial variation was designated Type 3.

The cause of the varying radial patterns among elements can not be determined with certainty at present, but some observations are appropriate. The fact that the same type of radial variation occurred for each element in both species indicates the pattern is closely linked to the nature of the element and not to the considerable difference in wood structure between the ring-porous red oak and diffuse-porous black cherry. Groupings of the elements into the three types of radial variation suggest the cause may be linked to the origin of the elements, e.g. soil vs. atmosphere, or the nature of the element. Type 1 elements were largely bivalent alkaline earth metals which are quite abundant in the soil. Type 2 and 3 elements are primarily trace metals found in the soil and atmosphere. The role radial translocation may have played in shaping the patterns of element variation observed is unknown. Thus, more research is needed to ascertain the true cause of the observed radial variation patterns.

Regression Models of Element Radial Variation

Piece-wise regression models were developed to describe the radial variation in concentration of elements from pith to cambium. Two line segments were used in the piece-wise regression: one for the near-cambium outer region needed for at least Type 1 elements and the second segment for the inner region. The dependence of concentration on growth rate was also included in the models by using basal area increment as an independent variable. The model form used was:

$$Y=b_0+b_1X_1+b_2X_2+b_3(X_2-c)X_3$$

where:

Y = concentration of element in segment, ppm
X_1 = basal area increment for tree, mm^2/5 yr
X_2 = age of growth segment, yr
c = age at inner zone-outer zone boundary, yr
X_3 = indicator variable, X_3=1 if outer, X_3=0 if inner zone.

Through trial and error analysis, the best value for the variable c was determined to be 15 years.

Serial correlation existed in the residuals from application of the above model in most cases. Since serial correlation invalidates hypothesis testing relative to the significance of regression coefficients, a method was needed to remove serial correlation. An adaptation of the transformed variable-iterative approach described by Neter et al. (1985) which involves running the regressions using all variables differenced over time with a serial correlation coefficient was used to remove serial correlation in the residuals. Using this procedure regressions are run on transformed variables as:

$$Y_t'=Y_t-rY_{t-1} \text{ and } X_t'=X_t-rX_{t-1}$$

where r is the serial correlation coefficient. The maximum R^2 equation with a non-significant Durbin-Watson coefficient was adopted after iteration on the serial correlation coefficient in increments of 0.2 from r = 1.0 to r = -1.0. Serial correlation coefficients ranging between -0.2 and 1.0 were needed to eliminate serial correlation in the model residuals based upon a two-tailed Durbin-Watson test statistic. Results of these regressions run with differenced data are summarized in Tables 1 and 2.

Trends of chemical element concentration with ring age or time in the inner-zone, as indexed by the b_1 coefficient, were highly variable among elements, species and sites. In Tables 1 and 2, a positive b_1 coefficient indicates that concentration increased with time or decreased with ring age. Significant trends in the inner zone were indicated in 21 equations, 14 positive and 7 negative regression coefficients, out of the 76 total equations. Within a species the only consistent trend was an increase in Mo concentrations with ring age for red oak at both sites. This trend is opposite that found by Guyette et al. (1989) in heartwood of eastern redcedar after 1860. Within sites the only consistent trend was an increase in P content with time in both species at Pea Vine Hill.

Trends for Ca with ring age in the inner zone varied between species. At Pea Vine Hill, Ca decreased in red oak and increased in black cherry with time. Release from competition by cutting and chestnut blight would be expected to increase availability of Ca. Atmospheric deposition would probably initially increase Ca availability due to mobile sulfate anions in the soil solution and later deplete Ca if the site fertility were low. Pea Vine Hill soil was less fertile than that at Fork Mtn. Increases of Ca with time in black cherry at Pea Vine Hill would more likely be a response to increased atmospheric deposition, since effects of release would be minor by 1935 when these young black cherry reached breast height. Older red oak at Pea Vine Hill showed a general decline of Ca with time in this inner wood zone. Alone, this trend might be taken to indicate general depletion of Ca from the soil by atmospheric deposition. The opposite trend in black cherry for at least the latter part of this time interval confuses the issue and may indicate species differences in accumulation of Ca in bole wood.

Differences in time trends for Sr were also found between species in inner zone wood at Fork Mtn. Strontium increased in red oak and decreased in black cherry at Fork Mtn. These trends are opposite those found for Ca in each species at Pea Vine Hill and may be related to the competition between Sr and Ca in biological systems. However, no significant trends were indicated for either Sr at Pea Vine Hill or Ca at Fork Mtn. to substantiate this relationship.

Other significant changes of element concentration with ring age were not duplicated at either site or for either species. Type 3 elements which were identified with general increases in concentration with ring age based upon visual inspection, did exhibit the majority of positive inner-zone ring age trends.

Variation of element concentration with basal area increment was almost always negative (negative b_2). In 17 out of 20 equations in which the b_2 coefficient was significant, the sign of the coefficient was negative. Negative correlations between element concentration and basal area increment were found for all types of elements. Thus, element concentration

Table 1.--Red oak regression analysis summary for Fork Mtn. and Pea Vine Hill based upon differenced data and use of serial correlation coeffcients.

	Fork Mtn.				Pea Vine Hill			
Element	R^2	b_1	b_2	b_3	R^2	b_1	b_2	b_3
Type 1								
Ca	42	-	N[2]	P	35	N	-	P
Mg	61	-	-	P	85	-	P	P
Sr	36	P	N	P	24	-	N	-
Ba	ns[1]	-	-	-	32	N	N	-
Mn	61	-	-	P	34	-	-	P
K	35	-	N	P	13	P	-	P
P	77	-	-	P	70	P	-	P
Type 2								
Cd	ns	-	-	-	ns	-	-	-
Pb	ns	-	-	-	ns	-	-	-
Cu	19	P	N	-	ns	-	-	-
Co	13	-	N	-	ns	-	-	-
Cr	ns	-	-	-	ns	-	-	-
Ni	18	P	N	-	ns	-	-	-
Al	13	-	N	-	ns	-	-	-
Type 3								
Na	21	-	N	P	ns	-	-	-
Fe	20	-	-	P	30	N	-	-
Zn	ns	-	-	-	28	-	N	-
Mo	30	P	N	P	13	P	-	-
Si	ns	-	-	-	ns	-	-	-

[1]ns = non-significant model, see text.
[2]N = negative trend with time.
P = positive trend with time.
- = no significant trend.

Table 2.--Black cherry regression analysis summary for Fork Mtn. and Pea Vine Hill based upon differenced data and use of serial correlation coeffcients.

	Fork Mtn.				Pea Vine Hill			
Element	R^2	b_1	b_2	b_3	R^2	b_1	b_2	b_3
Type 1								
Ca	19	-	-	P	30	P	N	P
Mg	ns[1]	-	-	-	63	P	N	P
Sr	27	N[2]	-	-	24	-	-	P
Ba	24	N	-	-	24	-	N	P
Mn	30	-	-	P	12	-	-	P
K	47	-	-	P	ns	-	-	-
P	70	N	-	P	70	P	N	P
Type 2								
Cd	ns	-	-	-	20	-	-	N
Pb	ns	-	-	-	ns	-	-	-
Cu	ns	-	-	-	ns	-	-	-
Co	20	N	P	P	ns	-	-	-
Cr	ns	-	-	-	ns	-	-	-
Ni	ns	-	-	-	ns	-	-	-
Al	ns	-	-	-	ns	-	-	-
Type 3								
Na	15	P	N	-	ns	-	-	-
Fe	ns	-	-	-	19	P	-	-
Zn	21	-	P	P	40	P	-	P
Mo	ns	-	-	-	ns	-	-	-
Si	ns	-	-	-	24	P	-	-

[1]ns = non-significant model, see text.
[2]N = negative trend with time.
P = positive trend with time.
- = no significant trend.

generally decreased as basal area growth rate increased. Similar negative correlation between ring widths and element concentration were found by Ragsdale and Berish (1988) for hickory (*Carya* spp.).

Analyses were also conducted using chemical element loads or xylem accumulation rates, computed as the product of concentration and weight of the five year core increments (Baes and McLaughlin 1984), as the dependent variable. This analysis approach did not eliminate growth rate effects. Since use of loads did not simplify the regression models, the analysis based upon concentrations and basal area increment was employed. It is clear that whatever form of dependent variable is used, growth rate effects must be considered when analyzing tree-ring chemical element time series.

Increases in the concentration of elements with time in the outer zone (positive b3) were commonly significant for both Type 1 and 3 elements, as expected. The regression coefficient b3 was significant in 28 out of 76 total equations; with b3 exhibiting a positive sign in 27 equations. Thus, element concentration increases in the outer zone were significant even after the effects of reduced basal area growth rates in this zone were removed. It is hypothesized that sap flow and cation exchange within the near-cambium xylem elements (Bondietti et al. 1989) is primarily influencing concentrations in this outer zone.

CONCLUSIONS

Distinctly different radial patterns of chemical element concentrations occur from pith to bark among elements regardless of species tested or site sampled. These patterns appear related to the nature of the elements and perhaps pathways for elements to reach the bole wood. Piece-wise multiple regression models with corrections for serial correlation were developed to describe radial chemical element concentration patterns. High concentrations of elements were generally associated with periods of low basal area growth. Chemical element concentrations also increased linearly as the cambium was approached in an outer zone of wood of 15 years width. With the possible exception of Ca and Sr, trends in chemical element concentrations with tree-ring age in the inner wood zone did not appear to be related to impacts of timber cutting, chestnut blight and atmospheric deposition.

ACKNOWLEDGMENTS

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FACTORS AFFECTING TEMPORAL AND SPATIAL SOIL MOISTURE VARIATION IN AND ADJACENT TO GROUP SELECTION OPENINGS

W. Henry McNab[1]

Abstract: Soil moisture content was intensively sampled in three, 1-acre blocks containing an opening and surrounding mature upland hardwoods. Openings covering 0.19-0.26 ac were created by group-selection cutting, and they were occupied by 1-year-old trees and shrubs. During 1989, soil water content at each site decreased rapidly during the summer and did not increase until evapotranspiration declined near the end of the growing season. During wet periods, when weekly precipitation exceeded potential evapotranspiration, soil moisture was about the same in openings as under the trees. In dry periods, soil moisture was greater (1) in the openings than in the adjacent stand and (2) on concave-shaped than on convex-shaped areas. In openings, soil water increased with distance from the edge during dry periods but not during wet periods. Prediction equations based on these site variables and an expression of point-to-point variation in soil water-holding capacity explained over 60 percent of the spatial variation in soil water content during dry periods. Soil water-holding capacity was the most important variable in all prediction equations during both wet and dry periods, accounting for about 23% and 39%, respectively, of the variation in soil moisture. These results suggest that spatial variability in soil moisture in group selection openings is associated with relatively few stand and site variables.

INTRODUCTION

Regeneration by group selection creates small (<1 acre) openings in the forest canopy within which environmental conditions can vary widely (Smith 1962). Compared with our knowledge of environmental conditions in large openings, such as those made by clear cutting, we know little about conditions in small openings. Information gathered in large openings cannot be applied to small openings because of differences in the ratio of area to edge and because of gradients in light and soil moisture caused by the stand boundary. While both light and water influence the response of regeneration in openings (Godman and Krefting 1960, Geiger 1965, Minckler et al. 1973), the soil water regime has received less attention than light. Additional information on variation of soil moisture in openings during the growing season and within sites is needed to better understand the growth response of regeneration. In the present study, I measured temporal and spatial variation in soil water in and around openings of 1/5 to 1/4 acre in a mature hardwood stand during the growing

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season. My purpose was to determine the relative importance of soil, tree stand, and topographic factors on spatial variations in soil moisture.

METHODS

Study Area

This study was conducted in the Bent Creek Experimental Forest, a 6000-acre research facility maintained by the USDA Forest Service in western North Carolina, about 10 miles southwest of Asheville. The Forest is in the Blue Ridge Physiographic Province, whose geology is dominated by granites, gneisses, and schists. Winters are short and mild, and summers are long and warm. Annual precipitation, which averages about 46 inches, is evenly distributed during the year with little occurring as snow. Precipitation generally increases with elevation due to local orographic effects.

The study was installed in the Boyd Branch drainage, at the lower end of a large, east-facing cove at an elevation of about 2500 feet. The cove contains a variety of sites ranging from shallow concave drains to low convex ridges. It is dominated by mesophytic species, including yellow-poplar (*Liriodendron tulipifera* L.), northern red oak (*Quercus rubra* L.), and red maple (*Acer rubrum* L.) trees and an understory of flowering dogwood (*Cornus florida* L.) and sourwood (*Oxydendrum arboreum* (L.) DC). Scattered sweet birch (*Betula lenta* L.) and white oak (*Q. alba* L.) are also present. Steeper side slopes of the cove are dominated by chestnut oak (*Q. prinus* L.) and an understory of mountain laurel (*Kalmia latifolia* L.). This 40-acre cove stand is being regenerated by the group selection method.

During late 1987 and 1988, trees were harvested to create 14 small openings ranging from 0.1 to 0.4 acre in area. Improvement cutting and thinning were done in the timber stand between the group selection openings. Logs were skidded with a small farm tractor equipped with a winch. Logging was restricted during wet weather to reduce soil compaction and erosion. Site preparation in the openings consisted of felling all vegetation over 4.5 feet tall. When the study was initiated in June 1989, each opening was fully stocked with 1- to 2-year-old herbaceous vegetation, shrubs, tree seedlings, sprouts, and advance regeneration that had responded to removal of the overstory.

Soils in the stand are mapped as a complex of Tusquitee, Tate, and Brevard. Tate and Brevard are fine-loamy, mixed, mesic, Typic Hapludults. Tusquitee is a coarse-loamy, mixed, mesic, Typic Dystrochrept. All three soils are mixtures of alluvium and colluvium, and all have surface horizons over 6 inches thick and solums over 40 inches deep.

Plot Establishment and Measurements

Three openings, spaced from 500 feet to 900 feet apart and ranging in size from 0.18 to 0.26 acre, were selected for study. Each opening represents a distinct landform: a small cove branching off the main cove, a low ridge, and a midslope that is linear rather than convex or concave. A square, 1-acre block was defined around each opening. A grid of 25 sample points (spaced at 50x50 feet) was located in each block for soil moisture determination. Total volumetric (in^3water/in^3soil) moisture content was determined by time-domain reflectrometry (TDR) (Topp and Davis 1985) using a Tektronix Model 1502 portable cable tester. Moisture content in the top 6 inches of soil was estimated using a pair of permanently placed 0.125-inch-diameter stainless steel welding rods spaced 2 inches apart and set flush with the soil surface. TDR methods are nondestructive, accurate, and allow repeated measures of soil moisture over time. Perhaps the most important advantage of TDR over conventional gravimetric methods of soil water estimation is that repeated sampling over time is free of errors normally associated with variations among sample location. An empirical, universal calibration curve was used to convert TDR readings to volumetric water content (Topp et al. 1980). The universal calibration curve was verified by measuring soil water content in the 0-6 inch layer at 10 randomly selected, coincident points by TDR and gravimetric methods. Means (and standard deviations) in soil water estimates by the two methods were nearly identical:

TDR	0.321 (0.030) in^3/in^3
Gravimetric	0.309 (0.031) in^3/in^3

Soil moisture was intermittently sampled eight times, from June to mid-October, on a schedule that allowed as much drying as possible before the next anticipated rainfall.

Seven soil, stand, and topographic variables were measured at each of the 25 points in each 1-acre block:

Soil variable
1. Soil compaction (lb/in^2)

Stand variables
2. Inside or outside of the opening
3. Distance from edge of opening (feet)
4. Basal area (10-factor prism)

Topographic variables
5. Aspect (degrees)
6. Slope gradient (percent)
7. Land surface shape

Four measures of soil compaction were taken in a square pattern around each sampling point using a Soiltest Model PR-025 Proving Ring Penetrometer (30-degree cone with 1.0 in^2 base area) and averaged. Compaction was determined when soil moisture was near field capacity. Several sample points were shifted slightly to avoid logging access roads. All stand and topographic variables were determined by standard methods and are self-explanatory except

for land surface shape. Microsites (0.04 acre area that surrounded each soil sample point) varied in surface shape, ranging from slightly convex to concave. Land surface shape of each microsite was quantified by measuring the terrain shape index (McNab 1989). Means and ranges of the continuous variables measured on the three sites are presented in Table 1.

Table 1.--Mean and range of soil, stand, and topographic variables in the three sites studied.

Variable	Midslope	Cove	Ridge
	---------- Mean (min./max.) ----------		
Compaction (lb/in^2)	145 (74/236)	124 (54/238)	95 (51/184)
Basal area (ft^2/ac)	44 (0/100)	65 (10/120)	66 (0/120)
Distance from edge of plot (feet)	51 (5/105)	34 (30/40)	32 (5/85)
Aspect (degrees)	68 (9/159)	35 (333/87)	138 (63/193)
Slope gradient (%)	16 (5/26)	31 (16/51)	35 (16/22)
Terrain shape index	.01 (-.05/.19)	.00 (-.09/.12)	.02 (-.09/.24)

Soil moisture can also vary in response to other factors including bulk density, organic matter, and proportions of sand, silt, and clay. An indicator variable, soil water capacity, was determined at each sample point to account for these undetermined properties. This approach is similar to that of Helvey et al. (1972), who determined a factor to "remove the relatively unaccountable variation in moisture content resulting from the soils' ability to retain water against drainage and evapotranspiration." This variable, which I call "soil water capacity", is the amount of moisture in the soil when it is wetted to near field capacity. Values were determined somewhat arbitrarily in early June, 2 days after a 2-day rain. Water capacity values were determined for each of the 25 soil sample points on each 1-acre block (Table 2). Variation in the water capacity factors within 1-acre blocks was relatively wide, with no indication of a consistent gradient. Presence within an opening appeared to have little effect on the values. For example, water capacity values on the ridge ranged from 0.259 to 0.337 over a distance of 50 feet. Average water capacity varied somewhat among sites, as indicated by the means and standard deviations:

Cove	0.269 (0.035)
Midslope	0.286 (0.043)
Ridge	0.307 (0.046)

At near field capacity, soils had slightly greater water-holding capacity on the ridge than in the cove.

Precipitation and air temperature were determined and recorded by an automatic weather station located in the midslope opening. Weekly potential evapotranspiration was determined by the method of Thornthwaite and Mather (1957) using a computer program (Stone 1988).

Table 2.--Soil water capacities in the top 6 inches of soil at 25 sample points on each of three sites. Sample points were arranged in a grid with each row and column spaced 50 feet apart. Underlined sample points are in an opening.

	Column				
Row	1	2	3	4	5
			Cove		
1	.209	.267	.283	.275	.209
2	.283	.291	.322	.267	.314
3	.274	.299	.209	.275	.275
4	.267	.267	.322	.209	.283
5	.275	.226	.283	.307	.226
			Midslope		
1	.322	.299	.218	.307	.314
2	.267	.314	.259	.307	.242
3	.299	.322	.330	.307	.337
4	.283	.259	.226	.226	.314
5	.251	.209	.242	.345	.359
			Ridge		
1	.322	.291	.352	.291	.330
2	.307	.330	.267	.299	.322
3	.426	.259	.330	.259	.337
4	.366	.185	.291	.306	.259
5	.337	.322	.251	.306	.322

That method of estimating plant water use and evaporation has been criticized as too simplistic, but it is useful in this case for broadly characterizing environmental conditions. Because precipitation is a major cause of temporal variation in soil water content, sampling dates were stratified into two periods, dry or wet. Dry periods were arbitrarily defined as weeks in which potential evapotranspiration exceeded precipitation. In wet periods, weekly precipitation exceeded evapotranspiration.

Data were analyzed in two phases. Effect of the discrete factor (in or out of opening) on soil water was examined by analysis of covariance. Correlation and multiple regression analysis were used to determine the relationship of the continuous site variables to soil moisture content on each measurement date. Since sites were unreplicated, statistical comparisons among sites could not be made. Regression coefficients were tested for significance at the

0.05 level. Those results are omitted from this presentation because of its limited scope. A dynamic local model of soil moisture as a function of time and amount of precipitation was not developed, but such a model has been developed for a nearby region of greater precipitation in the southern Appalachians (Helvey et al. 1972).

RESULTS AND DISCUSSION

Temporal Variation

In 1989, losses of soil water to evapotranspiration generally exceeded inputs from precipitation at Bent Creek from early July through early September (Figure 1). The pattern of precipitation was typical, except for September, when heavy rain associated with a hurricane fell for 2 days. July through early September precipitation in 1989 was about 50 percent above the 44-year normal at Bent Creek Experimental Forest. Soil moisture was sampled during three wet periods and five dry periods:

Wet periods: June 22, 29, October 13
Dry periods: July 10, 18, 28; August 18, September 5

Soil moisture content decreased rapidly during July, as precipitation decreased and evapotranspiration increased, and then leveled off during August (Figure 2). Total soil water content during June was slightly higher in the cove than at midslope or on the ridge site. By mid-July, water contents were almost identical on all blocks. Soil moisture contents in mid-September were about 40 percent below those of early June. Soil moisture began to increase by October, as potential evapotranspiration decreased. A similar trend in seasonal soil moisture content was reported for Coweeta Hydrologic Laboratory by Helvey and Hewlett (1962).

Spatial Variation

During wet periods, there was little spatial variation in soil water content. During dry periods, a typical drying pattern emerged, which was dependent upon several factors. For analysis of spatial soil water data, June 22 was selected as a typical wet period and September 5 as a typical dry period.

Soil Water Capacity. Water capacity values were highly correlated with soil water content during both wet and dry periods, as indicated by the following correlation coefficients:

Wet	r=0.48
Dry	r=0.63

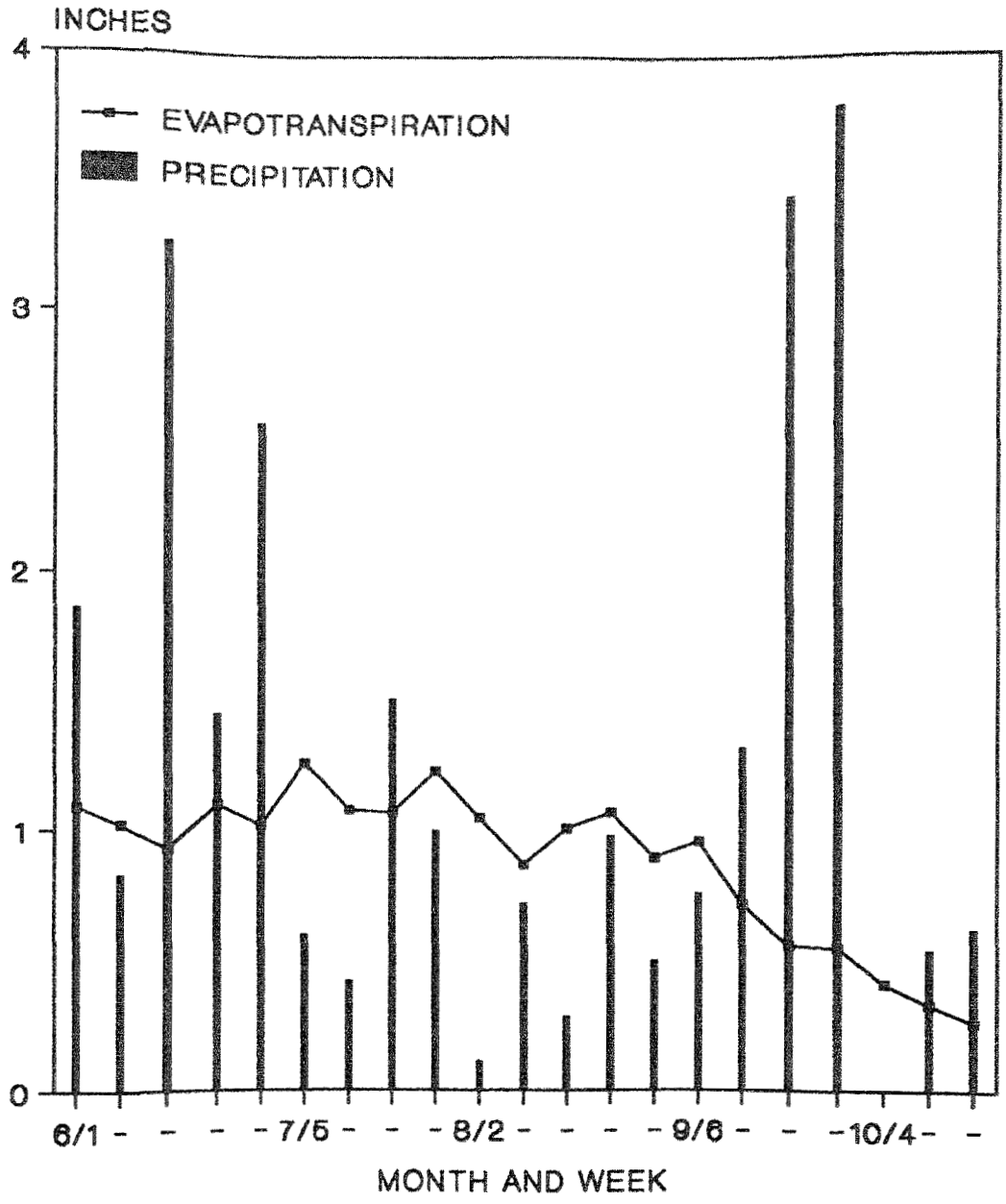

Figure 1. Weekly precipitation and potential evapotranspiration at the midslope site from June 1 to October 4, 1989.

Helvey et al. (1972) reported that a similar variable, which accounted for variation in moisture-holding ability of the soil, was the single most important variable affecting soil water in a study at Coweeta Hydrologic Laboratory.

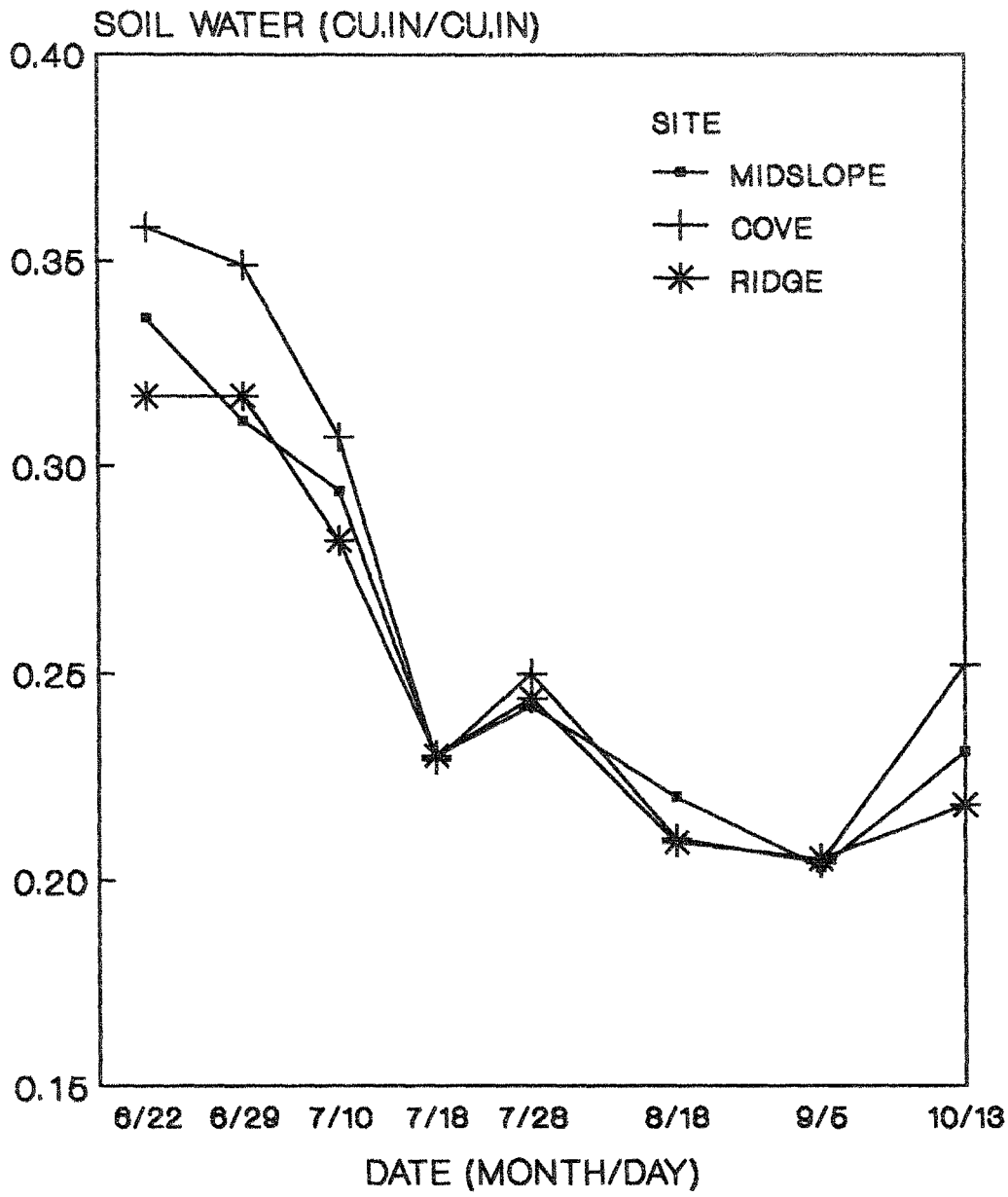

Figure 2. Temporal variation in moisture content of soil on three sites, 1989.

Group Selection Openings. During wet periods soil water content was about the same inside and outside the openings. In dry periods, however, soil moisture was significantly greater inside the openings. The cove site had somewhat greater soil water contents inside openings during dry periods than did the ridge site, with the midslope intermediate between the two (Table 3).

Table 3.--Means and standard deviations () for soil moisture contents in openings and adjacent stands by rainfall period and site.

Site	Inside opening	Adjacent stand	Mean
		WET PERIOD	
Cove	0.351 (.085)	0.349 (.025)	0.349 (.038)
Midslope	0.327 (.028)	0.297 (.042)	0.311 (.038)
Ridge	0.311 (.053)	0.322 (.057)	0.317 (.054)
Mean	0.324 (.052)	0.327 (.044)	0.326 (.047)
		DRY PERIOD	
Cove	0.282 (.059)	0.189 (.041)	0.204 (.055)
Midslope	0.246 (.061)	0.163 (.061)	0.203 (.073)
Ridge	0.214 (.054)	0.197 (.084)	0.205 (.070)
Mean	0.251 (.049)	0.182 (.061)	0.204 (.065)

Soil water content in openings was affected by rainfall period and distance from the edge. During wet periods, no differences in soil water content were evident at sample points in the stand or the opening. In dry periods, however, water content at the edge of the opening was about equal to that in the adjacent stand. Soil water content increased rapidly with distance into the opening (Figure 3) and tended to level off about 30 feet into the opening. These results suggest that trees along the opening boundary influence soil water content mainly through water use by roots. Casual observations revealed that crowns typically extended about 15 to 30 feet into the openings. Minckler et al. (1973) also reported increased soil moisture with distance into the openings.

Although not measured in this study, tree regeneration toward the center of the openings appeared to be taller than that near the edges. Increased light is one reason for better growth, but greater soil moisture is also a likely contributing factor. An application of these findings is that the group selection openings should be large enough so that soil moisture in much of the area is not influenced by the adjacent stand and can be utilized by the regeneration for rapid height growth.

Soil, Stand and Topographic Variables. Soil water content was closely correlated with soil compaction, basal area, and terrain shape index, and somewhat less with slope gradient (Table 4). With the exception of terrain shape index, all correlations were negative. And, except for basal area, the significant variables were correlated with soil moisture in both wet and dry periods.

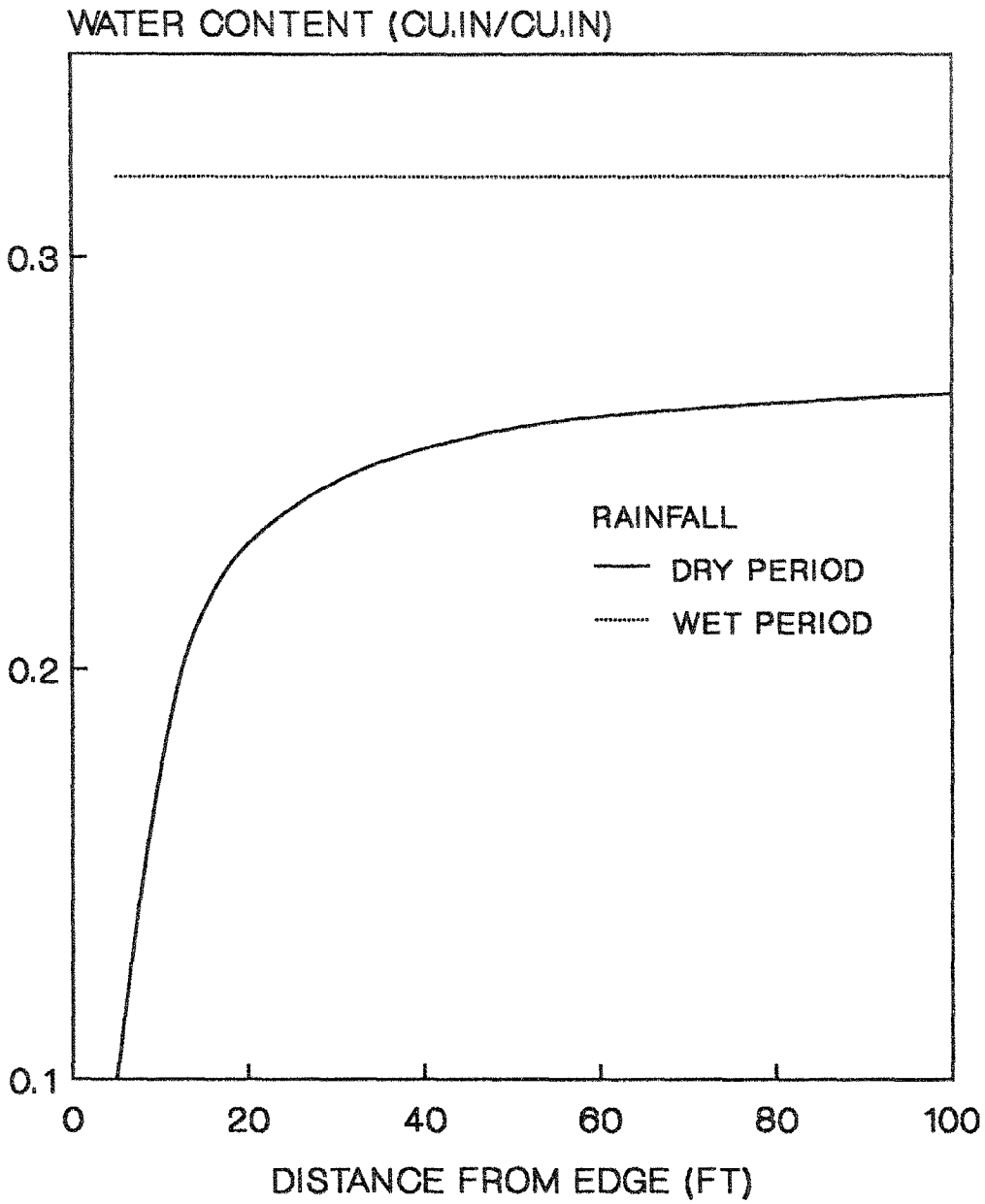

Figure 3. Predicted soil water content in an opening during a dry period as related to distance from edge of opening.

Soil, stand, and topographic variables significantly correlated with soil water content, along with soil water capacity, were included in a multiple regression analysis for the typical sample date during wet and dry periods. The following linear model provided the best fit during dry periods:

$$\text{Soil water } (in^3/in^3) = b_0 + b_1(\text{soil water capacity}) + b_2(\text{basal area}) + b_3(\text{terrain shape index}) \quad [1]$$

This model accounted for 62 percent of the variation in soil moisture at individual sample points. The soil water capacity was the single most important variable, accounting for 39 percent of the variation. Stand basal area and terrain shape index were about equally important. During wet periods, only the water capacity factors had a significant effect on soil moisture, accounting for 23 percent of the variation.

Table 4.--Pearson correlation coefficients of soil water content with soil, stand, and topographic variables.

Variable	Wet periods	Dry periods
	r	
Soil water capacity (in^3/in^3)	.46**	.57**
Compaction (lb/in^2)	-.29**	-.36**
Basal area (ft^2/ac.)	-.24	-.39**
Aspect (azimuth)	-.09	-.09
Slope gradient (%)	-.10*	-.12*
Terrain shape index	.20**	.37**

* Significant at the 0.05 level.
**Significant at the 0.01 level.

Several variables that were correlated with soil moisture content were not significant in the prediction model because of intercorrelations among variables. Soil compaction was not a significant variable in the model because it was strongly correlated with the soil water capacity (Figure 4). The effect of slope gradient on soil moisture was largely accounted for by terrain shape index. Similar interrelationships between topographic variables have been found in many soil-site studies.

Figure 5 illustrates the response surface of the model for soil water in the 0-6 inch layer on a typical sample date (September 5) during a dry period. Lowest predicted values of soil water content are found on a convex soil surface with high basal area. The model indicates that soil water content approximately doubles when: (1) basal area is reduced from 120 to 0 ft^2/acre with constant surface shape, or (2) soil surface shape changes from slightly convex to concave with constant overstory basal area. If basal area and surface shape change simultaneously, predicted soil water contents are about three times greater in a group selection opening with 0 basal area and a concave surface, compared to a sample point in the adjacent stand with high basal area and a convex shape.

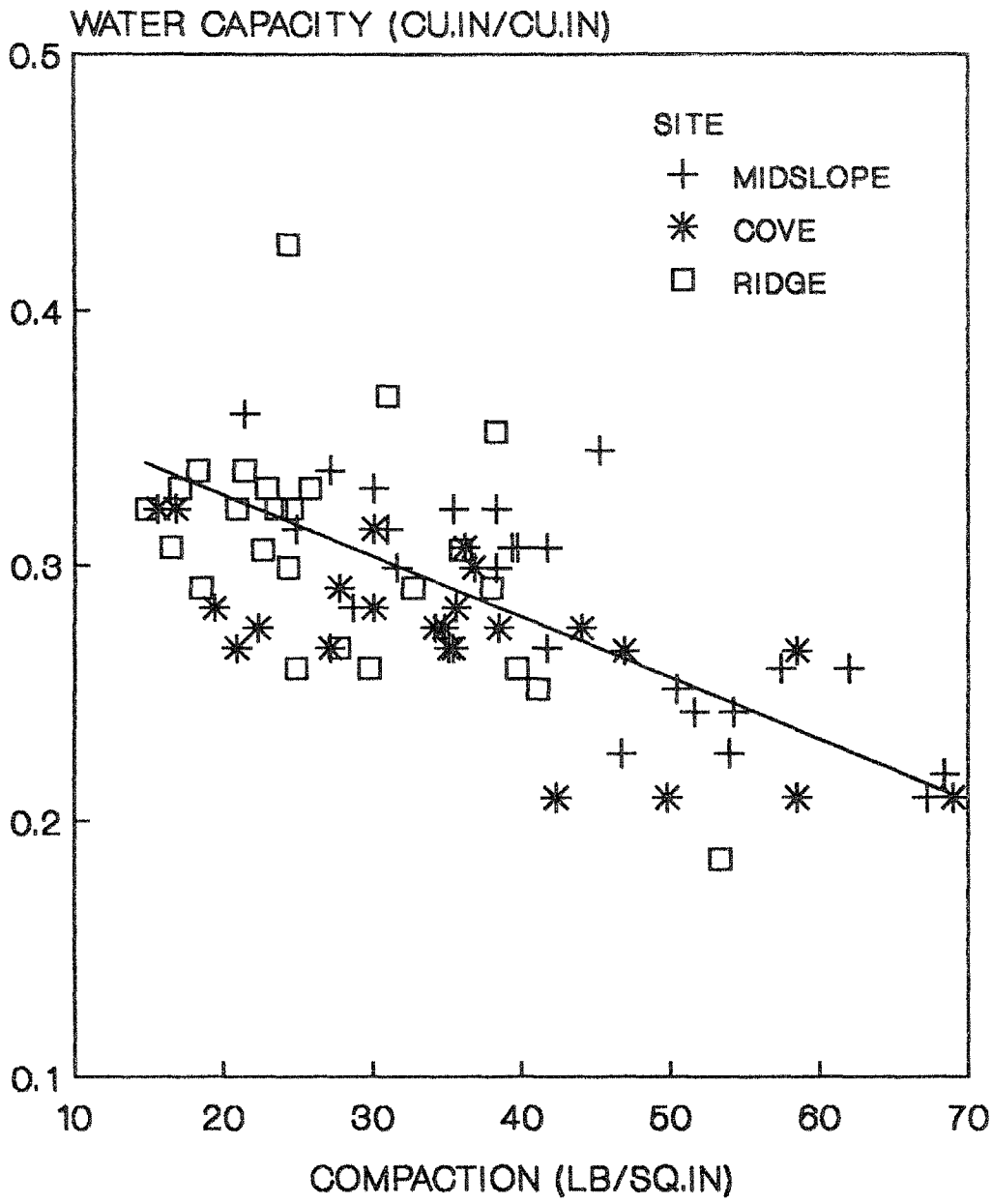

Figure 4. Relationship of soil water capacity to soil compaction, by site and sampling point.

The relationship between soil compaction and soil water capacity may be useful for field application of these results. Field determination of water capacity is time consuming and requires specialized equipment. However, by using a relationship similar to that of Figure 4, the soil water capacity might be estimated from the more easily measured variable, soil

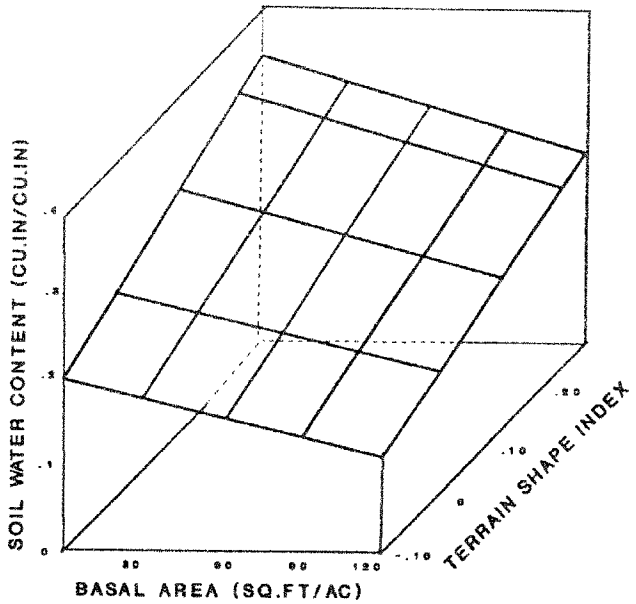

Figure 5. Predicted soil water content as a function of stand basal area and terrain shape index for the 0-6 inch layer on September 5, 1989.

compaction. Another approach would be to reformulate the prediction equation in terms of soil compaction. In any event, water holding capacity of the soil can be estimated with little need for soil sample collection and laboratory analysis.

The effects of temporal and spatial variations in soil moisture on the growth of mesophytic species like yellow-poplar may be quite large. In my own work, I have found an increase in yellow-poplar site index of over 20 feet at age 50 associated with a change in terrain shape from convex to concave. Results of the present study indicate that the effect of terrain shape is probably through additional soil moisture during dry periods. In addition, Beck (1984) reported that a very large proportion of the annual variation in radial growth of individual yellow-poplar trees in the southern Appalachians can be explained by annual variations in rainfall in June and July. He postulated that soils were typically fully charged with moisture early in the growing season, but that supplies sufficient for rapid growth were exhausted by the end of June in dry years. Similar sorts of relationships between soil moisture and growth may also hold for other mesophytic species on well-drained sites.

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RESPONSE OF AN APPALACHIAN MOUNTAIN FOREST SOIL, SOIL WATER AND ASSOCIATED HERBACEOUS VEGETATION TO LIMING

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Abstract: Agricultural limestone was applied in varyious amounts to the surface of three 10-m square forested plots on Pea Vine Hill in Westmoreland County, Pennsylvania; a fourth plot served as a control. Measurements of soil exchangeable calcium and base saturation revealed positive responses to limestone addition on all treated plots. However, percolating soil water (leachate) was not significantly affected up to five months after treatment. Four years after treatment, A horizon exchangeable Ca and base saturation were reduced almost to pre-treatment levels. Response of E horizon soil to limestone treatment was manifested in a doubling of base saturation after two years with a return to pre-treatment values after four years. E horizon exchangeable Ca was also increased but by a lesser amount. Forest floor vegetation responses were highly variable; however, liming increased species diversity.

INTRODUCTION

Current interest in the potential impact of acid deposition on terrestrial ecosystems is in part centered around the long term supply of soil base cations as it relates to increased leaching caused by acid deposition, (Bondietti and Shortle 1990). Many investigators have been attempting to relate observed tree decline symptoms to nutrient depletion. Roberts et al. (1989) reviewed literature related to Type I Spruce Decline and concluded that acid deposition-induced soil magnesium (Mg) deficiencies are a chief cause of these symptoms. They cite several studies that reported reversal of decline symptoms following Mg fertilization. Ke and Skelly (1990) reported Mg deficiencies in a Norway spruce (*Picea abies* (L.) Karst) plantation near the site of this work. Joslin and Wolfe (1989) reported significant correlations between Ca concentrations in northern red oak (*Quercus rubra* L.) roots and leaves and various liming treatments.

Johnson and Todd (1990) and others have recently reviewed Ca depletion on forested sites in relation to leaching by acid deposition. Bondietti and Shortle (1990) and Federer et al. (1989) have concluded that acid deposition has resulted in increased Ca leaching. Based on an analysis of long term soils data at five sites in the eastern U.S., Federer et al. (1989) have estimated Ca leaching rates to be 4-16 kg/ha/yr.

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However, previous work on the fertilization of hardwoods in Pennsylvania is equivocal on this point. Auchmoody (1983) reported increased growth of black cherry (*Prunus serotina* Ehrh.) following N and P fertilization and he further contended (Auchmoody 1985) that Ca was not limiting growth for black cherry in the Allegheny National Forest. Ward and Bowersox (1970) showed increased growth in an oak stand that received both N and Ca applications. Sharpe et al. (in preparation) report increased growth of red oak seedlings after fertilization with bone meal ($CaPO_4$) in a greenhouse study. Fertilizer applications have been shown to be beneficial to the establishment of black cherry following harvesting activity (Auchmoody 1985). The effects of applications of N, K and lime on element fluxes were investigated by Matzner et al. (1983). They concluded that N and K fertilization increased leaching of Al and Mn while liming substantially increased the Ca/Al ratio in soil solution.

In 1983 an investigation of biogeochemical cycling of acid deposition was initiated on Pea Vine Hill in southwestern Pennsylvania. As a part of this effort, 10m x 10m plots were treated with agricultural limestone to determine the impact of calcium (Ca) addition on soil leachate quality. In this study we attempted to determine the impact of lime additions on soil leachate chemistry, soil exchangeable Ca, base saturation, and herbaceous and woody ground vegetation.

METHODS

A description of the study area is given by DeWalle et al. (1988). Instrumentation for the collection of soil leachate samples, leachate analysis and estimation of nutrient fluxes are given by DeWalle et al. (1988) and Swistock et al. (1990). The soil was a Hazelton/DeKalb loamy-skeletal, mixed mesic typic Dystrochrept located on Pea Vine Hill in southwestern Pennsylvania.

Adjacent 10m x 10m plots were established next to an excavated soil lysimeter pit. Suction lysimeters were installed on these plots and pan lysimeters were positioned beneath the plots. Soils in each pit were characterized (DeWalle et al. 1988). One plot (plot #2) was designated as the control and received no limestone. Plots #1, #4 and #5 received bagged agricultural limestone on November 1, 1984 at the rate of 5.9, 11.1, and 2.9 tonnes/ha, respectively in a one-time application. The limestone was applied to the surface of the litter layer by hand. These application rates were designed to produce a buffer pH of 5.5, 7.0 and 1/2 the 5.5 rate, respectively in the A soil horizon. The calculation of limestone application rates was based on the SMP buffer pH (Penn State Soil and Forage Testing Laboratory) of the O, A, and E horizons prior to treatment and the volume of stone free soils in each horizon. The soil in the A and E horizons was estimated to be 30 percent stone. The standard agricultural lime requirements to produce the buffer pH's mentioned, for an initial buffer pH of 5.8 for a soil depth of approximately 17 cm, were adjusted by reducing the lime requirement by 30 percent. The 1986 measurements of A horizon soil pH for the light, moderate and heavy application revealed estimated pH's of 4.0, 6.1, and 5.8, respectively. The control A horizon pH remained near pH 3.8. Consequently, the method used to estimate lime application is in need of further refinement for acid soils.

Two samples were obtained from each soil horizon on each plot. Soil samples were analyzed in the Soil and Forage Testing Laboratory at the Pennsylvania State University for CEC, pH, exchangeable Ca, Mg, P and K and base saturation.

Soil leachate was collected bi-weekly utilizing both zero tension pan and ceramic-cup suction lysimeters. Swistock et al.(1990) contains the details of lysimeter installation, data collection, and laboratory methods. Only E horizon zero-tension data are reported in this paper.

Surveys of forest floor vegetation employed ten randomly selected permanent $1m^2$ plots on each 10m x 10m treatment area. All woody and herbaceous stems were counted once prior to treatment and four times after treatment. Surveys were conducted in September of 1984, 85, 86 and 89 and June of 1990.

RESULTS

Soil Chemistry

Limestone applications resulted in increased levels of exchangeable Ca and base saturation in the A and E soil horizons. The greatest increases were in the A horizon soil (Tables 1 and 2). Within two years after surface application of ground limestone, levels of both exchangeable Ca and base saturation increased dramatically; however, within five years of treatment significant declines approaching pre-treatment levels were apparent. Despite these declines, more Ca was present on the treated plots than prior to treatment.

Table 1.--Changes in exchangeable Ca in A and E horizons with time for all plots.

	Plots							
	Control		Low Lime		Med. Lime		High Lime	
Year	A	E	A	E	A	E	A	E
	Ca (meq/100g)							
1983	0.85	0.70	0.75	0.35	0.70	0.60	0.60	0.35
1986	1.45	0.40	3.65	0.62	16.4	0.58	21.0	0.62
1988	0.35	0.30	1.40	0.30	0.98	0.40	1.72	0.30

The precise fate of much of the applied Ca is not known. A portion was most probably taken up by plants growing on the site and is being cycled through the system, with temporary storage in the forest floor and humus. It is also quite likely that Ca has been leached from the root zone by percolating soil water.

Table 2.--Changes in A and E horizon base saturation with time for all plots.

	Plots							
	Control		Low Lime		Med. Lime		High Lime	
Year	A	E	A	E	A	E	A	E
	Base Saturation %							
1983	5.1	7.50	4.75	5.60	5.45	6.55	3.04	5.20
1986	11.47	7.22	21.78	10.82	81.68	10.27	79.32	11.10
1988	2.52	4.00	10.38	5.31	8.55	5.18	9.68	4.88

Soil Water

Soil water was collected beneath the E and B horizons on all plots with zero-tension pan lysimeters for one year prior to lime application and five months afterward. Because of seasonal differences in soil water quality, statistical comparisons of before and after leachate data are for the same five month period (November-May). Table 3 contains a summary of E horizon leachate chemistry before and after lime application. There were no significant differences in Ca concentrations as estimated by the E horizon lysimeters before and after limestone applications or among plots. Al concentrations were not significantly different for any comparisons except the before and after periods on the control plot. In general, there were no consistent differences in these data. Unfortunately, monitoring of soil water chemistry could not be continued beyond the five month period. Because ground limestone dissolves relatively slowly, five months was probably not sufficient to detect an increase in Ca concentration in the E horizon soil water. Marschner et al. (1989) reported that increased Ca was not monitored in leachate at 50 cm depth until six months after liming a sandy soil. However, the fact that E horizon soil exchangeable Ca and base saturation increased is evidence for leaching of Ca from the litter, humus and A horizons.

Forest Floor Vegetation

Changes occurred in herbaceous and woody vegetation growing on the test plots. For some species these changes appeared to be consistent and statistically significant. For others, however, it was difficult to ascertain either trends over time or significant differences among treatments. We have selected some species of greatest interest to management foresters for discussion. These include grass (unspecified), hay-scented fern (*Dennstaedtia punctilobula* Michx.), blueberry (*Vaccinium* spp.), deer tongue grass (*Panicum clandestinum* L.), blackberry (*Rubus* spp.), red maple (*Acer rubrum* L.), black cherry, red oak and chestnut oak (*Quercus prinus* L.).

Table 3.--Mean soil water chemistry at the E horizon depth for all plots before and after liming.

Parameter	Plots							
	Control		Low Lime		Med. Lime		High Lime	
	Before	After	Before	After	Before	After	Before	After
pH	4.37ab[1]	4.75a*[2]	4.64a	4.43a	4.34b	4.39a	4.41ab	4.46a
	(mg/L)							
Ca	2.1a	1.3a	2.0a	1.7a	1.4a	1.7a	1.2a	0.9a
Mg	0.4a	0.3a*	0.6a	0.4b	0.4a	0.4ab	0.4a	0.3ab
K	2.1a	2.6a	0.8b	0.8b	0.9b	1.1ab	0.2c	0.3b
Na	2.4ab	4.4a	3.9a	2.8ab	0.4b	0.6b	0.7b	0.4b
Al	4.5a	2.0a*	2.5a	3.3a	3.2a	3.0a	2.8a	2.5a

[1] Values in the same row followed by different letters are significantly different between plots at α=0.05 for the same period.

[2]An asterisk (*) denotes a significant difference (α=0.05) for the before and after periods on the same plot.

Some care in the interpretation of the vegetation data is appropriate. For example, although 1985 was the first year following liming, much of the lime remained visible on the forest floor indicating that it was not yet available for plant use. Consequently, 1985 should be viewed as a transition year where the full affect of the treatment was not evident. From 1985 to the present there is an increase in the amount of grass (unspecified) on the limed plots. However, except for 1985, the amount of grass on any limed plot was not significantly different from that on the control. Deer tongue grass (Figure 1) increased from 1986 through 1990 on the plot which received the least lime. On the medium lime plot, deer tongue grass was always greater than the pre-treatment year and on the high lime plot, deer tongue abundance was greater in 1986, 89, and 90. Within year differences were significant between the control and high and low lime plots in 1989 and low lime plot in 1990. There appeared to be an increase in deer tongue grass on the plots receiving the most lime.

Numbers of blueberry on the medium lime plot declined after the 1986 high, but this decline is confounded by an equally steady decline in numbers on the control plot. The relatively low pre-treatment numbers on high and low lime plots also appeared to decline after treatment. None of the within year differences were statistically significant.

Hay-scented fern (Figure 2), a plant that seems to be increasing in prominence in the forests of Pennsylvania, appeared to decline on medium and low lime plots. The high lime plot showed no decrease in fern numbers. Pre-treatment and 1985 fern numbers were not significantly different between the control and medium and low lime plots; however, in 1986 all limed plots had significantly fewer ferns than the control. By 1990, differences between plots were similar to those prior to treatment.

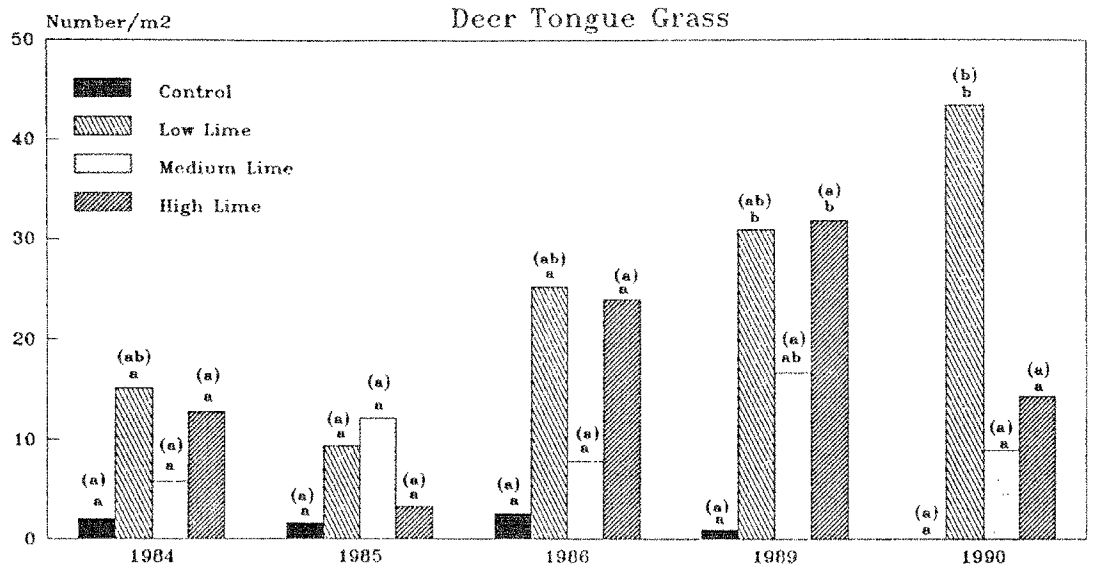

Figure 1. Trends in abundance of deer tongue grass on the control (unlimed) and each limed plot from 1984 to 1990. Different letters above bars indicate a significant difference ($\alpha = 0.05$) within a given year. Different letters in parentheses above bars indicate a significant difference ($\alpha = 0.05$) between years for that plot.

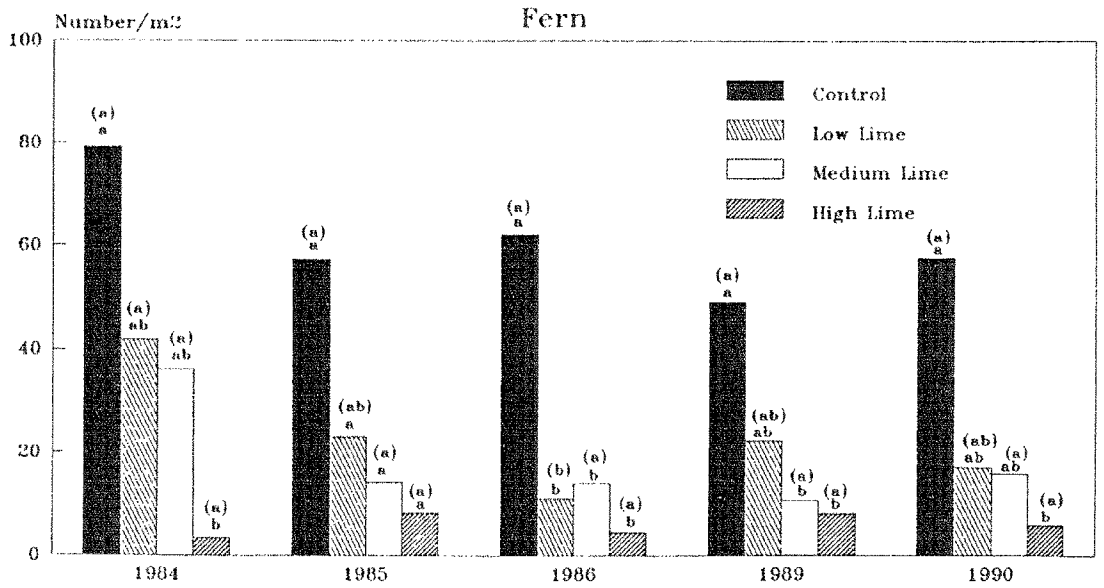

Figure 2. Trends in abundance of ferns on the control (unlimed) and each limed plot from 1984 to 1990. Different letters above bars indicate a significant difference (at $\alpha = 0.05$) within a given year. Different letters in parentheses above bars indicate a significant difference ($\alpha = 0.05$) between years for that plot.

Rubus spp. an important food species for white-tailed deer, appeared to increase on all plots after treatment with the exception of 1986 when no *Rubus* spp. were encountered on any of the plots. Numbers were low in all cases; consequently, there were no significant differences among the plots in any year.

Red maple seedlings did not appear to respond to liming with the exception of 1985, when the low lime plot had significantly more seedlings than any of the other plots. All plots had consistently higher numbers of red maple seedlings after treatment; however, with the exception of 1985, the limed plots and the control were never significantly different. It would appear that red maple did not respond to liming.

The data for black cherry are portrayed in Figure 3. Only the high lime plot appeared to have increased black cherry reproduction following liming. More black cherry seedlings were counted on the low lime plot, but the total numbers were low. Black cherry seedlings did not increase on the control plot.

As can be seen from Figure 4, red oak seedlings were scarce on all of the test plots. Only the medium lime and control plots had any oak seedlings in 1984. No plots had oak seedlings in 1985 and only the medium lime plot had seedlings in 1986. Following an exceptionally good seed crop in the fall of 1989, all plots except the control had oak seedlings in 1990.

A Shannon Diversity Index (Margalef 1968) was computed for all plots for each year that survey data were collected. The diversity of forest floor vegetation increased on the limed plots after 1985, but decreased on the control plot (Figure 5). The indicies computed for all limed plots in 1990 were significantly different ($\alpha = 0.05$) from those for 1984. The control plot index in 1990 was not significantly different from that of 1984.

These plots were not fenced to exclude deer. The area in which the plots were located had a high deer population. During the study, an average of 41 deer were harvested from this 324 ha management unit each year (Fritz, personal communication). With the exception of 1990, all vegetation surveys were done in September. In all years except 1990 every tree seedling was browsed and no seedlings were observed to attain a height greater than 20 cm throughout the course of the study.

DISCUSSION

These limited results, present evidence that addition of ground limestone to the forest floor increased the Ca concentration of soil in the rooting zone. The heaviest applications of lime produced the greatest increases in exchangeable Ca. Within five years after application, exchangeable Ca had returned to near pre-treatment levels in the treated soils. These results are in close agreement with the findings of Marschner et al. (1989) for a limed plot experiment conducted in Berlin, Germany. Plants growing on the plots were undoubtedly involved in removing a portion of this calcium through uptake and cycling through the forest

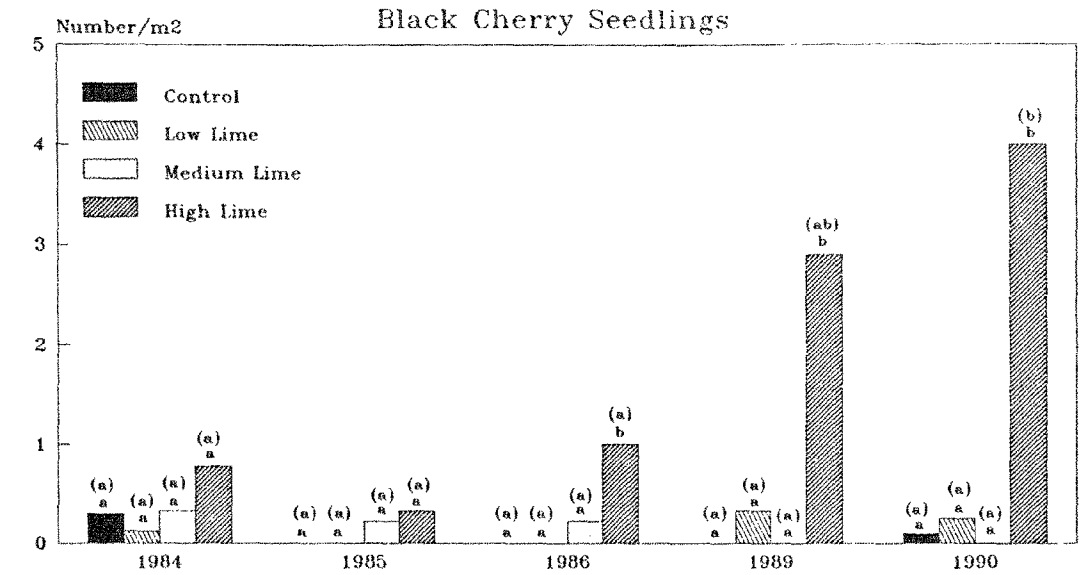

Figure 3. Trends in abundance of black cherry seedlings on the control (unlimed) and each limed plot from 1984 to 1990. Different letters above bars indicate a significant difference ($\alpha = 0.05$) within a given year. Different letters in parentheses above bars indicate a significant difference ($\alpha = 0.05$) between years for that plot.

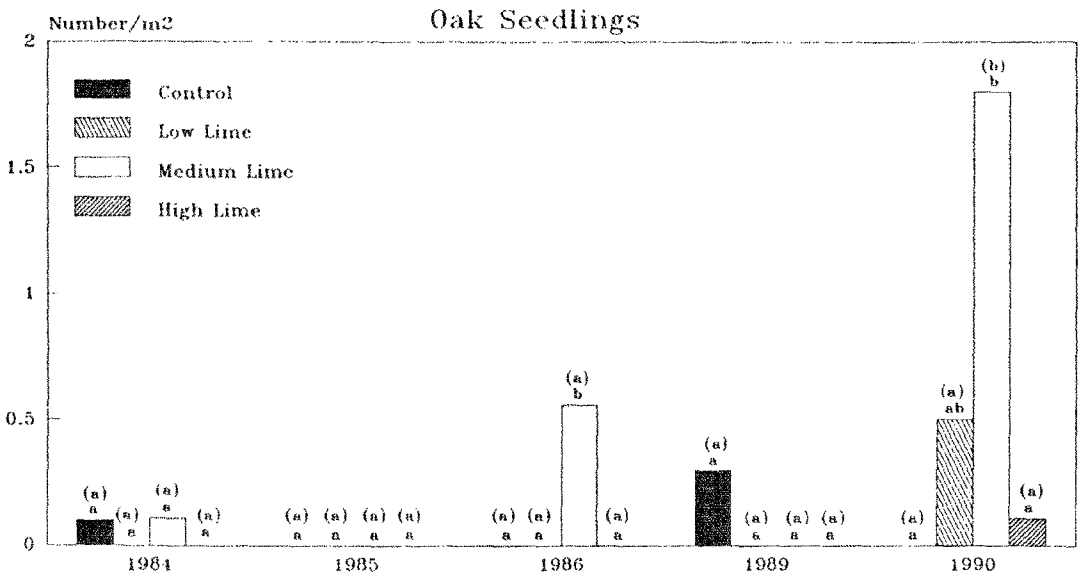

Figure 4. Trends in abundance of oak seedlings on the control (unlimed) and each limed plot from 1984 to 1990. Different letters above bars indicate a significant difference ($\alpha = 0.05$) within a given year. Different letters in parentheses above bars indicate a significant difference ($\alpha = 0.05$) between years for that plot.

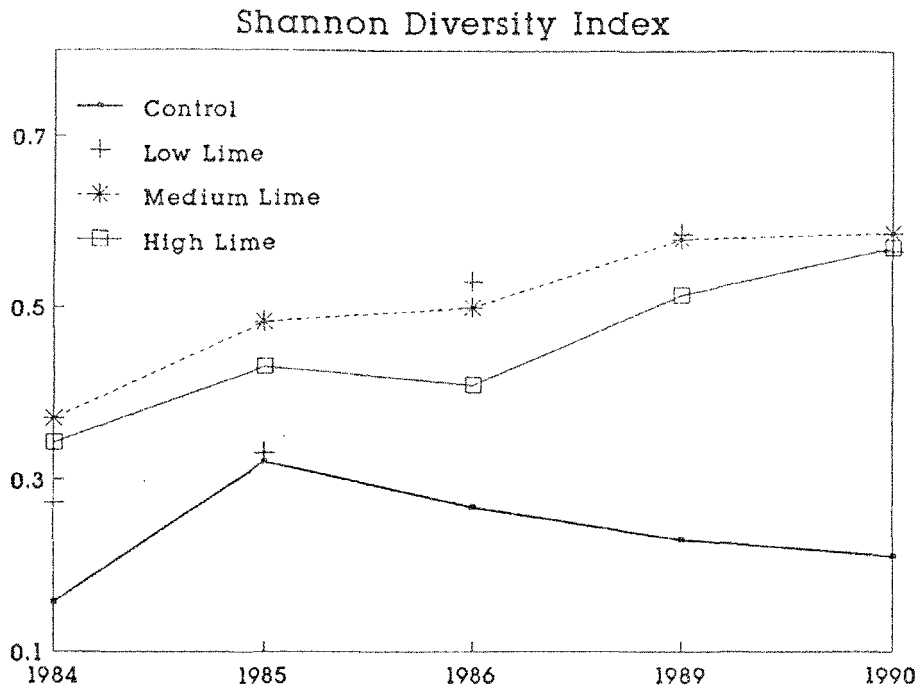

Figure 5. Trends in the Shannon Diversity Index on the control (unlimed) and each limed plot from 1984 to 1990.

floor and humus back to the above ground portions of the plants. Leaching of Ca by percolating soil water also probably contributed to the depletion of the Ca applied to the test plots. Unfortunately, long-term soil water measurements were not made to enable an assessment of the relative importance of these Ca sinks.

Forest floor herbaceous and woody vegetation appeared to respond positively to liming. Species diversity increased on the limed plots as did the numbers of some plant species. Black cherry, deer tongue grass and red oak seedlings all increased significantly in relation to the control plot after liming. Hay-scented fern declined significantly on the plot that received 5.9 tonnes/ha of lime. Other species that declined, but not significantly, were blueberry and red maple. Species increasing in number, but not significantly, were grass and blackberry with the highest numbers generally occurring on the plot that received the heaviest lime application. As mentioned previously, all of these changes occurred despite the presence of large numbers of deer and evidence of considerable deer browsing on the test plots.

SUMMARY

Lime application to several test plots on Hazelton-Dekalb soil located on Pea Vine Hill in southwestern Pennsylvania resulted in increased diversity of plants growing on the plots. Numbers of black cherry seedlings increased and hay-scented fern numbers decreased. Deer tongue grass also increased significantly on the limed plots. Increases in exchangeable Ca in the A horizon of this soil were still evident but approaching pre-treatment levels within five years after liming. Soil water sampling probably did not continue long enough after liming ($\leq$ 5 mo) to detect Ca leaching. In general, the plot receiving the heaviest lime application (11.1 tonnes/ha) showed the greatest overall vegetation response; however, even the plot receiving the lowest application (2.9 tonnes/ha) appeared to demonstrate positive response to liming. It would appear that moderate (5.9 tonnes/ha) or light (2.9 tonnes/ha) lime applications would be sufficient to produce favorable changes in rooting zone soil chemistry. To maintain such changes on this site, additional lime in these amounts would have to be applied at approximately four-year intervals.

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LONG-TERM IMPLICATIONS OF FOREST HARVESTING ON NUTRIENT CYCLING IN CENTRAL HARDWOOD FORESTS

James A. Lynch and Edward S. Corbett[1]

Abstract: Fourteen years of streamflow and water quality data from the Leading Ridge Experimental Watersheds in central Pennsylvania were analyzed to determine the long-term impacts of a commercial forest harvest on stream water chemistry and nutrient loss. Clearcutting 44.5 ha of an 104-ha watershed resulted in significant increases in nitrate and potassium concentrations and significant decreases in calcium, magnesium, potassium, and sodium concentrations the first-year following harvesting. The lower concentrations resulted from a dilution effect caused by an increase in stream discharge. Although statistically significant, the observed changes in ionic concentrations did not cause any serious deterioration in stream quality. The changes in most solute concentrations, which were most pronounced during the growing season, appeared to return to pre-cutting levels by the third-year. However, concentrations of most macro-nutrients have periodically exceeded pre-harvesting levels as late as eleven years after harvesting. Although nutrient export increased, the losses were quite small, restricted to the first year, and did not appear to be sufficient to affect site fertility.

INTRODUCTION

Changes in stream chemistry following timber harvesting were not considered a problem until the late 1960's following publication of results of a study on the Hubbard Brook Experimental Forest in New Hampshire (Bormann et al., 1968; Likens et al., 1970). Since then a number of studies have shown that changes in the concentration of a number of inorganic ions, all of which are important plant nutrients, do occur following timber harvesting (Aubertin and Patric, 1972; 1974; Corbett et al., 1978; Douglass and Swank, 1975; Federer et al., 1989; Hornbeck et al., 1987; Kochenderfer and Aubertin, 1974; Lynch and Corbett, 1990; Lynch et al., 1985; Lynch et al., 1975; Martin et al., 1984; Martin and Pierce, 1980; Reinhart, 1973; Swank and Douglass, 1975). Increases in nutrient concentrations following harvesting have been attributed to accelerated nutrient leaching due to exposure of the site to greater than normal amounts of heat, acceleration of the nitrification process, and increased leaching of nutrients due to the loss of uptake following plant removal (Likens et al., 1970). These studies have also shown that the changes are highly variable, very site

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specific, and generally related to the severity of the cut and the rate of revegetation of the cut-over area. The rate and degree of revegetation appear to control the longevity of increased nutrient concentrations.

Two things most forest harvesting-nutrient cycling studies have in common are that most have been restricted largely to nutrient concentrations and that most have been relatively short-term studies, lasting three to five years. Since timber harvesting, particularly clearcutting, substantially increases stream discharge (Hibbert, 1967; Lynch et al., 1972), evaluation of its impact on nutrient cycling must take this into consideration. For example, increases in nitrate concentrations that generally following forest harvesting are actually greater when dilution effects from increased flow are considered. Conversely, decreased concentrations of calcium and other ions, which are often observed and caused by a dilution effect attributed to increased flow, may actually represent an increase in export if the concentration-dilution effects are not linear. Consequently, the most effective way to evaluate the effects of forest management activities on nutrient cycling is to express the changes in both concentration (mg/L) and export units (kg/ha), the latter of which considers both concentration and discharge interactions.

The longevity of forest-management-nutrient-cycling studies are of particular interest since forest management activities can impact both the hydrologic regime and plant communities for tens of years. Consequently, the common practice of terminating a study three to five years after forest harvesting might be premature with regards to evaluating its total impact on nutrient cycling. Long-term changes in nutrient cycling can result from alteration of weathering processes, disruption of hydrologic flow paths, failure of water control devices, inadequate regeneration, and site disturbance due to unauthorized entry, among other things. Whenever any of these conditions prevail, the overall impact of forest harvesting on nutrient cycling and stream quality might persist for 10 to 20 years or more. Such long-term impacts have been assessed on the Hubbard Brook Experimental Forest in New Hampshire where impacts of forest harvesting on hydrologic and nutrient cycles were observed to last 10 years (Hornbeck et al., 1987). A study of long-term depletion of nutrients from six forests in eastern United States suggests that forest harvesting and increased leaching stimulated by atmospheric deposition could remove as much as 50% of the available calcium in only 120 years (Federer et al., 1989). However, the authors caution that additional research is needed because the uncertainties in the estimates are large.

The purpose of this paper is to report on short- and long-term changes in nutrient export from a 44.5-ha commercial clearcut in central Pennsylvania. The impacts of this commercial clearcut on nutrient concentrations, turbidity, sediment levels, and stream temperature, and the importance of these changes with respect to meeting Pennsylvania's water quality goals and EPA's anti-degradation policy of the Water Quality Act of 1987 were published earlier by Lynch and Corbett (1990).

SITE DESCRIPTION

This study was carried out on the Leading Ridge Experimental Watershed Research Unit located in the Ridge and Valley Province of central Pennsylvania. This unit consists of three adjacent watersheds that are 123 (LR1), 104 (LR3), and 43 (LR2) ha in area. These watersheds were selected to be representative of approximately 4 million ha of forestland, much of which lies within established municipal watershed boundaries.

Watersheds within this research unit are equipped with modified broad-crested Trenton weirs with a sharp-crested, 90-degree, V- notch in the center to measure stream discharge. Streamflow is monitored using FW-1 water level recorders and a seven-day chart cycle. All watersheds have southeastern aspects and range in elevation from 244 to 442 m. Mean slopes on the watersheds vary from 12 to 17 percent, with maximum slopes approaching 50 percent. Most of the soils on the watersheds are residual, having developed in place through the weathering of underlying strata. Soils on the lower slopes are primarily silt loams and stony loams that are well drained and have high moisture holding capacity. The middle and upper slopes include well drained cobbly loams and stony loams with high moisture holding capacity. The ridge top is composed of cobbly and sandy loams. The average depth of the soil mantle is <2 m. Eight soil series are found on the watersheds. They include four Ultisols--Andover, Buchanan, Clymer, and Laidig--and four Inceptisols--Berks, Dekalb, Hazleton, and Weikert. Three major geologic formations underlie the watersheds. Most of the lower slope is underlain by Rose Hill shale. Castanea sandstone underlies the upper portion of the lower slope, middle slope, and most of the upper slope. Tuscarora quartzite underlies the ridge top.

Repeated timber harvesting plus the effects of fire and disease during the 1800's have resulted in the present-day, uneven-aged forest. Changes occur in the vegetative community from the valley to the ridge top. The ridge top and upper slope consists of a community of red oak (*Quercus rubra* Ashe.), chestnut oak (*Quercus prinus* L.), black oak (*Quercus velutina* Lamb.) and pitch pine (*Pinus rigida* Mill.). The lower slope and bottomland species include white pine (*Pinus strobus* L.), eastern hemlock (*Tsuga canadensis* (L.) Carr.), black birch (*Betula lenta* L.), red, black, and white oak (*Quercus alba* L.), and tulip poplar (*Liriodendron tulipfera* L.). The dominant understory include black gum (*Nyssa sylvatica* Marsh.), red maple (*Acer rubrum* L.), flowering dogwood (*Cornus florida* L.), and witch hazel (*Hammamelis virginiana* L.).

The climate of central Pennsylvania is of the humid, continental type. Although frontal storms are the most common source of precipitation, convectional showers are prevalent throughout the summer months. Monthly distribution of precipitation is such that approximately 25% more is received during the growing season (May-October) than during the dormant season (November-April). Monthly precipitation ranges from 11.66 cm in June to 5.92 cm in December. Annual precipitation averages approximately 112 cm.

The streams draining each basin develop from two perennial, first-order channels and several intermittent channels, all of which lie below the boundary of the upper slope unit. Runoff

takes place primarily as subsurface flow, rather than surface runoff. Monthly stream discharge, reported as a percentage of the total annual streamflow, increases steadily from October to April, after which it declines throughout the growing season. Historically, about 40% of the annual precipitation occurs as streamflow.

RESEARCH APPROACH

The paired watershed method was used to evaluate changes in nutrient export and stream discharge following commercial harvesting on these central Pennsylvania watersheds. Leading Ridge Watershed One (LR1) was used as the undisturbed control watershed. Leading Ridge Watershed Three (LR3) was selected for the commercial clearcut. Changes in water quantity were based on linear regression analysis using 17 years of pre-harvest stream discharge measurements from both the treated and control watersheds. The annual and seasonal regression equations and measured stream discharge from the control watershed were used to predict stream discharge from the treated watershed assuming it had not been clearcut. The difference between the predicted discharge and the measured discharge on the harvested watershed represent the change in streamflow as a response to harvesting. Statistical significance of differences between predicted and measured values was determined using standard t-test techniques.

Changes in stream chemistry were based on chemical analyses of weekly stream water samples collected during a three-year calibration period (October, 1973 to September, 1976) and an 11-year post-harvest period. Statistical significance of differences between the control and harvested watersheds before and after harvesting were determined using analysis of variance techniques.

The entire timber sale was under the direction of the Pennsylvania Department of Environmental Resources, Bureau of Forestry, Rothrock District Forest. Harvesting, which was conducted following established Bureau policies, commenced on October 1, 1976 and ended on May 3, 1977; 44.5 ha of the 104-ha watershed were harvested. Rubber-tired tractor skidders were used to move the logs to the log landings. It was estimated that approximately 6% of the area cut was disturbed as a result of skidding activities. All logs were removed via an existing forest road that cut diagonally across the watershed from the ridge to the lower slope. The road was approximately 610 m in length.

In order to control nonpoint pollution during and following logging, the Best Management Practice (BMP) approach was used on this commercial harvesting. These BMP's included:

1. A protective buffer strip 100 feet wide was left on each side of all perennial streams. Logging of selective trees was permitted in the buffer zone.

2. The timber sale was divided into four blocks. Harvesting within a block had to be completed before cutting commenced in another block.

3. Skidding over perennial streams, except over approved culverts, was prohibited.

4. Slash was not permitted within 25 feet of any perennial or intermittent stream.

5. Logging activities were closely monitored by a forester from the Bureau of Forestry, especially during wet periods.

6. Main skid trails, logging roads, and log landings were carefully laid out by a forester from the Bureau.

7. Logging was prohibited during excessively wet periods.

8. Upon retirement, culverts were removed and water bars and other drainage devices installed on all logging roads and major skid trails. Logging roads were also graded to pre-logging conditions and gated.

9. Filtration strips between road surfaces and stream channels were utilized.

10. Road grades were limited to a maximum of 10 percent and a minimum of least 3 percent. Grades of 15 to 20 percent were permitted for short distances.

11. A performance bond was required prior to logging. This bond was set at 25% of the timber value.

12. Yearly inspections of the harvested area were conducted for five years.

Routine stream quality samples were collected weekly with some sampling during stormflow periods to assure that all discharge classes were represented. All samples were analyzed for pH, sulfate, calcium, magnesium, potassium, sodium, nitrate, and alkalinity ($CaCO_3$) in the water quality lab of the Environmental Resources Research Institute at The Pennsylvania State University. All laboratory analyses followed methodology recommended by the Environmental Protection Agency (EPA, 1983).

Each water sample taken over the study period was matched with the hydrologic status of the stream as determined from the hydrograph. The hydrologic status and ionic concentrations were used to develop stream discharge/nutrient concentration relationships for each ion. These regression relationships were used to estimate ionic concentrations, which were then used in conjunction with the discharge data to estimate export of each ion from the watersheds. Daily export estimates were calculated for both watersheds and summarized by annual and seasonal periods. Statistical comparisons of pre- versus post-harvest concentration and stream discharge data using standard analysis of variance techniques were used to

evaluate the significance of the commercial harvest on nutrient export from this experimental watershed.

RESULTS AND DISCUSSION

Water Quantity

Water yield increases resulting from the commercial clearcut are given in Table 1. The first-year increase was 13.7 area-cm, all of which occurred during the growing season. The dormant season showed a non-significant decrease of 2.8 area-cm. The first-year increase is equivalent to 32 cm on an area-cut basis. The annual yield increase was sharply lower the second-year following harvesting amounting to only 3.4 cm. The second-year decrease was greater than generally reported for similar studies and was attributed to the rapid regrowth on the cut-over area that increased evapotranspirational losses and an unequal distribution of rainfall during the summer and early fall months. Rainfall was below normal for four of the six growing season months even though growing season precipitation was above normal. The magnitude of water yield increases is influenced strongly by the amount and distribution of both seasonal and annual precipitation (Lynch et al., 1972). The decreasing trend in water yield increases continued through the third growing season. By the fourth growing season, water yield increases were statistically unaffected by harvesting.

Table 1.--Annual and seasonal water yield increases following the commercial clearcutting of 44.5 ha on Leading Ridge Watershed Three.

Water Year (May-April)	Water Yield Change		
	Growing Season[1]	Dormant Season[2]	Annual
1977	+14.55*	- 2.85	+13.72*
1978	+ 2.74*	+ 0.43	+ 3.43*
1979	+ 1.40*	- 1.04*	+ 1.78*
1980	+ 0.13	+ 6.04*	+ 5.08*
1981	- 3.31	- 1.12	- 3.66
1982	+ 0.06	- 2.02	- 2.65
1983	+ 0.79	+ 0.13	+ 1.44
1984	+ 0.22	+ 0.62	- 0.80
1985	+ 0.30	+ 0.72	+ 2.23

* Significant at 0.05 level
[1] May through October
[2] November through April

Stream Chemistry

Stream chemistry concentration data for the clearcut and control watersheds prior to and following harvesting are presented in Table 2. Except for magnesium and sulfate, stream chemistry during the three-year calibration period was very similar on both watersheds. Following harvesting, the concentrations of most parameters underwent significant change. Calcium, alkalinity ($CaCO_3$), magnesium, and sodium concentrations decreased the first- year as did specific conductance and pH; nitrate and potassium concentrations increased (Table 2). The reductions were attributed to dilution caused by an increase in stream discharge. Increases in nitrate and potassium concentrations were attributed to an increase in residue decomposition and a reduction in the uptake of these ions due to harvesting and a corresponding increase in leaching rates. The combined effects of dilution and increased nitrate leaching resulted in a decrease in pH the first year. As expected, changes in stream chemistry were most evident during the growing season.

A pattern similar to the first-year changes was observed the second-year after harvesting, although the magnitude of the changes were not as great. By the third-year, water yield increases were sharply reduced, thereby eliminating the effects of dilution on mean annual ionic concentrations (Table 2). Nitrate and magnesium concentrations were the only ions that were significantly elevated above pre-harvesting concentrations, although the increases were quite small. Essentially, stream chemistry on the clearcut watershed appeared to return to pre-cutting levels by the end of the third-year. However, this apparent return to pre- cutting levels was short-lived as a general increase in the concentrations of most parameters was observed the fifth year (Table 2). Associated with the increased concentrations of most of the macro-nutrients was an increase in alkalinity, pH, and specific conductance. Such increases were also noted the seventh and ninth years following harvesting but not in the tenth and eleventh years; nor were all parameters significantly elevated during the sixth and eighth years. This year to year variability in mean annual concentrations appeared to be related to differences in the amount and distribution of precipitation, particularly during the growing seasons, and its subsequent impact on ionic concentrations when compared to observed values during the three-year calibration period. Differences in climatic patterns and subsequent solute concentrations between pre- and post-harvesting periods makes it difficult to assign statistical significance to observed differences in stream quality. It should be noted that the three-year calibration period on this watershed is relatively long when compared to similar studies, but of insufficient length to permit the development of seasonal and annual predictive equations.

Significant increases in the concentrations of macro-nutrients and subsequent increases in alkalinity, pH, and specific conductance during the fifth and following years may have resulted from an increase in the weathering of parent materials on the watershed. This is supported by the fact that fluctuations in calcium, magnesium, and sodium were very similar and that each is a by-product of weathering. Temporal trends in stream water potassium, nitrate, and calcium concentrations for the control and harvested watersheds for both the calibration and post-harvesting periods are shown in Figures 1, 2, and 3.

Table 2. Mean annual nutrient concentrations, alkalinity, pH, and specific conductance of streamwater draining the commercial clearcut (LR3) and control (LR1) watersheds before and following harvesting.

	Post-Harvest Period[1]															
	Pre-Harvest[3]		First Year		Second Year		Third Year		Fifth Year		Seventh Year		Ninth Year		Eleventh Year	
Parameter[2]	LR1	LR3	LR1	LR3	LR1	LR3	LR1	LR3	LR1	LR3	LR1	LR3	LR1	LR3	LR1	LR3
Specific Conductance	50.9	48.1	79.6	34.8*	59.8	42.7*	36.9	32.1	45.9	48.9*	53.3	68.6*	54.2	63.6*	37.4	36.8
pH	6.89	6.91	6.63	6.52*	6.86	6.85	6.64	6.72	6.50	6.72*	6.72	6.98*	6.58	7.00*	6.79	7.01*
Alkalinity	14.6	15.3	15.5	5.5*	19.3	11.0*	6.4	6.7	10.4	14.4*	15.6	26.2*	16.9	23.2*	9.5	10.7
Sulfate	8.39	6.75	7.87	5.55	7.95	5.82	7.16	5.02	7.87	5.83	7.95	7.80*	7.20	6.70*	8.47	6.44
Nitrate	0.03	0.04	0.11	0.40*	0.05	0.28*	0.05	0.14*	0.05	0.12*	0.10	0.10	0.05	0.08*	0.11	0.09*
Calcium	4.43	4.45	5.56	2.49*	6.22	3.58*	2.80	2.50	3.65	4.53	5.52	9.68*	5.87	9.00*	3.37	3.96
Magnesium	2.15	1.72	2.14	1.27*	2.47	1.67*	1.40	1.14*	1.85	1.67*	2.32	2.24*	2.34	2.18*	1.93	1.41
Sodium	0.98	1.02	1.00	0.88*	1.09	0.99*	0.77	0.82	0.85	0.96	1.00	1.22*	1.04	1.24*	0.87	0.80*
Potassium	1.00	0.99	0.93	1.05*	1.01	1.22*	0.96	1.01	0.98	1.07*	0.99	1.01	0.97	1.08*	1.00	1.00

* Significant at 0.5 level

[1] May 1 through April 30 water year

[2] All values except pH and specific conductance are given in mg/L. Specific conductance is given as μS/cm.

[3] October 15, 1973 through September 30, 1976

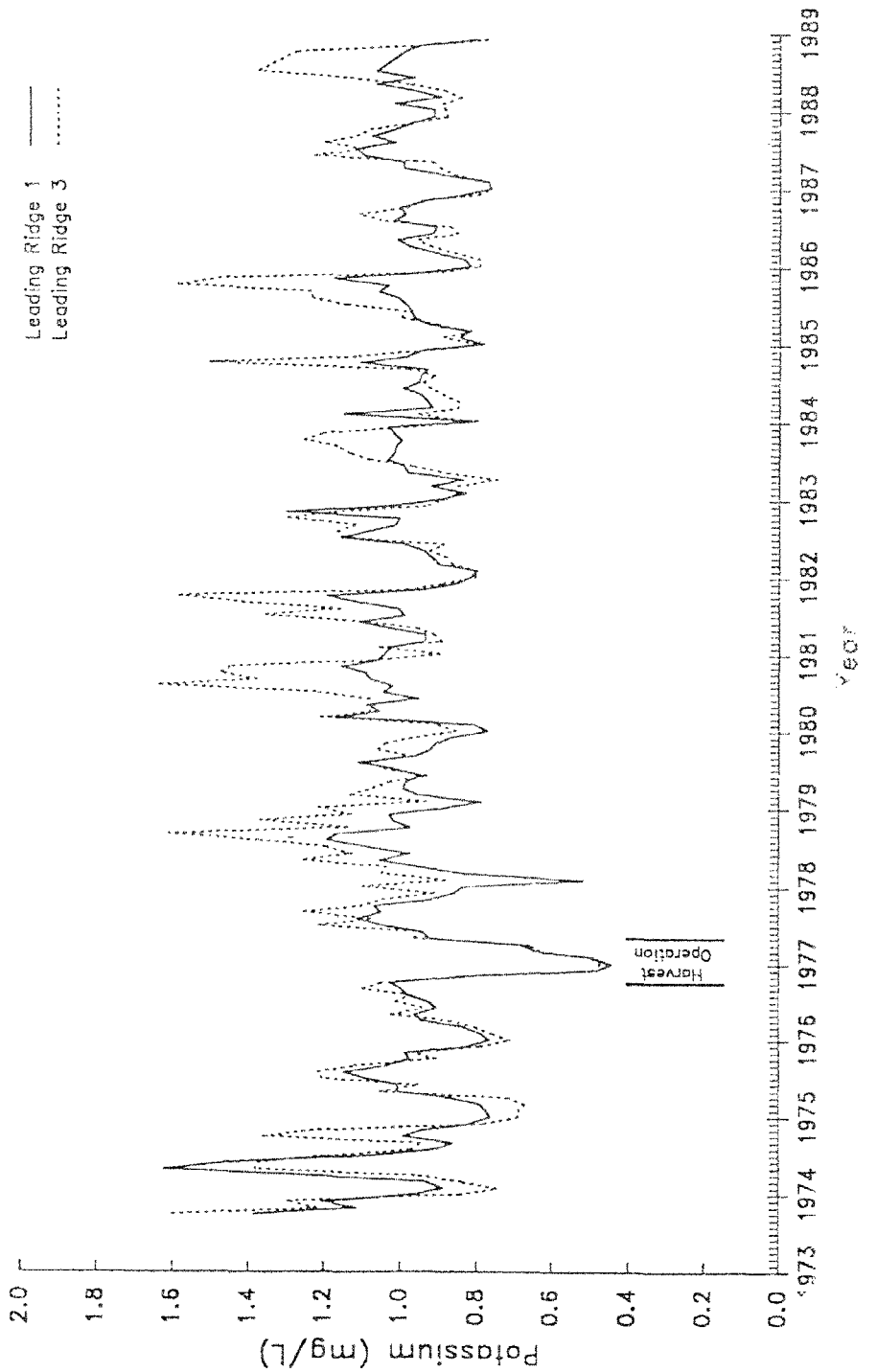

Figure 1. Trends in stream water potassium concentrations for the control (LR1) and harvested (LR3) watersheds before (1973-1976), during (Oct. 1976-May 1977) and after harvesting.

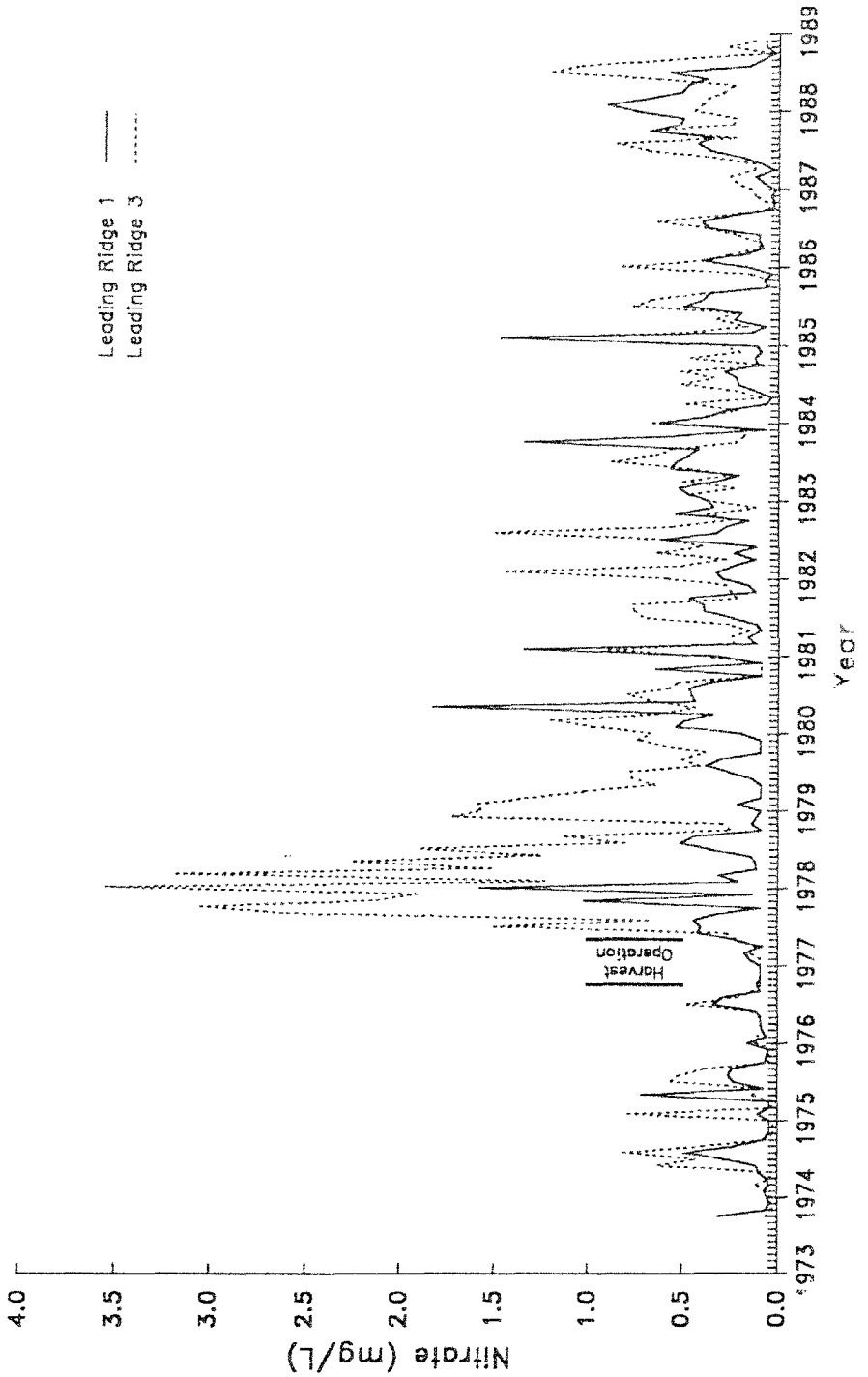

Figure 2. Trends in stream water nitrate concentrations for the control (LR1) and harvested (LR3) watersheds before (1973-1976), during (Oct. 1976-May 1977) and after harvesting.

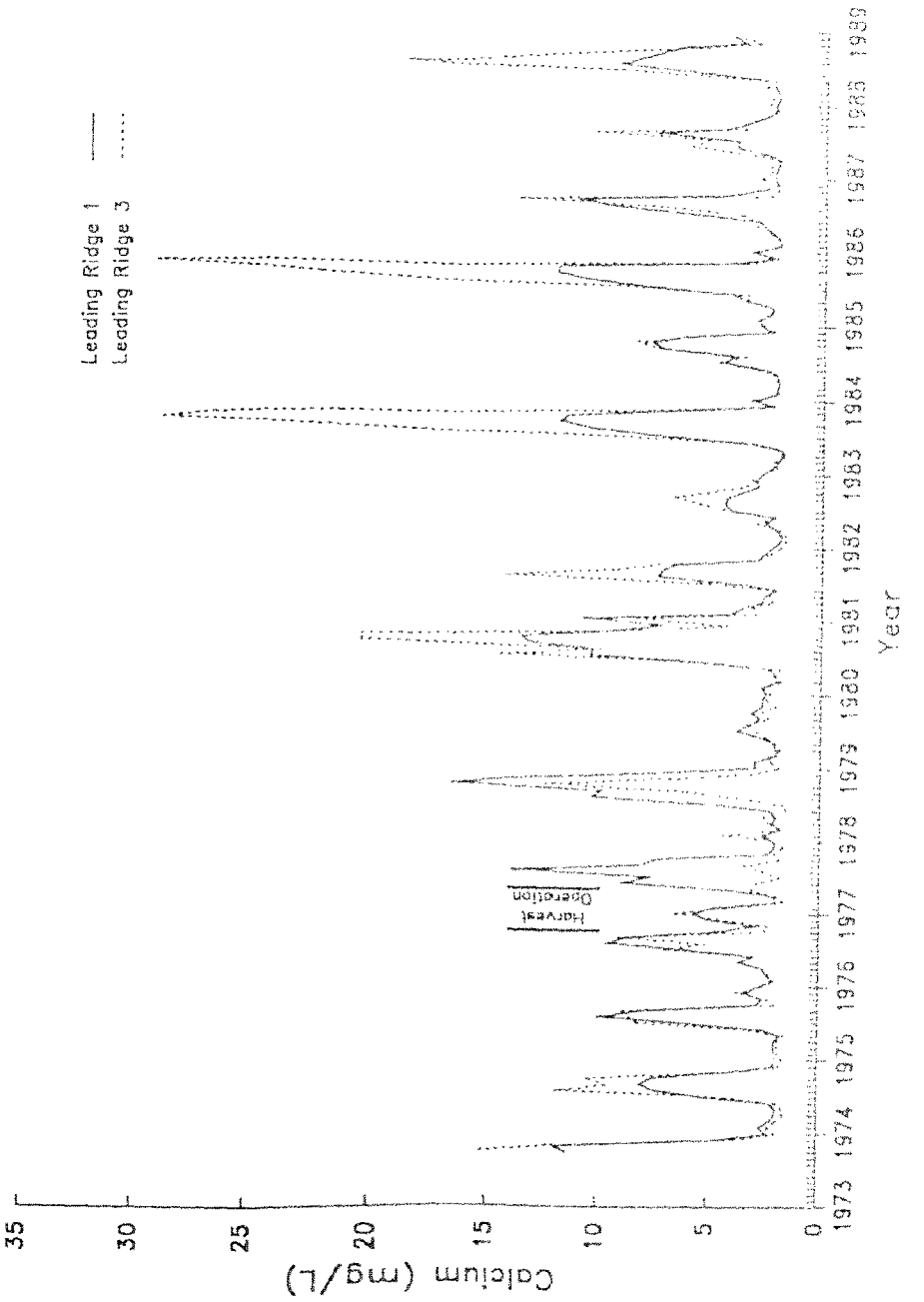

Figure 3. Trends in stream water calcium concentrations for the control (LR1) and harvested (LR3) watersheds before (1973-1976), during (Oct. 1976-May 1977), and after harvesting.

Nutrient Export

Clearcutting did increase the export of most nutrients from the watershed; however, the increases were restricted almost entirely to the first-year growing season (Tables 3 and 4). Calcium export increased from 12.1 kg/ha during the calibration period to 16.1 kg/ha the first-year after harvesting, but was only slightly higher the second-year. Almost all of the increased calcium export occurred during the growing season (Table 4) and was largely due to increases in stream discharge (Table 1) that were greatest the first-year growing season and decreased rapidly thereafter. Calcium export relationships between the clearcut and control watersheds during the remaining nine post-harvest years were essentially the same as those observed during the calibration period (Table 3, Figure 4) despite the fact that calcium concentrations were significantly higher during some of the latter post-harvest years (Table 2, Figure 3). Increased calcium concentrations during the fifth, seventh, and ninth years occurred during the growing season under low-flow conditions and thus accounted for only a small percentage of the total annual export. Over the 14-year study period, growing season calcium export accounted for an average of 30% of the annual calcium export on the control watershed and 32% on the clearcut watershed (Tables 3 and 4).

Magnesium and sodium export also increased the first-year (Table 3) with most of the increase occurring during the growing season (Table 4). Since magnesium and sodium concentrations actually decreased the first-year, the increased export resulted from an increase in stream discharge. Like calcium, magnesium and sodium export values returned to pre-harvesting levels by the second-year and have remained unchanged during the last nine years of the post- harvest period despite significant increases in sodium and magnesium concentrations during the seventh and ninth years following harvesting. As was the case with calcium, these increased concentrations occurred during low flow periods and consequently contributed little to total annual export. Although an increase in growing season export might be expected, the increased concentrations have been restricted largely to a one or two-month period in the latter part of the growing season under generally the lowest flow conditions. Since the growing season export data presented in Table 4 represent a six-month summary period (May 1 through October 31), small increases in concentrations for one or two months, especially the drier months of August through October, would have little effect on the overall growing season export.

Clearcutting increased both potassium (Figure 1) and nitrate (Figure 2) concentrations the first-year after harvesting. These increases, along with the increased stream discharge, resulted in a significant increase in potassium and nitrate export (Table 3), the bulk of which occurred during the growing season (Table 4). Like the other nutrients, potassium and nitrate export returned to pre-cutting levels by the second-year and have remained near pre-harvesting levels throughout the remainder of the post- harvest period (Figures 5 and 6). Again, slight increases in potassium and nitrate concentrations, primarily during the growing seasons, have been insufficient to significantly increase annual or seasonal export of these ions.

Table 3. Annual export (kg/ha) of important plant nutrients from the commercial clearcut (LR3) and control (LR1) watersheds before and following harvesting.

			Post-Harvest Period[1]													
	Pre-Harvest[2]		First Year		Second Year		Third Year		Fifth Year		Seventh Year		Ninth Year		Eleventh Year	
Parameter	LR1	LR3	LR1	LR3	LR1	LR3	LR1	LR3	LR1	LR3	LR1	LR3	LR1	LR3	LR1	LR3
Calcium	11.2	12.1	12.1	16.1*	11.0	12.5	14.5	15.9	7.8	8.5	10.9	11.9	9.3	10.6	9.7	9.9
Magnesium	7.3	6.3	8.1	8.5*	7.3	6.3	9.8	8.4	4.8	4.1	7.1	6.0	6.0	5.3	6.2	5.1
Potassium	5.0	5.1	5.7	7.2*	5.2	5.4	6.9	7.1	3.1	3.3	4.9	5.0	4.0	4.4	4.0	4.0
Sodium	3.3	3.7	3.5	5.0*	3.2	3.7	4.3	4.9	2.2	2.4	3.1	3.5	2.7	3.1	2.8	3.0
Nitrate	0.18	0.34	0.22	0.50*	0.21	0.41	0.26	0.54	0.11	0.24	0.18	0.34	0.15	0.31	0.14	0.25

* Significant at 0.5 level
[1] May 1 through April 30 water year
[2] Mean annual export for 1974 through 1976

Table 4. Growing season export (kg/ha) of important plant nutrients from the commercial clearcut (LR3) and control (LR1) watersheds before and following harvesting.

			Post-Harvest Period[1]													
	Pre-Harvest[2]		First Year		Second Year		Third Year		Fifth Year		Seventh Year		Ninth Year		Eleventh Year	
Parameter	LR1	LR3	LR1	LR3	LR1	LR3	LR1	LR3	LR1	LR3	LR1	LR3	LR1	LR3	LR1	LR3
Calcium	4.0	4.5	2.8	5.8*	4.1	5.3*	4.8	5.2	3.3	2.7	2.5	2.7	1.6	1.7	2.7	2.6
Magnesium	2.5	2.2	1.7	3.0*	2.7	2.5	3.1	2.7	1.9	1.2	1.4	1.2	0.7	0.6	1.5	1.2
Potassium	1.7	1.8	1.1	2.5*	1.9	2.2	2.0	2.2	1.2	0.9	0.9	0.9	0.3	0.3	0.9	0.9
Sodium	1.1	1.3	0.7	1.8*	1.1	1.5	1.4	1.6	0.9	0.7	0.6	0.7	0.3	0.3	0.7	0.7
Nitrate	0.06	0.12	0.04	0.17*	0.08	0.19	0.07	0.15	0.04	0.05	0.03	0.06	0.01	0.02	0.03	0.04

* Significant at 0.5 level
[1] May 1 through October 31
[2] Mean annual export for 1974 through 1976

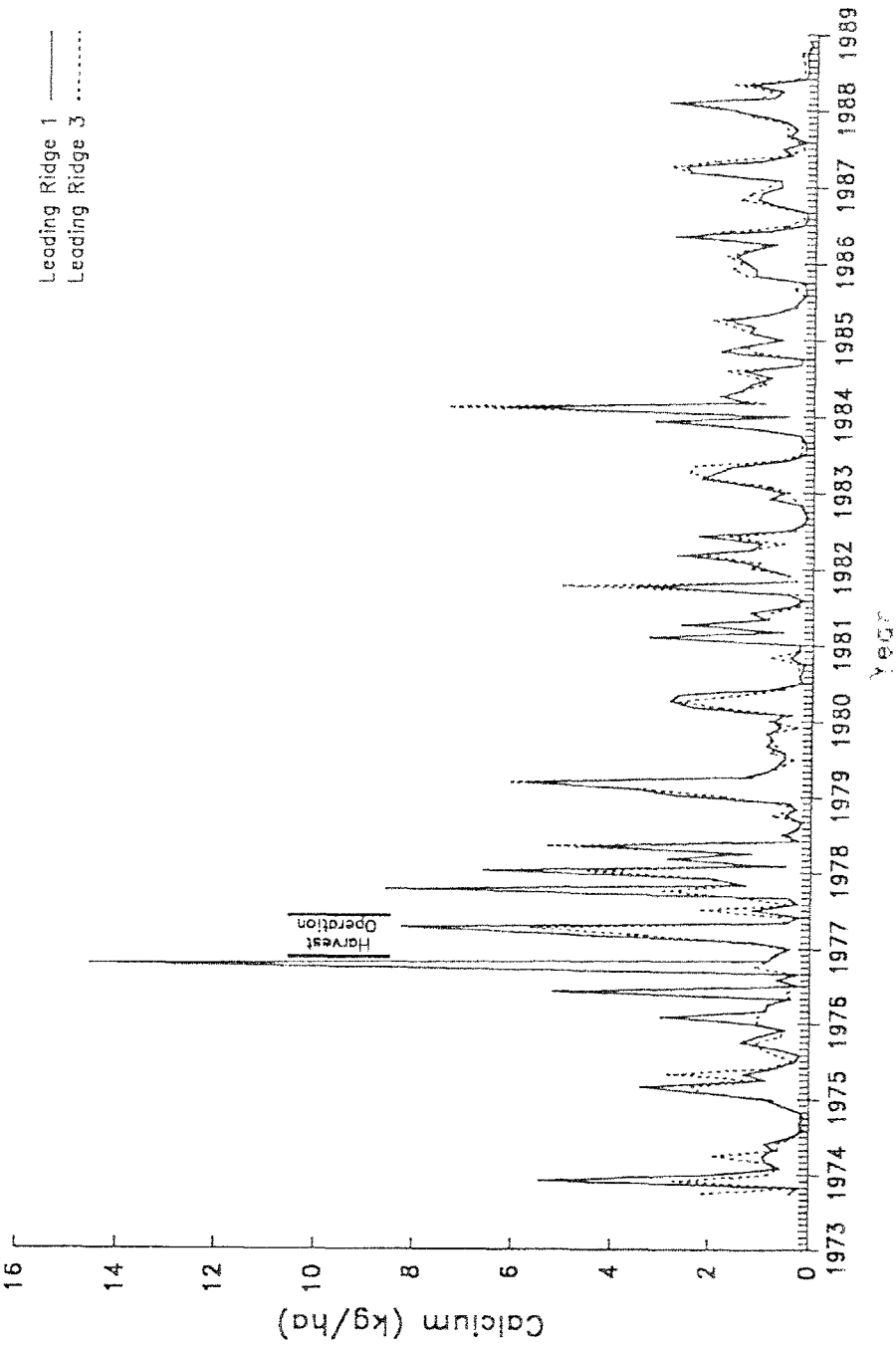

Figure 4. Trends in calcium export from the control (LR1) and harvested (LR3) watersheds before (1973-1976), during (Oct. 1976-May 1977), and after harvesting.

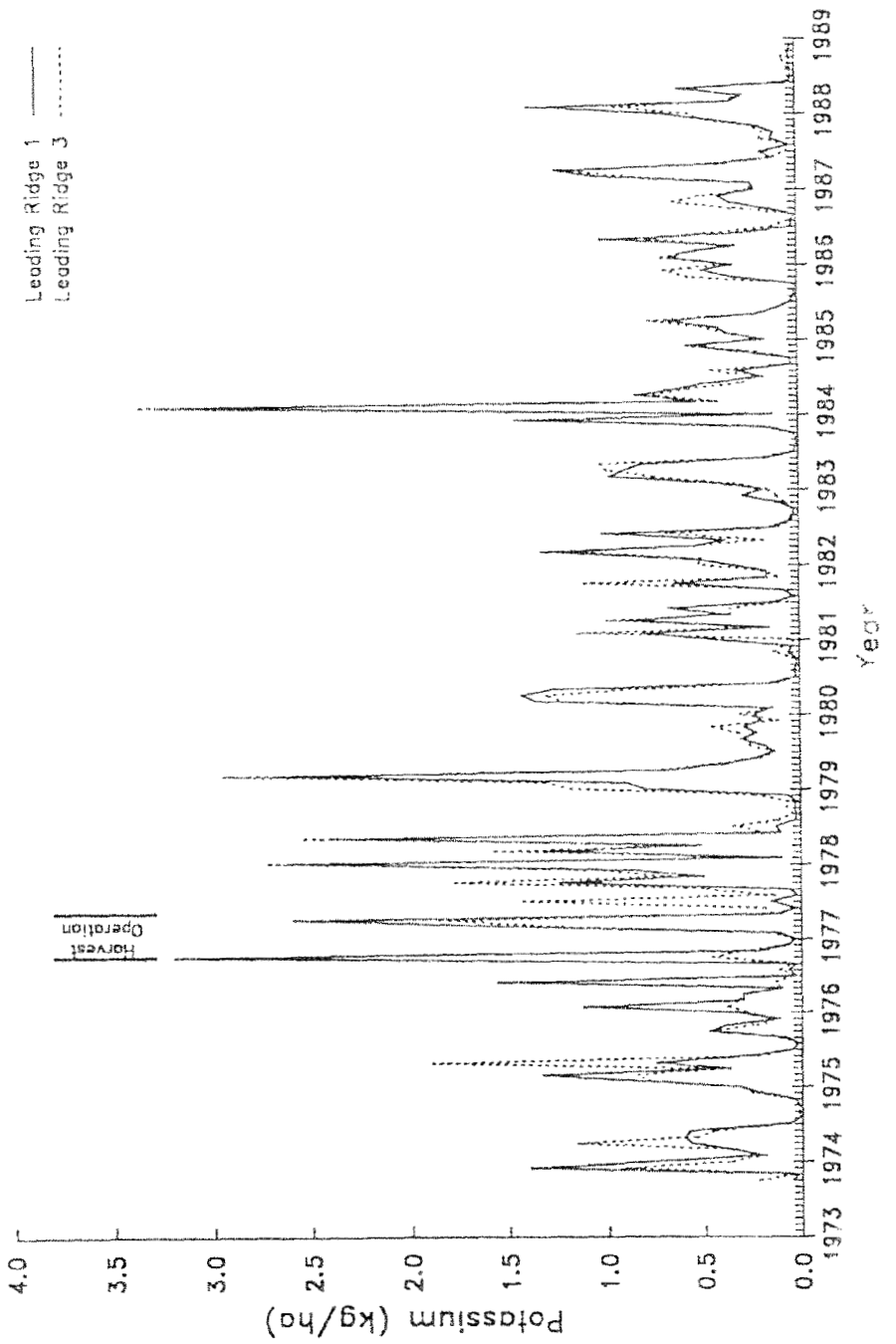

Figure 5. Trends in potassium export from the control (LR1) and harvested (LR3) watersheds before (1973-1976), during (Oct. 1976-May 1977), and after harvesting.

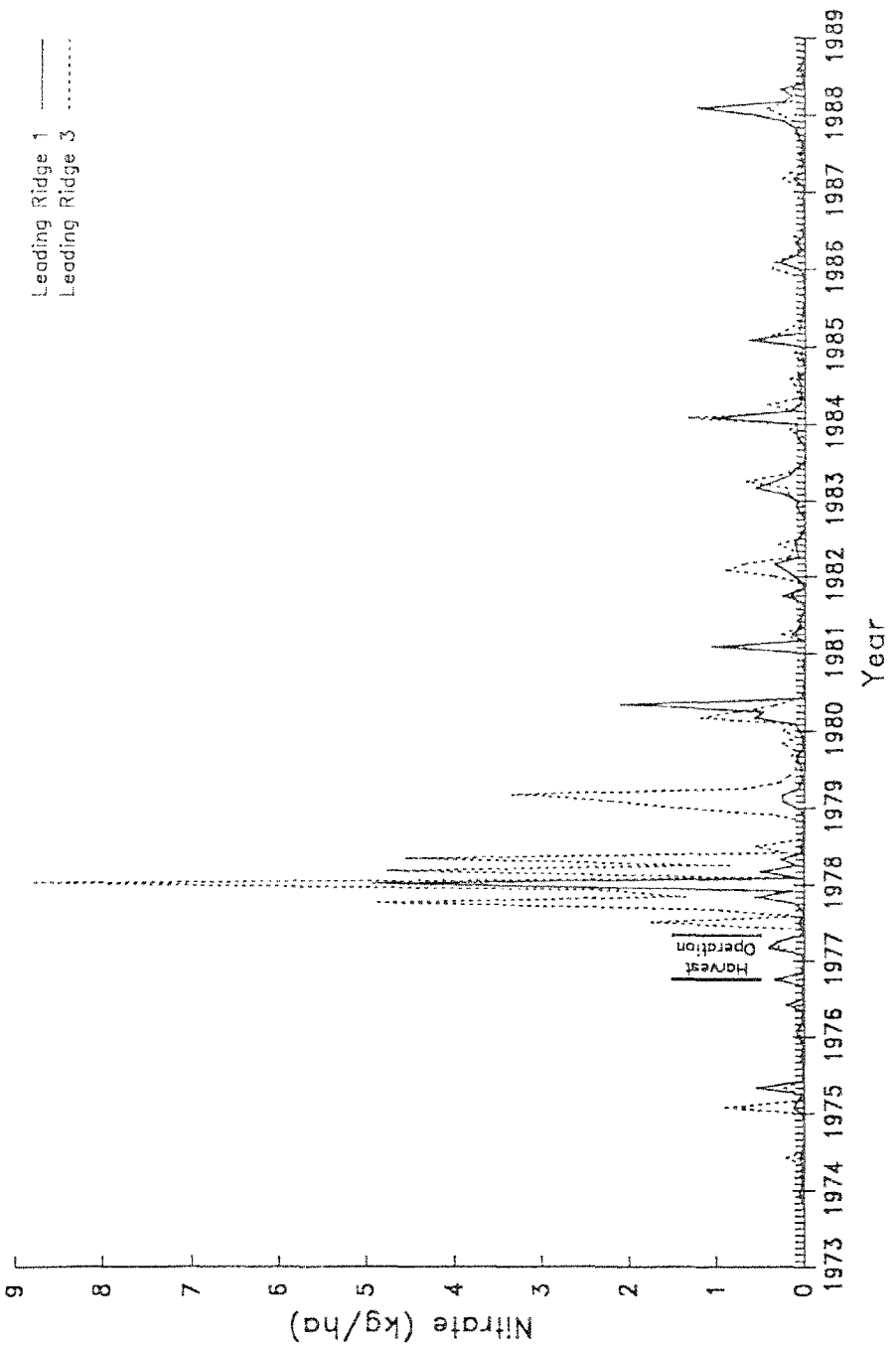

Figure 6. Trends in nitrate export form the control (LR1) and harvested (LR3) watersheds before (1973-1976), during (Oct. 1976-May 1977), and after harvesting.

SUMMARY

The observed changes in stream water chemistry do not represent a signification degradation of stream quality nor do they indicate a significant deterioration of site quality and fertility. Rapid recovery to pre-harvest levels and subsequent minimal nutrient loss was due largely to rapid revegetation of the cut- over area. Increases in nitrate concentrations were quite small and well below drinking water standards. Nevertheless, such small increases may violate EPA's anti-degradation policy of the Water Quality Act of 1987. This policy requires that surface water quality that exceed minimum state water quality standards be maintained at their existing water quality levels. EPA has been most stringent in applying this policy where pristine waters, such as those draining forested watersheds, are involved. Overall, it appears that the "Best Management Practices" developed by the Pennsylvania Bureau of Forestry were very effective in controlling nutrient loss from this silvicultural operation.

The results of this study clearly indicate the need for long-term forest management/nutrient export studies. Although not a component of this project, accurate estimates of total nutrient pools and nutrient losses through harvest removal under various forest harvesting practices should be a part of such studies in order to determine the significance of increased leaching with respect to long-term site fertility. Excessive leaching of calcium and other plant nutrients following harvesting have been suggested as a possible limiting factor in growth in intensively managed northeastern forests (Federer et al., 1989). However, the authors acknowledge that the uncertainties in their estimates are large and that further research is needed.

ACKNOWLEDGMENT

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ESTIMATING TIMBER SUPPLY FROM PRIVATE FORESTS

Donald F. Dennis[1]

Abstract: Nonindustrial private landowners, who hold a majority of the Nation's commercial forests, own land primarily for reasons other than timber production. The multiple objective and dynamic nature of private ownership make planning and estimation of timber availability from this sector extremely difficult.

Insight into the determinants of timber supply from private forests is provided through development of both theoretical and empirical models of harvest behavior. Tobit and probit models were used to analyze cross-sectional, and pooled time-series and cross-sectional data, respectively. The results highlight the influence of forest characteristics and landowner affluence on the harvest decision. Decomposition of the Tobit coefficients indicates that changes in timber supply are expected to result primarily from changes in the number of acres from which timber is offered for sale and to a much lesser extent from changes in per-acre harvesting intensity.

INTRODUCTION

Almost half of the Nation's hardwoods, approximately 140 million cubic feet of growing stock and 334 million board feet of sawtimber, are contained in the Northeast and North Central regions (USDA Forest Service 1988). For several decades growth has outpaced removals, leading to a doubling of sawtimber volumes since 1952. Increased use of this vast resource could stimulate the regional economy, improve our trade balance, and breathe economic life into rural communities.

An immense population, with a growing appetite for wood products, lives within, or in close proximity to, the region. Demand projections indicate substantial increases in roundwood consumption, well into the future (USDA Forest Service 1982).

There is great potential for increased utilization of the region's hardwoods. Concerns over tropical deforestation and a more competitive dollar may focus attention on eastern hardwoods as a strategic resource in supplying world markets. New and existing technologies for producing composite products from low-quality hardwoods offer numerous opportunities. The political viability of additional nuclear reactors and environmental concerns over increased coal use make wood an attractive alternate energy resource. This is particularly true in the

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energy-dependent Northeast. Traditional sawmilling and manufacturing of specialty products will remain important and are particularly attractive to localities seeking to enhance their economic fortunes.

There is a seemingly abundant resource, sufficient final demand, and some arguably good reasons to use this resource. However, there is apprehension over availability. Seventy percent of the region's hardwood resource occurs on nonindustrial private forests (USDA Forest Service 1988). An additional 21 percent occurs on public lands, where intense recreation pressures often limit timber harvesting. Since forest industry holds only 9 percent of the hardwood growing stock, the key to increased utilization rests with the nonindustrial private landowner.

Surveys reveal that most nonindustrial owners hold land primarily for reasons other than timber production (Widmann and Birch 1988, Birch and Dennis 1980). The multiple objective and dynamic nature of private ownership leads to complex and difficult-to-predict supply responses.

Planning and policy development are further hampered by a lack of knowledge of how trends in demographic patterns of landownership and forest characteristics will affect harvest behavior. There are fears that timber availability will be further limited by increased fragmentation of the forest and by an increasingly affluent landowning population, who may be more interested in the nontimber aspects of forest ownership. In addition to the large increases in timber volume, changes in species composition will influence future harvesting. Red maple has increased dramatically across the region and is now the second most abundant species in New Hampshire, the state from which the empirical portion of this study is drawn.

This study provides insight into the determinants of timber supply from private forests through development of both theoretical and empirical models of harvest behavior. Forest, owner, and economic variables are fully integrated into the analyses.

A MICROECONOMIC MODEL OF HARVEST BEHAVIOR

This model was adapted from an approach originally developed by Becker (1965) to analyze an individual's choice in allocating time between work and leisure. Each landowner seeks to maximize utility (satisfaction) from nontimber or forest-related amenities and from the generalized purchasing power of income, subject to two constraints:

$$\max\ U(A,I) \tag{1}$$

subject to

$$I=PH+E \text{ and } A=V-H \tag{2}$$

where

U(A,I) = utility defined over A and I,
A = quantity of timber reserved for amenities,
I = total income,
P = stumpage price,
H = quantity of timber harvested,
E = exogenous income,

and

V = initial timber inventory.

The first constraint defines total income as the sum of income from the sale of timber and all income from other sources, and the second defines the amount of timber retained for amenities as the initial timber inventory less the amount harvested.

The first-order conditions of the Lagrangian solution for utility maximization indicate that the landowner will maximize total satisfaction when the following condition is met:

$$P\frac{\partial U}{\partial I} = -\frac{\partial U}{\partial A}\frac{\partial A}{\partial H} \tag{3}$$

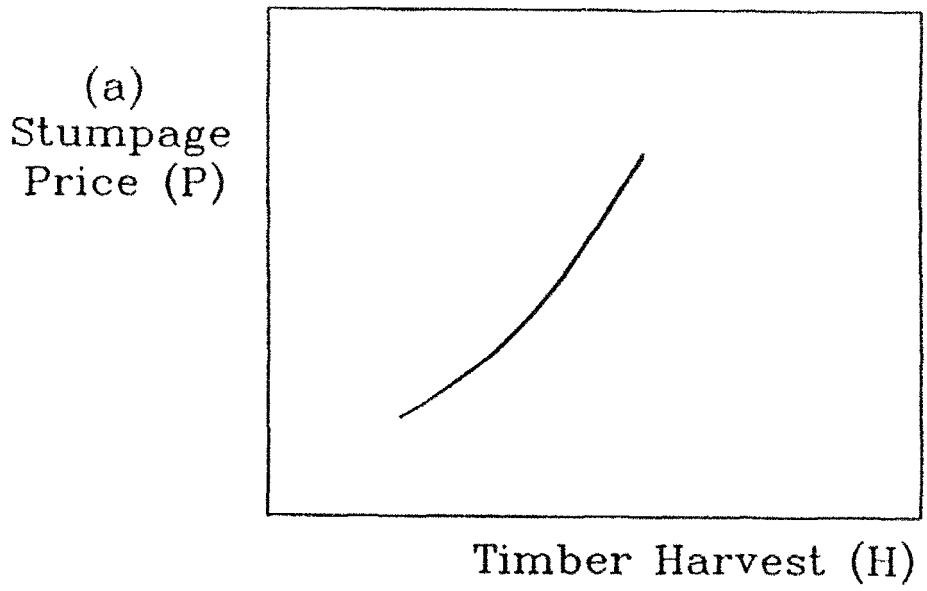
At the optimal mix of amenities and income, the satisfaction gained from increased timber income just equals the satisfaction foregone from amenities to obtain that income.

Further analysis of the first-order condition, called comparative statics, indicates how changes in different variables are expected to influence timber supply. Comparative statics analyses are performed by differentiating equation 2 with respect to the variable of interest. Binkley (1981) and Dennis (1989) provide more detailed discussions of the comparative statics results regarding timber supply.

In this simple model, changes in most of the variables have the expected effect. An increase in the initial timber inventory (V) has a positive effect on harvesting. More timber is available for both amenities and harvest. Increased exogenous income (I) has a negative effect on harvesting. Greater wealth reduces the relative value of additional income and makes harvesting less desirable.

Comparative statics results are not always so obvious. Differentiating with respect to stumpage price (P) yields an ambiguous result. This ambiguity arises from the interaction of two opposing effects. As prices rise we expect landowners to harvest more timber because the relative price of timber is higher. This is called the substitution effect; timber income is substituted for amenities. However, there is an opposing income effect. Swedish economists have called it the Volvo effect (Johansson and Lofgren 1985). Landowners harvest enough timber to buy a new Volvo and then stop; so, increasing the price of timber could actually reduce the harvest.

Normally we expect the substitution effect to dominate and the supply curve to be upward sloping (Figure 1a). However, if the income effect is dominant, the supply curve could be backward bending as shown in Figure 1b. Which effect dominates is an important empirical



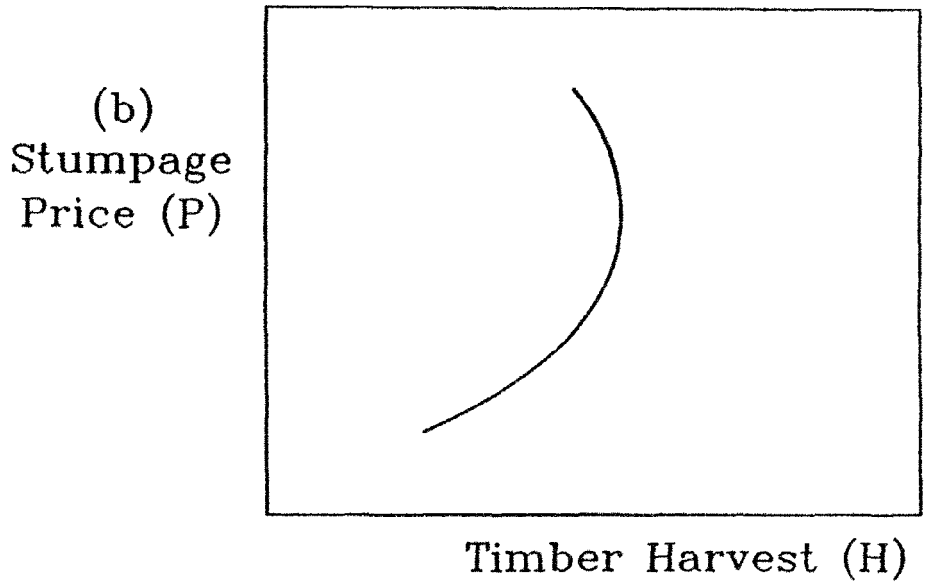


Figure 1. Two possible shapes for an individual landowner's supply curve for timber.

question.

Although theoretical models provide insight into harvest behavior, usefulness is limited by the simplifying assumptions required to make the model tractable. Additional insight can be provided empirically.

DATA SOURCES AND CHARACTERISTICS

Forest data were obtained from 68 fixed-radius (1/5 acre) sample plots measured by the USDA Forest Service, during its periodic statewide survey of New Hampshire. Frieswyk and Malley (1985) provide a thorough discussion of survey procedures. Each sample plot was measured in 1973 and again in 1983, with all trees either measured or accounted for (e.g. harvest or mortality). Species composition and a variety of other forest characteristics were recorded.

A questionnaire, sent to each landowner in conjunction with the forest survey, provided data on ownership (Birch 1988). This included information on size of holding, tenure of ownership, education, age, occupation, whether the owner was raised in an urban or rural environment, and several other owner characteristics. Descriptive statistics for selected forest and owner variables are provided in Table 1.

The exact offer price that each landowner faced was unknown, so price indices, representing sawlogs, pulpwood, and fuelwood, were constructed to proxy for offer prices. The prices were taken from the New Hampshire Forest Market Reports, published annually by the New Hampshire Cooperative Extension Service. Sawtimber prices were available by county and species, pulpwood prices were reported by region (north and south), and statewide prices were reported for fuelwood. The indices were weighted by the relative proportion of removals for each product during 1983, as reported by Frieswyk and Malley (1985) and Nevel, Engalichev, and Gove (1986).

METHODS

The data available for estimating harvest behavior may be examined in several ways. Two dependent variables were considered: (1) a dichotomous variable indicating whether timber was harvested, and (2) the quantity of timber harvested. In addition, an estimation strategy may be employed that accounts for only cross-sectional effects or a combination of cross-sectional and time-series effects.

A binary choice (probit) model was used to analyze the landowner's decision of whether to harvest timber from a particular parcel. Detailed general discussions of probit analysis may be found in most textbooks on econometrics (e.g. Judge et al. 1982). Dennis (1990) provides a thorough discussion of the application of probit analysis to timber harvesting data, which is outlined below.

Probit analysis was used to estimate the relationship between a dichotomous dependent variable (Y_i), coded 1 if timber was harvested from the sample plot, and 0 if no harvesting occurred, and selected explanatory variables (X_i). It is assumed that a landowner's propensity to harvest timber from a particular parcel is represented by an unobservable random index (Y_i^*), which is defined as a function of observable characteristics ($X_i'B$) and a random

Table 1.--Descriptive Statistics[a]

Variable[b]	Units	Mean	Std. dev.	Harvested mean	Non harvested mean
Timber harvest	bd ft/ac	111	332	628	0
Timber volume	bd ft/ac	961	949	1,597	824
Volume (white pine)	bd ft/ac	477	934	1,275	306
Ratio (white pine)	proportion	0.41	0.42	0.73	0.34
Volume (red oak)	bd ft/ac	79	197	136	67
Ratio (red oak)	proportion	0.10	0.24	0.15	0.08
Ownership size	acres	425	1434	917	320
Education	years	15.9	3.8	13.7	16.4
Landowner age	years	59	12	60	58
Tenure	years	23	13	23	23
Coded variables:					
Professional	proportion	0.44	0.50	0.33	0.46
New Hampshire resident	proportion	0.72	0.45	0.75	0.71

[a]N = 68.
[b]See Table 2 for definitions.

disturbance (e_i). If the observed choice (Y_i) equals one when $Y_i^* > 0$ and zero when $Y_i^* < 0$, then :

$$P(Y_i=1)=P(Y_i^*>0)=P(e_i<X_i'B)=F(X_i'B)=\int_{-\infty}^{XB} f(e)de \qquad (4)$$

where F( ) is the cumulative distribution function and f( ) is the probability density function of e_i. Normal specifications are assumed for these functions in the probit model.

Since the model is nonlinear, the estimated coefficients do not represent the change in the probability of timber harvest (P_i) resulting from a unit change in an explanatory variable. Since:

$$P_i=F(X_i'B) \text{ and } X_i'B=F^{-1}(P_i), \qquad (5)$$

the coefficients estimate the effect of a change in an explanatory variable on $F^{-1}(P_i)$. The magnitude of the change in harvest probability depends on the original probability as

determined by the initial values of all the variables and coefficients:

$$\frac{\partial P_i}{\partial X_{ik}} = f(X_i'B)B_k \qquad (6)$$

where k indexes the explanatory variables. The estimated sign shows the direction of change, but the magnitude is influenced by the steepness of the cumulative distribution function at $X_i'B$.

Additional insight into harvesting behavior may be obtained through analysis of a model that includes the quantity of timber harvested. We assume that landowner's harvest timber when their desire to do so reaches a certain level and the observed harvest provides a measure of that desire. However, because no measure of the relative desire is obtained when there is no harvest the sample is said to be censored at zero. Judge et al. (1985) defines a censored sample as one in which some observations on the dependent variable, corresponding to known sets of independent variables, are not observable. Least-squares estimation procedures produce biased and inconsistent estimates for censored samples because the conditional expectation of the error term is not zero.

Tobin's (1958) pioneering analyses of censored samples, with respect to consumer durables, has led to these models being termed "Tobit models". Amemiya (1984) provides a thorough survey of censored regression models.

As with the probit model, coefficients obtained from Tobit analysis must be interpreted with care. McDonald and Moffitt (1980) offer an innovative procedure for interpreting these coefficients. They show how Tobit analysis can be used to determine both changes in the probability of being above the limit, zero in the case at hand, and changes in the dependent variable if it is already above the limit. Thus, estimated timber supply responses resulting from marginal changes in an explanatory variable may be decomposed into changes in harvesting intensity on lands already being harvested and changes in the number of acres harvested. A more detailed discussion of analytical procedures for analyzing censored samples, with specific reference to timber harvesting, is provided by Dennis (1989).

Both probit and Tobit models may be estimated from cross-sectional or pooled time-series and cross-sectional data. The cross-sectional approach has the advantage of yielding unbiased estimates with minimum variance. Its main disadvantage is that it ignores information on variation over time. A pooled time-series and cross-sectional approach may be used to examine the influence of both annual and cross-sectional variation in the explanatory variables on the harvest decision. This procedure permits the introduction of variables, such as interest rates, that only vary over time, and also allows for annual, as well as cross-sectional, variation in stumpage prices. Although the presence of autocorrelation will cause the variance to be larger than if the same number of independent observations were used, this approach has the advantage of using more information to yield unbiased estimates.

RESULTS AND DISCUSSION

Two models were used to analyze harvesting behavior. Tobit analysis was performed on cross-sectional data, where the dependent variable measured the quantity of timber harvested during the period between surveys (1973 to 1983). A probit model was used to analyze pooled cross-section and time-series data. In this situation the dependent variable was dichotomous, indicating whether timber was harvested from a sample plot during a particular year.

For the pooled sample, the exact year of harvest was obtained from a questionnaire sent to each landowner or by personal contact if there was any ambiguity. Linear interpolation was used to calculate timber volumes for the years between surveys. Harvested trees were removed from plot totals and species composition was adjusted accordingly for years subsequent to harvest.

Table 2 provides a list of acronyms and a brief description for the explanatory variables, and Table 3 shows the regression results. The results are discussed first with respect to the estimated signs and statistical significance of the selected explanatory variables and then with respect to overall inferences concerning timber supply.

Signs and Significance of the Coefficients

Economies of scale in timber harvesting and the assumption of decreasing marginal utility of timber reserved for amenities led us to anticipate a positive relationship between harvesting and both size of forest ownership and timber inventory. The estimated coefficients (probit model) for the natural logarithm of ownership size and for per-acre timber volume were positive, but not statistically significant at the 10-percent level. Tobit analysis yielded a positive correlation between harvesting and timber inventory that was significant at the 5-percent level. Mean per-acre timber volumes were 1.6 mbf for plots that were subsequently harvested, compared to 0.9 mbf for plots that were not harvested.

The presence of commercially valuable species, such as white pine and red oak, were expected to enhance the probability of harvest. The empirical results support this hypothesis. Statistically significant coefficients were obtained for variables measuring the proportion of total timber volumes represented by these species, for both the probit and Tobit models. On average, stands that were subsequently harvested contained about double the percentage of white pine and red oak than those that were not harvested.

Positive coefficients were obtained for the price variables but neither were significant at the 10-percent level. The income and substitution effects, discussed earlier, effectively may be canceling one another. However, before accepting this conclusion there are several other possible reasons for the apparent lack of price responsiveness to consider.

Table 2.--Variable Summary

Variable	Definition (unit)
ACRES	Total woodland acres owned.
MBF	Timber volume (Mbf/acre).
PINE	Proportion of white pine; ratio = [volume of white pine (Mbf/acre)/MBF].
OAK	Proportion of oak[a]; ratio = [volume of oak (Mbf/acre)/MBF].
PI	Composite price index [real (1983) dollars, weighted by state level production]; includes stumpage prices for sawlogs, pulpwood and fuelwood.
SPI	Sawlog price index; sawlog portion of PI.
PICHG	Change in PI between current and previous year.
R	Yields for 3-year Treasury bills (percent).
ED	Years of formal education.
PRO	Coded variable equal, to 1 if owner was employed in a white collar occupation, and 0 otherwise.

[a]Includes red, white, and black oaks.

Since price indices do not generally measure the exact price that a landowner was offered, an "error in variables" problem is suspected. If the price index measures the true offer price with a random error, then the statistical significance of the price coefficient will be biased toward zero. Therefore, the probability of incorrectly rejecting the hypothesis that the coefficient is not zero is greater than the indicated level of significance. This potential problem is particularly troublesome when analyzing the cross-sectional sample, because the price variable is an average of annual prices for the period between surveys. Although pooling the time-series and cross-sectional data provides an improvement by including annual as well as cross-sectional price variation, the results were still not significant.

Multicollinearity is also of concern when analyzing the pooled sample. Correlations are expected between stumpage prices and variables, such as interest rates, that measure or are correlated with timber demand (see below). A potential consequence is that the precision of estimation is reduced, but more importantly, it becomes difficult to disentangle the relative influences of the correlated explanatory variables.

Table 3.--Results

Explanatory variables	Tobit[a] coefficient	Std. error	Probit[b] coefficient	Std. error
Constant	-2.765	2.319	-1.804	1.305
Log_e (ACRES)			0.127	0.101
MBF	0.320**	0.119	0.167	0.131
PINE	1.810**	0.693	1.057**	0.431
OAK	1.432*	0.764		
PI			0.043	0.036
SPI	0.040	0.036		
PICHG			-0.016	0.011
R			-0.126*	0.074
ED	-0.127**	0.053	-0.145**	0.054
PRO	0.585	0.381	0.638*	0.372

**Significant at 5% level.
*Significant at 10% level.
[a]Cross-sectional sample (N = 68); dependent variable equals quantity of timber harvested between surveys (1973-1983).
[b]Pooled cross-sectional and time-series sample (N = 706); dependent variable coded 1 if harvest occurred in a particular year and 0 otherwise.

Price responsiveness may be further obscured by the possibility that landowners are not responding to current price increases because they anticipate higher prices in the future. The most recent price change was used as an indication of price expectation in the pooled sample. Although not significant at the 10-percent level, the estimated coefficient had the anticipated negative sign, providing weak evidence that expectations of future prices affect current decisions.

The expected influence of interest rates on timber harvesting is ambiguous. Higher interest rates effectively increase the opportunity cost of growing timber, making current harvesting more desirable. However, changes in interest rates affect exogenous income, which influences harvest behavior. Interest rates are also correlated with the demand for timber. Housing starts and the demand for consumer goods, such as furniture, are sensitive to mortgage rates and rates charged on consumer credit. Changes in timber demand influence harvest decisions by affecting stumpage prices and by causing timber buyers to adjust their efforts at securing stumpage. Examples of buyer effort that are expected to influence harvesting decisions are advertising and number of landowner contacts.

To examine the influence of interest rates on harvesting decisions, the yield on 3-year Treasury bills, a readily available form of alternate investment and general indicator of interest rates across the economy, was introduced as an explanatory variable in the probit analysis of the pooled sample. A negative relationship was estimated between interest rates and timber harvesting, which suggests that the positive influence expected from an increase in the opportunity cost of growing timber was outweighed by other factors. Since no direct measure of buyer effort was available, the number of housing starts and an index of lumber and wood products manufacturing were used as proxies in an effort to disentangle these effects. The coefficients for these variables, whether introduced singly or in combination, were not significantly different from zero at even the 20-percent level, and the interest rate coefficient remained negative. The problem of multicollinearity may be obscuring the relative influences of the correlated variables, namely stumpage price, interest rate, and buyer effort.

Our theoretical model indicated that the harvest decision is influenced by exogenous income and by the relative value landowners place on amenities and consumption. Concerns have arisen that demographic changes in landownership, particularly with respect to increasing affluence, may adversely affect timber supply. Several explanatory variables that measure a landowner's education, age, occupation, early life environment, and state residency were examined to provide insight into the merit of these concerns.

Education and income levels were used to examine the affect of affluence on timber harvesting. Coefficients were negative, but not significant at the 5-percent level, when both variables were included in the model. The low significance levels probably were due to the high collinearity between the two variables. The significance level for each variable improved beyond the 5-percent level when the other was removed from the model. I chose to retain education in the model because 15-percent of the landowners did not respond to the income question. Deletion of this many observations weakened the overall model.

Both analyses yielded a strong negative correlation between education and timber harvesting. There are several plausible explanations for this correlation. Education may directly influence the way landowners value amenities and income or it may proxy for social background or other factors that influence attitudes toward timber harvesting. Also, more highly educated individuals generally have larger incomes, which our theoretical analyses suggest reduce the marginal utility of timber income. It appears that affluence, whether measured by income or education, has a negative effect on timber harvesting.

The influence of occupation on the propensity to harvest timber was examined using two coded variables that indicated whether the owner was a professional or was retired. Probit analysis yielded a positive coefficient for the variable indicating professional status. There is no clear intuitive interpretation for this result. Perhaps professionals have a greater tendency to view their woodlands as an income-producing asset or are more aware of market opportunities than others. No relationship was established between retirement status and timber harvesting.

Several other ownership variables were examined but no significant correlations were found. These included the landowner's age, whether he or she was raised in a rural or urban

environment, in-state residency, tenure of ownership, and whether the owner was involved in the purchase or sale of forest land within the previous 10 years.

Inferences About Timber Supply

Further analysis of the Tobit model, using the procedures of McDonald and Moffitt (1980), provides insight into timber supply from private forests. The signs of the coefficients indicate the direction of change but the magnitude of the marginal responses is determined by the values for all the independent variables and coefficients. Figure 2 shows the X_iB distribution. The results were interpreted at three values for the explanatory variables (X_iB): (1) -1.75, arbitrarily chosen to represent the lower portion of the distribution; (2) -1.098, computed using the mean values for the explanatory variables for the entire sample; and (3) 0.038, computed using the mean values for the harvested plots (see Table 4). Because the dependent variable measured harvest activity over the period 1973 to 1983, the estimates are per-acre values for an 11-year interval.

The first row of Table 4 gives the expected harvest, which may be obtained by multiplying the probability of harvest by the conditional harvest, shown in the second and third rows, respectively. The expected per-acre harvest varied considerably depending on the values of explanatory variables. The probability of harvest was miniscule when computed for the lower third of the distribution and this led to a very small expected harvest. Furthermore, estimated marginal responses were very small for these observations. Directing efforts to increase timber supply at more responsive portions of the population appears more fruitful.

The expected harvest was approximately 18 times larger when computed at values equivalent to the mean values of the plots that were subsequently harvested than for the sample mean. The estimated marginal responses were also considerably higher for these observations. Decomposition of the results indicates that the marginal responses are expected to occur primarily from changes in per-acre harvesting intensity and, to a lesser extent, from changes in the number of acres harvested.

Elasticities measure the estimated response resulting from a 1 percent increase in an explanatory variable. A supply elasticity of 1.06 was estimated for the inventory variable (MBF), which corroborates the inventory elasticity assumed in several aggregate supply models (e.g. Adams and Haynes 1980, Cardellichio and Veltkamp 1981, and Binkley and Cardellichio 1986).

An estimated supply elasticity of approximately -7.0 for the education variable provides credence to concerns that increased affluence may adversely affect timber availability. A 1 year increase in education level reduced the expected harvest by 36 percent when evaluated at the sample mean.

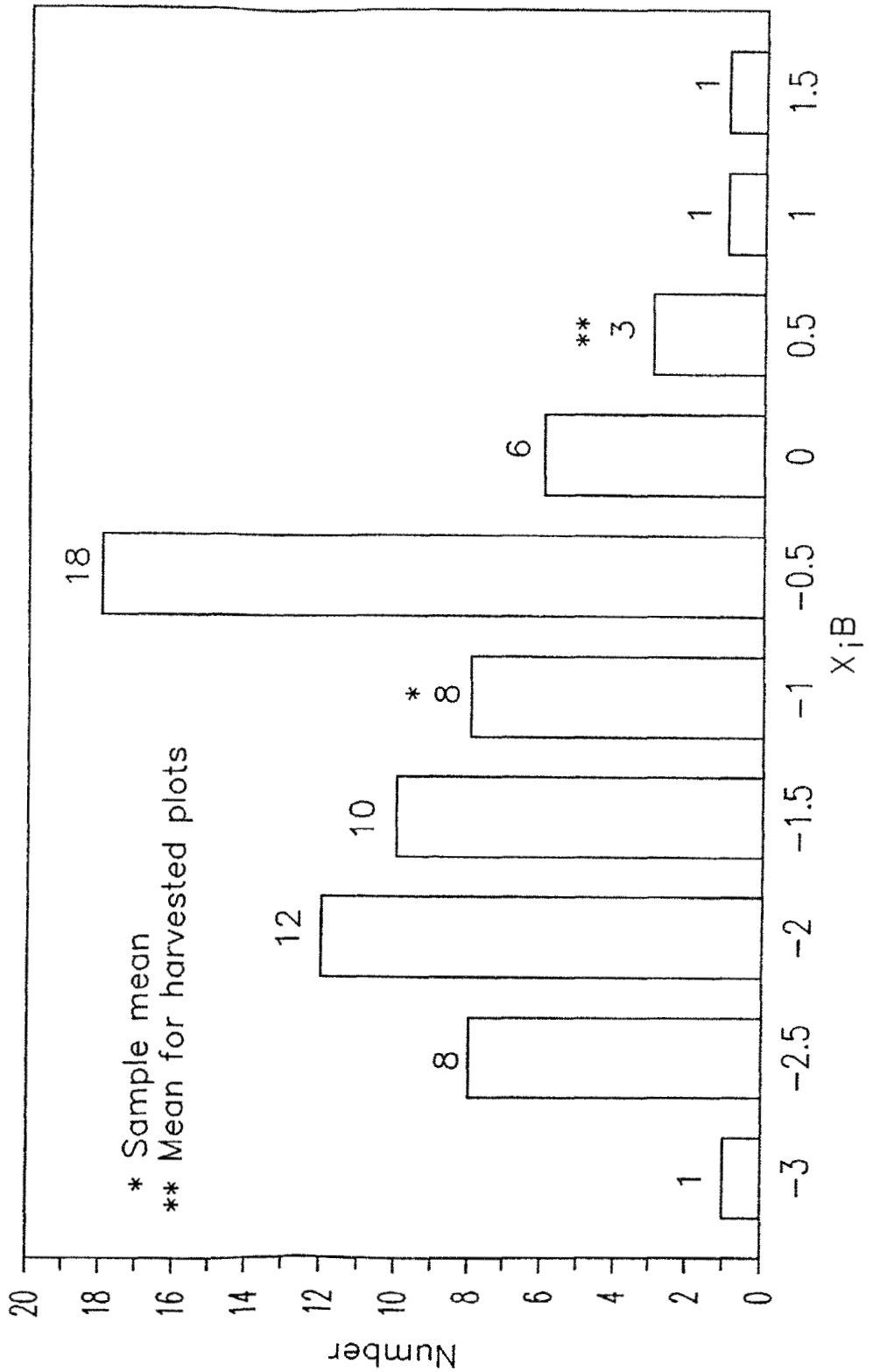


Figure 2. The X_iB distribution for the cross-sectional sample.

Table 4.--Decomposition of Tobit Results

	31st Percentile $X_iB = -1.750$	Sample mean $X_iB = -1.098$	Harvested plot mean $X_iB = 0.038$
Harvest[a] (Mbf)	.001	.016	.293
Probability of harvest (proportion)	.005	.054	.522
Conditional harvest[b] (Mbf)	.219	.290	.561
Marginal harvest response	$.005B_k$	$.055B_k$	$.522B_k$
Portion of marginal response resulting from:			
Per-acre harvest	8%	14%	38%
Probability of harvest	92%	86%	62%

[a]Estimated per-acre harvest across all plots at this point in the X_iB distribution.
[b]Estimated per-acre harvest for plots at this point in the distribution that are actually harvested.

Using the model to simulate the effect of a continuation of past trends in the explanatory variables can provide additional insight. Northeastern forests are maturing; sawtimber volumes in New Hampshire have increased 26 percent since 1973 (Frieswyk and Malley 1985). Timber quality has also improved, with grade 1 and 2 sawlogs comprising 27 percent of the pine sawtimber and 36 percent of the hardwood sawtimber in 1983. However, species composition is also changing. Red maple growing stock has increased by 137 percent since 1960 and is now the most abundant hardwood in New Hampshire. The affluence levels of landowners has increased. In 1983, almost three-quarters of New Hampshire's individually owned forest land was held by owners who completed education beyond high school.

The assumptions for the simulation were: average sawtimber volumes will be 15 percent higher over the next decade, the proportions of white pine and red oak will decrease by 10 percent, average education levels will increase by 0.25 years, and the proportions of "professionally" employed owners and real stumpage prices will remain constant. The simulations and comparisons were computed at the sample mean and measure harvest behavior for an 11-year interval.

The expected harvest dropped 22 percent, to 12.3 board feet per acre; the expected probability of harvest was reduced from 5.5 to 4.4 percent; and the conditional harvest declined from 290 to 283 board feet per acre. Additional analyses indicate that a 3 percent increase in real stumpage prices would be required to maintain harvests at current levels, under these assumptions. Of course, other options, such as programs designed to enhance growth or improve species composition, might be used to avert the need for increased stumpage prices.

SUMMARY

Forest characteristics, which generally were lacking in previous empirical work, were important determinants of harvest behavior. High per-acre volumes and the presence of commercially valuable species were positively correlated with timber harvesting. Concerns that an increasingly affluent population of landowners may be less likely to harvest timber were supported. Timber harvesting was negatively correlated with both income and education. Several other owner characteristics, such as, age, retirement status, tenure of ownership, whether the owner was raised in a rural or urban environment, and in-state residency, were not significantly correlated with timber harvesting.

Interest rates were negatively correlated with the propensity to harvest timber. This suggests that the positive influence expected from an increase in the opportunity cost of growing timber was out-weighed by other factors. Since interest rates are negatively correlated with housing starts and consumption of other wood products, they may proxy for the effort buyers exert at securing stumpage.

Positive coefficients and relatively high elasticities were estimated for the effect of stumpage prices. However, these results were not statistically significant at the 10-percent level. The opposing income and substitution effects may be canceling one another or the true effect may be obscured by problems of measurement and multicollinearity, inherent in these types of analysis.

Although prospects for timber harvesting should be enhanced as timber volumes increase, a net reduction in availability is anticipated due to changes in species composition, and the expectation that an increasingly affluent landowning population will be less interested in timber harvesting. Any changes in timber availability are expected to result primarily from a decrease in the number of acres from which timber is offered for sale and to a much lesser extent from changes in per-acre harvesting intensity.

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NEW ESTIMATES OF HARDWOOD LUMBER EXPORTS FROM THE CENTRAL HARDWOOD REGION

William Luppold and Edward Thomas[1]

Abstract: Exports have become an increasingly important part of the overall hardwood lumber market. However, recent findings indicate that much of the reported growth of hardwood lumber exports in the 1980's was based on inflated volume data. This paper presents new estimates of hardwood lumber exports to Asia and Europe with emphasis on the central hardwood region of the United States. The major finding is that, although the central region has become a major source of hardwood lumber, exporters in the eastern and western regions have a much larger share of the European and Asian markets.

INTRODUCTION

Exports have been one of the most visible components of the hardwood lumber market over the last decade. Statistics released by the U.S. Department of Commerce, Bureau of the Census (1989) indicate that lumber exports increased by 809 million board feet (or 327 percent) between 1980 and 1988 (Nolley 1990). These statistics report that exports to Asia and Europe increased by 388 million board feet and 249 million board feet, respectively. However, recent findings indicate that volume statistics reported by the Bureau of the Census for hardwood products have been greatly overstated (Luppold and Hansen 1989). This paper presents revised estimates of hardwood lumber exports to Asia and Europe with special emphasis on exports from the north and south-central hardwood regions.

The errors in statistics on hardwood lumber export volumes resulted from errors in the computer program that screens individual export declarations for accuracy, combined with an increasing number of incorrect export declarations. When the volume indicated on an export declaration was incorrect, the program developed a new volume estimate by dividing the declared value by a default price. Different default prices were used for each lumber product; however, most of the default prices had not been changed since the late 1970's. Since May 1989, new screening and default prices have been installed in the computer program, resulting in considerably better estimates of export volumes.

In addition to being historically inaccurate, official estimates of hardwood lumber export volumes are reported only by custom district from which lumber exits the United States and

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not the actual point of origin. This type of reporting does not allow for regional analyses of hardwood lumber exports. However, alternative information on hardwood lumber exports from seaports is available from the Port Import Export Reporting Service (PIERS) (Journal of Commerce 1989-90). This service provides information from individual shipping manifests, including product, weight, selling agent or company, and foreign destination.

Although the data provided by PIERS are extremely detailed, there are certain limitations in developing regional exports volumes. One difficulty with PIERS data is that they do not include material transshipped through Canada. Nearly 20 percent of the lumber exports to Europe travels through Canada via inland custom districts primarily in the northeast. Since dollar-volume figures by custom district are known to be fairly accurate, estimates of total export volumes can be obtained by combining both information obtained from PIERS and the Department of Commerce. However, there is no method for determining the origin of shipments leaving from inland exit points. Another problem in determining the regional impact of lumber exports is that lumber can be sold across regions and then exported. Still, with these limitations, PIERS data can provide the information needed for a rough analysis of hardwood lumber exports on a regional basis.

All non-Census data reported in this paper are derived from PIERS. The validity of these procedures is discussed in Luppold and Thomas (1990). The basic steps used in developing the data were: (1) Classify all observations into the specific 10-digit codes used by the Bureau of the Census; (2) Place all observations not designated by species in a NES (not elsewhere classified) category; (3) Develop export volumes on a shipment-by-shipment basis by using volume information listed on the manifest, or by estimating volume from weight or other information provided on the manifest;[2] and (4) Summarize volumes on a year-by-year, country-by-country basis for all known species and NES categories.

NATIONAL EXPORT TRENDS

In Figure 1, Census estimates of hardwood lumber exports to Asia are compared to estimates developed from PIERS data. Since value information also developed by the Bureau of the Census indicates that nearly all hardwood lumber exports to Asia go through U.S. seaports, the PIERS estimates represent the actual volume exported. The sharp decline in Census estimates between 1988 and 1989 resulted from changes made in the computer program used to compile official export statistics. Since these changes were not used in developing export data for January through April, 1989 Census estimates remain slightly inflated.

Even after discounting the volume inflation in the official hardwood export statistics, exports to Asia increased by nearly 1,000 percent (240 million board feet) between 1981 and 1989

[2]A detailed description of the procedures used to estimate volume from ship manifests, and the validity of these procedures, is discussed by the authors in "A Revised Examination of Hardwood Products Exports to the Pacific Rim (in preparation).

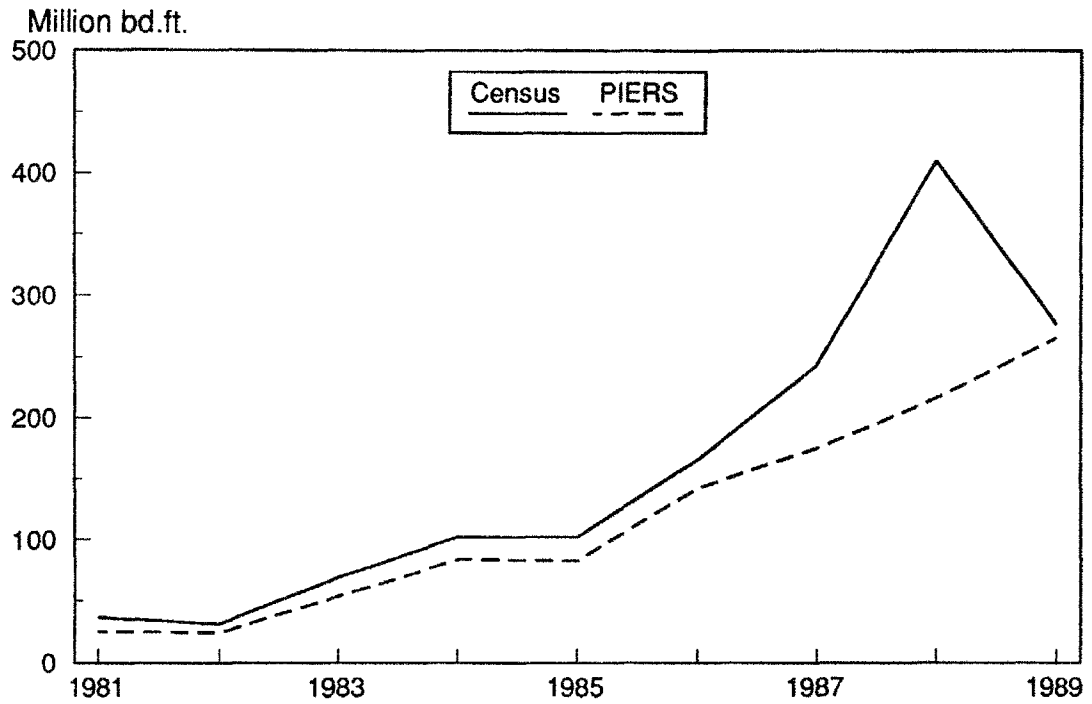

Figure 1. Estimates of hardwood lumber exports to Asia as reported by USDC Bureau of Census and developed from PIERS data.

(Fig. 1). The rapid growth in Asian exports emanated primarily from increased demand by Japan and Taiwan. These two countries accounted for nearly 90 percent of all hardwood lumber exports to Asia in 1989. Although the growth in these two markets occurred almost simultaneously, the demands by Japan and Taiwan are considerably different.

The Japanese use U.S. hardwood lumber for production of furniture, millwork, and fixtures that are consumed in the Japanese market. Red alder was the primary hardwood lumber species exported to Japan in 1989. Also shipped were large amounts of ash, yellow-poplar, white oak, and red oak. Exports to Taiwan were manufactured into furniture and other products that were exported primarily back to the U.S. market. Red oak was the primary species exported to Taiwan in 1989, with significant amounts of white oak also shipped.

Estimates of hardwood lumber exported to Europe as developed by the Bureau of the Census and from PIERS data are shown in Figure 2. Since a significant portion of European exports from the United States go through Canada, a third line representing adjusted PIERS estimates is shown. The adjusted PIERS estimates were developed by multiplying the PIERS estimate by the ratio of total value of exports to Europe over the value of European exports leaving primarily seaport custom districts. Again, the sharp decline in Census estimates between 1988 and 1989 resulted from changes made in the computer programs used to compile official export statistics.

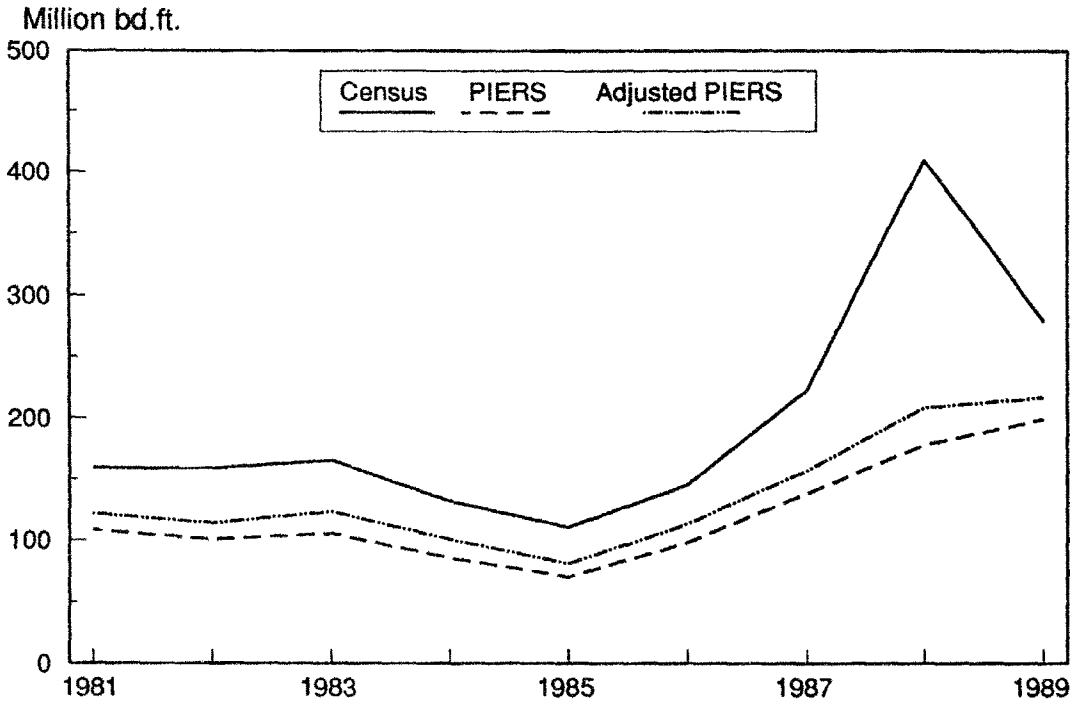

Figure 2. Estimates of hardwood lumber exports to Europe as reported by USDC Bureau of Census and developed from PIERS data.

Hardwood lumber exports to Europe nearly doubled in the 1980's from an already high base in the late 1970's. By the end of the decade, exports to Asia were higher than exports to Europe. The European market differed sharply when compared to the Asian market in that no single country or set of countries continued to be a dominant user of U.S. hardwood lumber. In the early 1980's, West Germany, the Netherlands, and Belgium were the primary markets for U.S. lumber. In the mid-1980's, Italian demand for U.S. lumber increased sharply while the traditional northern European market either remained static or declined. In the late 1980's, nearly all European markets increased; however, exports to the United Kingdom, Spain, and Italy increased at faster rates.

White oak was the major species exported to Europe in the 1980's. Significant quantities of red oak also were exported to Europe, with Belgium and France the major users. Ash and yellow-poplar also were exported to Europe in increasing volumes in the late 1980's. Yellow-poplar currently is the major species exported to Italy.

REGIONAL EXPORT TRENDS

The north and south-central regions produce well over 50 percent of the 11 billion board feet of hardwood lumber manufactured in the United States (Luppold and Dempsey 1989). At first analysis, this level of regional production indicates that these regions are the major suppliers of exported lumber. Surprisingly, the central region is a minor force in the Asian market when examining regional export information developed from PIERS data (Fig. 3). In 1989, only 17 percent of Asian exports originated directly from firms located in the central hardwood region.

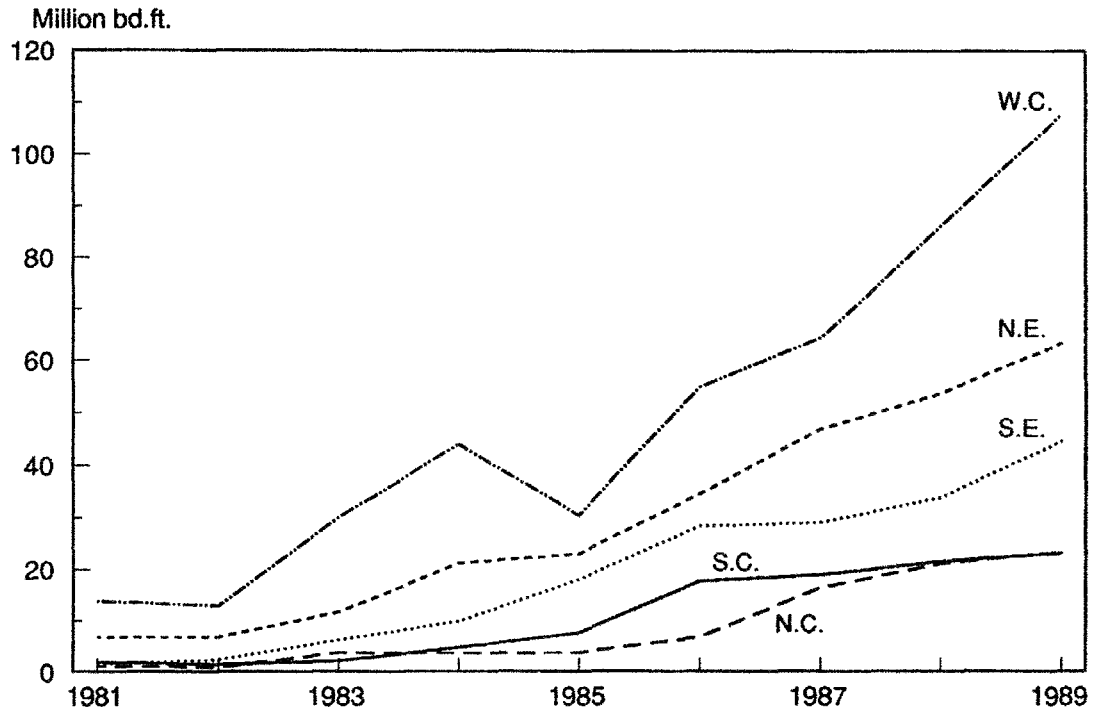

Figure 3. Regional estimates of hardwood lumber exports to Asia as developed from PIERS data.

Part of the reason why the central region appears less important in the Asian market is that nearly 40 percent of the nearly 250 million board feet of hardwood lumber going to Asia in 1989 was shipped by West Coast firms. A significant but unmeasurable amount of lumber shipped by West Coast exporters is eastern species such as red oak, white oak, ash, maple, and poplar. The closer proximity of the central region to the West Coast would suggest that a high proportion of this lumber is from the central region. Although this situation highlights the weakness of using PIERS data for U.S. regional analyses, some interesting trends can be drawn from the limited information at hand.

The first notable trend is that growth in exports to Asia from all regions has grown over time in a similar pattern. Until recently, exports to Asia from the south-central region have slightly exceeded exports from the north-central region. The recent slight increase in strength of the north-central market can be explained by examining the major Asian markets served by these regions.

Throughout the 1980's, Taiwan was the major market for south-central lumber exports, with red oak the major species. Ash, the only other significant export from the south-central region, was shipped in increasing amounts to Japan through the mid-1980's. Exports to Asia from the north-central region tended to vacillate between white oak shipments to Japan in the early 1980's, to red oak shipments to Taiwan in mid-1980, back to white oak shipments to Japan in the late 1980's. Today, Japan is the primary market for the north-central region. In the late 1980's, the Japanese market grew faster than the Taiwanese market; the result was that north-central exports to the Asian market increased at a faster rate than south-central exports.

Exports to Europe, by region, for 1981 to 1989 are shown in Figure 4. Exporters from the central hardwood region account for a much greater share of the European market than the Asian market. The northeast region, however, appears to be the largest source of exports to Europe. Some of the material shipped by northeastern and southeastern firms could have emanated from the central region, but there is no accurate information on these interregional transfers.

One interesting aspect of Figure 4 is that exports from the north-central region increased at a much faster rate in the 1980's than exports from the northeastern region. In 1981, 49 percent (52.6 million board feet) of the exports to Europe originated from the northeast while only 8 percent (8.5 million board feet) originated from the north-central region. By 1989, exports shipped from the northeast increased to 69.5 million board feet while exports from the north-central region increased to 30.6 million board feet. Alder exports from the West Coast to Europe also increased sharply in the 1980's. Exports from the southeast and south-central regions increased at about the same rate as total exports during the 1980's.

The primary European markets served from the north-central region changed as the overall European market changed. Germany and Belgium were the primary European markets for north-central lumber through the mid-1980's. In the late 1980's, Italy, the United Kingdom, and Spain became increasingly important markets for north-central hardwood lumber. White oak has been and remains the primary species shipped to Europe from this region regardless of country of destination.

In the early 1980's, Germany and the Netherlands were the most important export markets for the south-central region. In the mid-1980's, Italy rivaled Germany as the most important market. By the late 1980's, Italy, Spain, Belgium, and the United Kingdom were more important markets for south-central hardwood lumber than Germany. As in the case of the north-central region, white oak was the most important species exported to Europe from the south-central region.

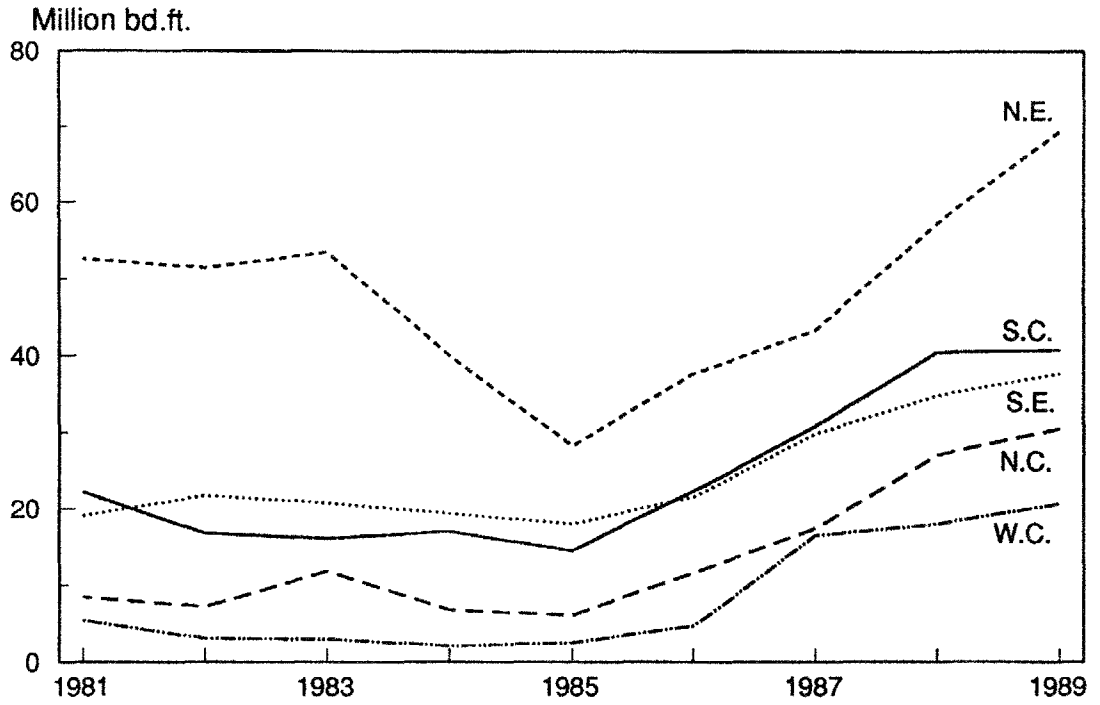

Figure 4. Regional estimates of hardwood lumber exports to Europe as developed from PIERS data.

SUMMARY AND CONCLUSION

Although the central hardwood region manufactures more than 50 percent of the hardwood lumber produced in the United States, the amount of lumber directly exported from this region is substantially less. Part of this apparent discrepancy can be attributed to shipments of exportable lumber from the central to coastal regions. However, the cost of transporting products to international markets is increased because many of the states in the central region are landlocked. Still, the north-central region has increased its share of exports to Europe relative to all other eastern regions. As the export markets in both Asia and Europe continue to expand, it is almost certain that the vast production and timber resources of the central hardwood region will be increasingly required to serve the growing international demand for U.S. hardwood lumber.

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SHIITAKE MUSHROOM PRODUCTION ON SMALL DIAMETER OAK LOGS IN OHIO

Stephen M. Bratkovich[1]

Abstract: Yields of different strains of shiitake mushrooms (*Lentinus edodes*) were evaluated when produced on small diameter oak logs in Ohio. Logs averaging between 3-4 inches in diameter were inoculated with four spawn strains in 1985. After 3-1/2 years, strain *S-1* produced a total of 432 lbs. of fresh shiitake per cord when log management included forced fruiting by soaking in water for 24 hours. Additional strain and fresh lbs. per cord results were *FWF*, 291 lbs.; *82A*, 120 lbs.; and *RA 3-2-E*, 39 lbs. For all spawn strains, forced fruiting increased shiitake mushroom yield when compared to a control. Foresters need to be aware of the dependency of shiitake mushroom yields on spawn strain and management practices when making recommendations to landowners on the utilization of small diameter oak logs. Foresters also can use shiitake mushroom production as another tool in stimulating private non-industrial forestland management.

INTRODUCTION

Foresters working in the hardwood regions of the U.S. are continually searching for methods to increase management on non-industrial private forestland. An accompanying goal, which often is a pre-requisite to management, is increased utilization of low quality tree species. Leatham (1982) presented documentation on how shiitake mushrooms (*Lentinus edodes* [Berk.] Sing.) could be grown on underutilized wood harvested from low-grade hardwood trees, particularly oak. With a 1988-89 wholesale price of $4.70 per lb. (USDA 1989), it is not surprising that foresters are eager to learn if shiitake mushroom production can be used as a tool to stimulate forest management.

Shiitake mushrooms can be cultivated on either intact hardwood logs or wood particles (Royse, Schisler and Diehle 1985). Relatively little scientific information has been published in the U.S. on cultivating shiitake mushrooms on logs (Leatham 1982, San Antonio 1981, San Antonio and Hanners 1983). Published information is also scanty on the potential yields and economic returns from shiitake cultivation on logs (Anon. 1989, Baughman 1989, Haney 1989, San Antonio 1981).

This paper compares shiitake mushroom production on mixed oak logs using a combination of different mushroom strains and management practices (soaking versus non-soaking of logs). Results are useful for making recommendations to foresters and forestland owners.

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MATERIALS AND METHODS

Spawn Selection

During January 1985, four spawn strains from three commercial U.S. spawn suppliers were purchased. The specific strains obtained were: *S-1* from Elix Corporation, Arvonia, VA, *82A* and *RA 3-2-E* from Mushroompeople, Inverness, CA, and *V3A*, *V3B*, *R56B*, and *R569* from Far West Fungi, South San Francisco, CA. Since it was not known that four, rather than one strain from Far West Fungi would be received, the four strains (after being mixed uniformly) were grouped together for testing purposes and named "FWF" strain. Therefore, the experiment was designed to test differences between the following strains: *S-1*, *82A*, *RA 3-2-E* and *FWF*. Strains *S-1* and *RA 3-2-E* were on a sawdust medium and *82A* and *FWF* were on wood dowels. All spawn was refrigerated until inoculation.

Obtaining the Logs

Two and one-half cords of wood, which came from tree tops and branches of harvested sawlogs and pulpwood, was cut in late February 1985. The unsplit logs consisted of 50 percent oak (*Quercus* spp.) and 50 percent American beech (*Fagus grandifolia*). Log diameters ranged from two to eight inches with lengths up to 12 feet. The average log diameter was slightly over three inches.

The harvested logs were taken to the Elizabeth L. Evans Outdoor Education Center in Jackson county, Ohio, site of the experiment. In early March 1985, logs were cut into four foot lengths and stacked firewood style until inoculation. A total of 801 logs, 386 oak and 415 beech, comprised the two and one-half cord sample. Spawn strain and management practice were randomly assigned to the logs. An aluminum tag was stapled on the ends of each log for coding purposes.

Inoculation Procedure

Approximately 90 percent of the logs were inoculated between March 25 and April 4, 1985. The remainder of the logs were inoculated May 3, 1985. The number of inoculation sites per four foot log was determined by log diameter with the log diameter in inches translating to the number of rows drilled in the log lengthwise. For example, a log with a diameter of four inches had four lengthwise rows of inoculation sites. Inoculation sites were spaced six inches apart within rows with each inoculation site offset three inches from the neighboring row. Regardless of the number of rows per log, rows of inoculation sites were spaced approximately three inches apart.

The wood dowel inoculation sites were drilled 5/16 inch in diameter and to a depth of approximately 3/4 inch. After drilling, the logs were moved to a work table where the dowels were tapped into the holes with a hammer. The inoculation sites were then painted with a hot, melted cheese wax.

Inoculation sites for the sawdust spawn were drilled 12mm (approximately 1/2 inch) in diameter and 3/4 inch deep. A sawdust spawn inoculation gun was used with the *S-1* spawn. The consistency of the *RA 3-2-E* spawn required the spawn to be placed by hand into the inoculation holes. Fifty percent of the sawdust spawn inoculation sites (*S-1* and *RA 3-2-E*) were randomly treated with melted cheese wax. The remaining fifty percent had a styrofoam plug placed into the hole on top of the sawdust.

Log Stacking

Following inoculation, all logs were restacked firewood style and covered with black plastic for one week and then with burlap. This log stacking pattern, known as a temporary laying position, was selected to conserve log moisture. The site for the temporary laying was the same site used for all other phases of the experiment (inoculation, permanent laying, soaking and raising). The location is a bottomland near the mouth of a large hollow or ravine. Air movement is good and the site is densely shaded by a stand of mature sugar maple. A small stream flows past the site.

In late May 1985, surface molds (*Trichoderma* spp. and *Daldinia concentrica*) appeared on the logs so the burlap was removed. One week following burlap removal, the logs were restacked into a cross-hatch or crib pattern. (Example: the first row of five to six logs were placed in a north-south direction, the second row in an east-west direction, etc., with the height of the stack approximately four feet). This stacking arrangement permitted better air movement around the logs in an attempt to control the surface molds. The cross hatch pattern was the chosen permanent laying position. The logs were restacked in late June 1985 in a more widely spaced cross-hatch of three to four logs per row in a successful effort to eliminate the surface molds.

The logs remained in the permanent laying cross-hatch pattern until October 1985 when mushrooms started to appear on a few oak logs. At this time, all oak logs were raised by leaning them against the fence which encircled the experiment. The beech remained in the cross-hatch pattern.

Log Irrigation and Soaking

During the summer of 1985, all logs were irrigated twice with a garden sprinkler. Since the effect of the irrigation was judged to be beneficial only to the surface molds, irrigation was

discontinued for the remainder of the experiment. During October and November 1985, 12.5 inches of rainfall (an unusually high amount) were recorded at the experimental site.

During 1986 and 1987 logs randomly selected for soaking were completely immersed in water for 24 hours. A total of four soakings were administered. All logs in the experiment were managed according to recommended shiitake management practices depending on whether or not they had been soaked. For example, soaked logs were placed in the upright fruiting position (leaned against a fence) immediately following a water soak while non-soaked logs remained in the cross-hatch pattern until fruiting occurred at which time they were placed in the upright fruiting postion.

RESULTS

Beech Logs

The beech logs in 1985 yielded one lb. of fresh shiitake per cord for both the *S-1* and *FWF* strains; there was no fruiting on the *82A* or *RA 3-2-E* logs. The beech logs were eliminated from the experiment during 1986 due to poor fruiting, low log moisture content, and splitting/sloughing bark.

Oak Logs

During the fall of 1985, which was prior to the water soaking treament initiated in 1986, the combination of logs designated for soaking and control yielded the following average fresh shiitake per cord: *S-1* strain, 38 lbs.; *FWF* strain, eight lbs. There was no activity on the *82A* or *RA 3-2-E* inoculated oak logs in 1985.

During 1986-88 mushrooms were produced during the period from April/May to November/December. Table 1 presents fresh shiitake yield in lbs. per cord for all four strains from 1986 through 1988.

The more prolific strains, *S-1* and *FWF* (as measured by total fresh lbs. per cord), had peaks in yield the first full year of production (1986) while strains *RA 3-2-E* and *82A* peaked during the last year of data collection (1988). All spawn strains showed mushroom yields to be greatest for the three-year period when log soaking was utilized as a management practice.

It is interesting to consider seasonal fruiting/harvest trends in addition to annual yields. For example, 78 percent of the 1987 *82A* yield occurred **after** October 14 while 98 percent of the 1987 *S-1* yield occurred **before** October 14 (on soaked logs). Even though the '87 *S-1* yield was nearly double the *82A* yield (79 to 40 lbs. per cord), the combinaton of the two strains would have extended the marketing season for a commercial grower.

Table 1.--Per cord 1986-88 shiitake yield on 1985 inoculated oak logs.*

Spawn Strain**	Treatment***	1986	1987	1988	Total
		---------- Fresh lbs./Cord**** ----------			
RA 3-2-E	Soak	0	13	26	39
RA 3-2-E	No Soak	0	7	3	10
S-1	Soak	350	79	3	432
S-1	No Soak	287	63	50	400
FWF	Soak	172	104	17	291
FWF	No Soak	149	43	13	205
82A	Soak	7	40	73	120
82A	No Soak	0	7	20	27

*Logs were inoculated at a spacing of approximately 6" by 3".
**RA 3-2-E and S-1 were on a sawdust medium. FWF and 82A were dowels.
***Logs soaked for 24 hrs. twice in 1986 (March/Sept.) and twice in 1987 (May/August).
****Approximately 330 logs/cord. Average log diameter slightly over 3".

Logs that were water soaked not only received additional moisture as compared to the control or non-soaked logs, but the soaking served as a forced fruiting with the peak growth flush occurring approximately seven days following soaking. The non-soaked logs were more dependent on weather conditions with growth flushes occurring in close proximity to natural precipitation.

Table 2 presents the same data as in Table 1 except Table 2 data is on a **per log** basis. The data for Table 2 was compiled for all logs originally inoculated in 1985 and thus represents mean production per log; mean production figures include individual logs which were poor, as well as good, producers.

DISCUSSION

Foresters recognize that landowners are often hesitant to invest in forest management activities when economic returns are in the distant future; timber stand improvement and non-commercial thinnings are two examples. However, if the management practice generates small diameter oak logs, then shiitake production is a potential source of short-term cash flow

Table 2.--Per log 1986-88 shiitake yield on 1985 inoculated oak logs.

Spawn Strain	Treatment	1986	1987	1988	Total
		---------- Fresh lbs./Log* ----------			
RA 3-2-E	Soak	0.00	0.04	0.08	0.12
RA 3-2-E	No Soak	0.00	0.02	0.01	0.03
S-1	Soak	1.06	0.24	0.01	1.31
S-1	No Soak	0.87	0.19	0.15	1.21
FWF	Soak	0.52	0.31	0.05	0.88
FWF	No Soak	0.45	0.13	0.04	0.62
82A	Soak	0.02	0.12	0.22	0.36
82A	No Soak	0.00	0.02	0.06	0.08

*Inoculated logs averaged slightly over 3" in diameter. All other footnotes from Table 1 apply to Table 2.

for the landowner. Foresters should be prepared to present this option to landowners since in certain instances it might be just the incentive needed to stimulate forest management.

Readers should be aware that the results reported in this paper are from an initial testing program. Since 1985 when this study was initiated, improved management practices and more desirable spawn strains have been identified. Experience gained in management technique is critical for optimal success. However, foresters who communicate with landowners about shiitake mushroom cultivation can use the methods and results of this study as general guidelines to move individuals through the process.

It is important to recognize that the optimum combination of host tree species, spawn strain and log management can be specific to a geographical area. For example, Haney (1989), using spawn from a local supplier found sycamore (*Platanus occidentalis*) to outperform other tree species in western North Carolina. The Forest Resource Center in Minnesota recently reported shiitake yields on force-fruited ironwood (*Ostrya virginiana*) to be nearly double red oak, the best species previously identified in the region (Anon. 1989). Based on the North Carolina and Minnesota research as well as the Ohio research presented in this paper, forest landowners interested in shiitake cultivation should be encouraged to experiment on a small-scale. Unfortunately, some individuals have jumped into large-scale shiitake production without understanding that tree species, spawn strain, log management and geographical area have an impact on mushroom production.

Management practices, such as force fruiting the logs by soaking, was shown in this study to increase the rate and amount of mushroom yields and is a management option that foresters can pass on to landowners. Although this article did not focus on economics, landowners need to be encouraged to analyze the economic impact of all management decisions. Landowners without available labor or a nearby source of water may choose not to soak their logs, thus decreasing mushroom yields but perhaps increasing net profit in their particular situation.

Finally, the concept of shiitake mushroom production goes beyond the idea of raising a gourmet mushroom on hardwood logs. Too often landowners and foresters think only in terms of traditional forest products such as pulpwood and sawtimber and overlook opportunities for economic returns from wildlife, recreation and food (Haney, 1989). Shiitake mushrooms could stimulate both foresters and landowners to broadened their vision of possibilities that can enhance both profits and forest management opportunities.

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THE PALLET INDUSTRY: A CHANGING HARDWOOD MARKET

Gilbert P. Dempsey and David G. Martens[1]

Abstract: From its inception during World War II, the wooden pallet industry has grown to become the Nation's largest industrial consumer of hardwood lumber products. Since most of the raw material in wooden pallets is lower grade lumber, the pallet industry's growth, efficiency, and changing raw material inputs must be of concern to the grade hardwood lumber industry, the fine-hardwood lumber-using sectors, and hardwood resource investors and managers.

INTRODUCTION

The United States' wooden pallet industry currently provides a viable market for more than 5.1 billion board feet of mostly lower grade hardwood lumber (or lumber equivalent) annually. This represents more than 46 percent of the total U.S. hardwood lumber production. Therefore, significant changes in either pallet output or its manner of production is important to the grade hardwood lumber industry and its prime outlets--the fine-hardwood-using industries, such as manufacturers of wood household and office furniture, cabinets, etc., and, to varying degrees, hardwood resource managers. For example, economic activity in the pallet industry affects both the physical availability and price structure of grade hardwood lumber used by these higher valued domestic product markets, including the export market. Hardwood forest resource managers also would have fewer management options if there were no pallet market to utilize much of the lower grade timber resource.

The pallet industry is currently in a sustained growth mode and has more than doubled its unit product output since the economic recession of 1982. Despite the higher costs of productive inputs, the industry is producing more pallets with less labor and at lower output prices. Industry efficiency, as measured by labor productivity, has increased by more than 83 percent since 1972 (Dempsey 1988). This has been accomplished in the face of more stringent manufacturing standards and higher costs. Contributing to these efficiencies were structural and operational changes that affected the source, quantity, and form of raw materials as well as their in-plant utilization.

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YESTERYEAR

Prior to World War II, the principal means of loading, moving, stacking, and storing industrial products was by hand, coupled with the use of wheeled hand jacks, platform carts, and various kinds of fixed and moveable hoists. Simple wooden platforms were used in these systems primarily for load separation and support. According to Wallin (1986), industrial pallets as we currently know them were introduced as a materials handling tool in the 1930's, though their use was minimal. For example, only 11 million wooden pallets were produced annually in the late 1930's. The early pallets were produced "in house" by the firms using them, or as specialty products by the manufacturers of wooden boxes and other containers.

Pallets were not used extensively in materials handling systems for two reasons. First, the technology to mechanize materials handling was not available until 1937 when the first generation of small, gas-powered forklift trucks was developed (Eichler 1976). Second, given the state of the economy and the surplus of labor during the 1930's, there was little economic incentive among the country's major industries to mechanize their materials handling systems.

During World War II, however, the urgent need for faster and more effective methods of handling vast amounts of materials stimulated the development of a variety of highly maneuverable, motorized forklift "trucks." The use of these vehicles allowed goods to be moved, stacked, and stored with extraordinary speed and versatility, and with a minimum of labor. The primary base structures used for these functions were the two- and four-way-entry wooden pallets. After World War II, the pallet industry continued to grow with the economy. As major industrial segments such as the food, beverage, chemical, metal, automotive, and transport industries expanded and sought more effective means of handling their products, the mechanization and use of wooden pallets became widespread.

TODAY'S INDUSTRY

Since its birth as a manufacturing segment, the United States' pallet industry has evolved from a "cottage" industry to a major supplier of base structures for materials handling. From an annual output of 11 million pallets in the late 1930's, the industry produced about 32 million in 1946 and grew to 505 million in 1989. Today, the wooden pallet industry is still growing. In units produced, the industry has averaged a 17.3-percent annual rate of growth over the past 9 years. In addition to the market's pallet replacement needs and an expanding economy, this growth has been in response to: (1) a broadened market as a larger proportion of industrial firms palletize; and (2) the increased mechanization and automation of materials handling systems by current users of pallets.

In 1989, pallet manufacturers produced more than 505 million new pallets and skids--the most ever according to estimates by the National Wooden Pallet and Container Association (1990). Pallet output in 1989 represented a 121-percent increase in production over that of 1982 (228.3 million) and more than tripled the 1972 output of 155 million. Since 1972, pallet

production has increased with general steadiness except for 1975 and 1982, both economic recession years. Between 1983 and 1989, the industry showed its strongest and most sustained growth since World War II.

The 17-year general expansion in pallet output brought about a corresponding but less than proportional increase in the total value of pallet products sold. This holds true whether shipment values are measured in either current or constant prices. In current dollars, the industry's value of pallet products shipped increased more than sixfold (642 percent), or from $623 million in 1972 to $4 billion in 1989.

In recent years, while both the total output and shipment values of new pallets have increased, the price per unit in terms of 1982 dollars decreased and then stabilized. Between 1972 and 1979, the inflation-adjusted average price of new pallets increased, reaching a peak in 1979 at $9.99 per unit. After 1979, the price of pallets decreased and then became relatively stable at a lower level. The real price of pallets sold between 1972 and 1982 averaged $8.83 per unit (1982 dollars). Similarly, adjusted prices averaged $7.66 per pallet from 1982 through 1989--with average annual prices ranging from $7.42 to $7.92 per unit.

Such patterns in production and prices show that the industry's recent 7-year growth in value of shipments was due to increased quantity and quality of pallet production rather than to increases in unit price. This efficiency has allowed the wooden pallet industry to grow despite counteracting forces such as increased competition from alternate materials; steadily rising costs of raw material, energy, transportation services, and other production items; and adverse changes in the automotive and defense materials handling markets.

CAPITAL/LABOR SUBSTITUTION

A major reason for the improved competitive position of the pallet industry is the substitution of capital for labor (Dempsey 1988). This trend has been most obvious since 1977 and particularly in the more repetitive, labor-intensive operations. In 1985, the last year for which complete data are available--the pallet industry invested more than $46 million in capital assets, 86 percent in new production items, and 14 percent in used assets. This investment was 8 percent higher than the annual average ($42.9 million) for the previous 4 years and nearly double that invested by the industry in 1977 ($24.1 million).

The industry's largest expenditures, $39.7 million, were for "new" capital assets in the form of machinery and equipment, plants, facilities, and other production structures. Within this category, new machinery and equipment for mechanizing and automating production were the capital goods purchased most heavily, totaling 85 percent of investments. The balance of expenditures, 15 percent, was for new plants, facilities, and other structures.

A break with the practice of relying on labor to sustain increases in output first became evident in the late 1970's. Innovative new machinery and equipment were coming onto the market, and capital investments increased to $1,418 per production worker. By 1979, there

was both a surge in capital investments and a leveling in employment of production workers. This production year represented a turning point in the pallet industry's capital and labor investment mix. And the manner in which these productive factors were used was changing. The developing trend emphasized the substitution of capital for labor in the production of pallets.

Capital investments continued strong from 1979 through 1985, and most likely to the present. Annual investments per worker nearly doubled (up 91 percent) from 1977 through 1985, increasing from $1,190 to $2,282 per production worker and continuing the trend toward a lessening dependence on labor to sustain output.

CHANGE IN RAW MATERIAL USE

Beginning in its formative years--in the late 1930's and early 1940's--and lasting over 2 decades, the pallet industry obtained its raw material almost exclusively from the lower grades of random-width, random-length lumber generated as a byproduct of the grade hardwood sawmills (Martens 1989a). The predominant grades used were No. 2 and No. 3 Common. Softwood lumber was substituted in some areas where hardwoods were difficult to obtain. In such cases, the softwoods used were primarily from the economy and utility grades of West Coast lumber and in the No. 3 and No. 4 southern pine structural grades.

As the pallet industry became a more consistent market for lumber, the hardwood sawmill industry began manufacturing a sound grade of lumber in 4-, 6-, and 8-inch widths commonly referred to as "pallet grade." The use of pallet grade lumber not only reduced the waste incurred by the industry's use of random-width lumber, but also assured the sawmill industry a steadily growing market for the difficult-to-move, lower furniture grades.

By the 1960's, the demand for the lower grades of hardwood lumber began to exceed the supply generated by the grade lumber mills in many areas. It was during this period that vertical integration began within both the sawmill and pallet plant sectors. Most of the integrated sawmills, however, still operated as traditional hardwood grade mills with high-value lumber going to the furniture industry and lower grade lumber going to the pallet industry. It also was about this time that we saw the advent of 4-, 6-, and 8-inch cants.

The cant concept quickly became popular because its use was advantageous to both the sawmill and the pallet mill. In the sawmill, the time that each log spent at the headsaw was shortened. This increased both the total volume of lumber produced and the volume of lumber in the higher valued grades. In the pallet plant, the use of cants eliminated the waste generated from random-width lumber and allowed greater flexibility in the variety of pallet part sizes that could be produced.

Cants, particularly the 4- by 6-inch size, provided maximum versatility in the production of pallet parts with minimum waste; they also could be handled and stored efficiently and breakdown could be automated, allowing increased production while minimizing labor costs.

The production of 1-5/8-inch thickness of lumber from cants also appears to be gaining in popularity for many of the same reasons--high flexibility, minimum waste, high production, and ease of handling. Full thickness is used for stringers, the lumber resawn once for 3/4-inch deckboards or twice for 1/2-inch deckboards. Many pallet plants with roundwood sawing facilities are cutting to 1-5/8 inch for internal storage and use.

In the 1970's, as raw material supplies tightened, more and more bolter mills and scragg mills were being used to produce pallet parts from pulpwood bolts. Also, in the captive sawmills there was less emphasis placed on producing grade lumber. The concept of going directly from roundwood to pallet parts became common. In the 1980's, a considerable portion of the pallet industry took this practice one step farther by shifting to tree-length material, thus eliminating the log step. With tree-length material, the stems are crosscut to the length, or multiples of the length, of the pallet parts to be produced. This virtually eliminates end trim waste, increases volume yield, and facilitates handling through multiple scragg saws, gang ripsaws, or other multiple sawing operations.

By 1986, according to McCurdy and Ewers (1987), the raw material used for pallet production in the predominately hardwood regions consisted of 24.4 percent logs, 36.7 percent cants, and 38.9 percent lumber. The lumber category also included 6/4 lumber that was resawn and precut pallet shook. Of the 24.4 percent in logs, 5.8 percent was purchased as stumpage, almost one-fourth of the total logs category.

THE FUTURE?

One of the more significant changes within the pallet industry has been the amount of raw material used in the manufacture of wooden pallets. In the last 20 years, the average volume of lumber contained in a pallet has decreased from 20 board feet to about 13 (McKeever 1987). Unpublished data from a 1985 survey conducted by Dwight R. McCurdy and James T. Ewers at Southern Illinois University showed that pallet part sizes had decreased. Where the deckboard thickness for nonexpendable hardwood pallets was 1 inch 20 years ago, more than one-half of these pallets now have deckboards that are 3/4-inch or less. Further, well over 50 percent of the expendable hardwood pallets produced had deckboards of 1/2-inch in thickness (Martens 1989a).

This trend in the reduction of raw material used per unit is expected to continue as the Nation's pallet-using industries progress toward faster, more automated materials handling systems to provide a more competitive service and reduce costs in the process. The demand is expected to increase for lighter, more versatile base structures of equal or better strength to complement such systems. In such a market, the challenge for the wooden pallet industry will be to produce a more tailored and better engineered product while maintaining tight controls over pallet manufacturing costs.

The trend away from the purchase of 1-inch lumber by the pallet industry will likely continue because of its comparatively high handling cost, limited flexibility, and lower efficiency. By

contrast, the use of sawn cants and 1-5/8 inch thick boards will likely remain strong because of their high versatility and low waste factors. The latter also can be used to supplement the raw material supply of pallet plants that maintain roundwood sawing facilities. Consequently, grade hardwood lumber mills producing these products should continue to have a steady market for them.

In recent years there have been considerable efforts to develop and market pallets produced from more energy intensive materials such as plastic, metal, corrugated paper, and reconstituted wood. Some have found their way into specialized use markets. To date, however, about 97 percent of all pallets are still made of wood. This probably will remain true for the foreseeable future. Wood is versatile, less energy intensive, and generally a less costly material to use for pallets.

In sum, the United States' wooden pallet industry has proven itself to be strongly competitive, both internally and externally. To meet the challenges cited, the industry is expected to continue its advancements in mechanization, automation, and communication processes as a means of improving quality and reducing costs in the more labor-intensive, production-flow processes, and provide better service in product marketing activities. In doing so, the wooden pallet industry may become even more aggressive in lowering the relative cost of raw materials and become less labor dependent and more capital intensive.

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FACTORS DETERMINING THE LOCATION OF FOREST PRODUCTS FIRMS

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Abstract: In the past decade there has been an increase in the number of intrastate, state and regional programs aimed at encouraging forest resource based economic development in northeastern USA. These programs were aimed at deriving economic benefits from the large volume of mature forest resources in the region. The improvement of rural communities by creating job opportunities was seen as one of the primary benefits of the development programs, and they therefore focused attention on attracting firms and new manufacturing facilities. Most of these programs set the location of forest products firms as their target and seem to operate on the hypothesis that all forest products firms have the same general requirement when choosing a new location. The purpose of this study was twofold: first to test the hypothesis that different types of forest products firms have the same location requirements and second to test the hypothesis that location determinants within communities are the same irrespective of their size. Statistical analysis of 30 independent variables representing the economic, infrastructural, geographic and social conditions of 1098 northeastern communities indicate that each of the three types of forest industry subsectors studied had a unique combination of location determinants. In addition, each subsector had location determinants in metropolitan communities which were significantly different from the location determinants of non-metropolitan communities. These results suggest that programs aimed at attracting forest products firms may derive greater benefit from matching firms and communities rather than following the common practice of going after whole industries.

INTRODUCTION

In the past decade there has been a significant increase in the number of intrastate, state and regional programs aimed at encouraging forest resources based economic development in northeastern USA (Jones and Koester 1989). These programs are usually geared to deriving economic benefits from the large volume of mature forest resources in the region (State Foresters 1984). Improving the economies of rural communities by creating job opportunities is seen as one of the primary benefits of developmental programs which focus on attracting new manufacturing facilities. Most programs attempt to promote their state\region by advertising the positive aspects of their area. The promotional activities are typically general with respect to content and audience. A possible explanation for this situation, in a marketing analogy, is that the programs (sales departments) have not identified target

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industries (the consumers) to whom they make their 'sales pitch', neither have they identified target communities (the products) they plan to 'sell' to the industries. A possible reason for this may be that implicit in these programs are two very important assumptions: first, firms in all forest products industries have the same requirements and second, these firms have the same requirements irrespective of the size of the community in which they choose to set up new businesses. These assumptions contradict industrial location theory. Since various wood product industries have different input requirements and markets, location theory would suggest that a community which is a good site for plants in one industry might be a poor site for plants in another wood products industry. Further, location theory suggest that plants in a given industry may have different orientations. For example, a furniture factory may locate in a metropolitan area solely because of the market in that area. Another furniture plant may locate in a rural area to take advantage of cheap inputs and plan to serve regional or national markets. Thus, location theory provides the conceptual base for two hypotheses: that is, (i) the location requirement of forest products firms are invariant with respect to industry type; and (ii) the location requirements of forest products firms are invariant with respect to community size.

METHODS

Conceptual Issues And Hypotheses

Types of Forest Products Firms: Conventional wisdom suggests that, in the aggregate, forest product firms would have a set of location requirements that are very different to firms in the broadcasting industry. Firms planning to locate forest products manufacturing plants would be concerned with the availability and cost of raw material, labor and utilities; the location of markets; and the transport linkages. On the other hand, firms planning to set up a new broadcasting facility would be primarily concerned with the size of their broadcast service niche/market and be little concerned about transport facilities or energy costs.

Empirical industrial location studies support this hypothesis. In fact, recent studies have looked at the factors influencing the choice of a geographic area as the site for a new facility. Coughlin's *et al.* (1989) study of foreign direct investment in the USA is an example of such a study. These researchers were able to determine those factors which are important in the site choices of aggregate (2 digit SIC) industries. The fundamental hypothesis of this study was that two digit SIC industries have different location determinants. The empirical analysis supported this analysis. Implicit in this analysis, however, was the hypothesis that the location requirements of sawmills (SIC 2421) and wood kitchen cabinet manufacturers (SIC 2434) are exactly the same. The same, as all other firms in the aggregate Lumber and Wood Products Manufacturing industry (SIC 24).

An alternative hypothesis suggests that, in spite of wood being a common component in the production process, there may be enough differences in the location requirements that a sawmiller would choose an entirely different location from the location chosen by a kitchen

cabinet manufacturer. A sawmiller, for example, would be concerned about the supply of sawlogs in a chosen locality, whereas, the kitchen cabinet manufacturer would be concerned about access to markets in a chosen locality.

Types of Communities: Most economic development programs are based on the conventional wisdom that firms in a given industry would choose similar types of communities to set up businesses. Most industrial location analyses are based on this assumption. Smith, et al, (1978) for example conducted a study of southern communities and found that seven factors (site quality, site ownership, access to interstate highways, availability of bond finance, fire protection, presence of a college, and educational expenditure) were important in explaining why firms chose to locate in these communities.

An alternative hypothesis suggests that the size of the community would affect what factors become important in making location choices. Two possible scenarios are presented to suggest why this hypothesis may have validity. First, large communities, that is metropolitan areas, may have most of the prerequisites to attract most types of firms. In contrast, smaller communities may be limited to meeting only some of the location requirements of some types of firms. In the small cities and towns therefore, there may be many different features of the location, economic base, or labor force which may have significant statistical importance. In larger cities so many important features may be common that only a few differences are statistically significant. Second, and more important, some firms may deliberately choose a larger city because they plan to satisfy a particular market niche within that city. Another firm may be less concerned about such a narrow market and choose, instead, a non-metropolitan community with a low tax rate. Population size and/or population density have been included in industrial location models as a control variable, but, there has never been an explicit test of the differences in the location determinants in metropolitan and non-metropolitan communities. That is, the interaction between community size and other location determinants has not been explored.

The following section contains a discussion of the models that were developed to test two hypotheses:

(i) different types of forest products firms have the same location requirements, and

(ii) location determinants for metropolitan communities are the same as the location determinants for non-metropolitan communities.

Models To Test The Hypotheses

To test these hypotheses it was neccessary to develop a model that contained a set of explanatory variables which would reflect the unique socioeconomic and place-specific attributes of communities. The Northeast Industrial Targeting and Economic Development Database (NIT & EDD) System developed by Goode and Hastings (1989) was the source of the 31 independent variables used in the analysis. These variables were (acronyms in capital letters):

i) Potential Market Access. This variable (MARKET), conceptualized and made operational by Goode (1986), reflects if there is an excess quantity demanded for the industry's product in the market area surrounding the community.

ii) Potential Net Input Availability (PNIA) of Intermediate Manufactured Inputs. There are three (INPUT1, INPUT2, INPUT3) of these intermediate manufactured input variables (operationalized by Goode and Hastings 1988) for each of the three wood processing industries. The input variables are different for each of the wood processing industries. These input variables were selected on the basis of the magnitude of their input coefficient in the national Input/Output model. Positive values of these variables reflect whether the community is located in an area where there is an excess quantity of the inputs.

iii) Potential Net Input Availability of Forest Resources. This variable (FOREST, estimated in the same way as the input variables) reflect whether the community is located in an area where there is an excess quantity of forest resources supplied.

iv) Taxes

Per-Capita State Taxes (STATE)
Per-Capita County + Local Taxes (LOCAL+CNTY)
Source: 1970 Revenue Sharing File - US Department of Treasury

v) Transportation

Number of Railroads (RAILROADS)
Number of Airlines (AIRLINES)
Distance to Interstate Highway (HIWAY)
Distance to Primary Highway (ROAD)
Source: 1970 Rand-McNally Atlas

vi) Labor Force Characteristics

% with College Education (EDUCATED)
Male Labor Force Participation (MALELABOR)
Female Labor Force Participation (LADYLABOR)
% Males Working More Than 27 Weeks (MALEFULL)
% Female Working More Than 27 Weeks (LADYFULL)
Source: 1970 Census of Population

vii) Community Services

% Houses with Sewer (SEWERS)
Number of Hospital Beds (HBEDS)
Source: American Directory of Health Care Providers

viii) Colleges in the Community

viii) Colleges in the Community
% Population in College (COEDS)
Source: Directory of America Colleges and Universities

ix) Level of Development
Per-Capita Income (INCOME)
% Employed in Manufacturing (MFTLABOR)
% Houses Vacant (VACANT)
Source: 1970 Census of Population

x) Community Attributes
Distance to Metropolitan Statistical Area
Source: 1970 Rand McNally Atlas (PROXIMITY)
Population size (POPULATION)
Complexity of Service Sector
SERVICES - developed service sector
BSERVICES - basic service sector
Source: 1970 Duns Market Indicators File

xi) Demographic Characteristics
% Living in Same County for 5 years (RESIDENTS)
% Population that is nonwhite (NONWHITES)
% Population older than 65 years (RETIREES)
Source: 1970 Census of Population
Region - NEWENGLAND
- MIDATLANTIC

The dependent variable in the models was a dichotomous variable with a one (1) indicating that the community had a new plant start in the industry during the period 1970-1980, a zero (0) indicated that the community did not have a start.

Data Analysis

Units of Analysis and Study Area: The units of analysis were communities in 13 northeastern states (Virginia, West Virginia, Pennsylvania, New York, New Jersey, Delaware, Maryland, Massachusetts, Rhode Island, Connecticut, New Hampshire, Vermont, and Maine). Communities were defined as a Census Place and surrounding minor civil divisions whose population centroid was within five miles of the population centroid of the Census Place. One hundred and five large metropolitan areas (population greater 100,000 people) were excluded from the 1203 communities in the NIT&EDD. The remaining 1098 communities were divided into two samples containing 368 small metropolitan and 730 non-metropolitan communities. Metropolitan communities were those located in Metropolitan Statistical Areas.

Forest Industries Studied: Three subsectors of the forest products industries were analyzed in this study. An aggregation of 4 digit SIC industries into subsectors was necessary in order to have large enough samples to provide statistically reliable results. Some problems of using aggregate data were reduced by combining only those industries with similar input requirements as determined from the national input-output table. The subsectors analyzed were:

(i) The Furniture Subsector
Comprised of the SIC industries
2431-Millwork,
2434-Wood Kitchen Cabinets,
2511-Wood Household Furniture, and
2517-Wood TV, Radio, and Sewing Cabinets
The three PNIA variables for this subsector were:
(1) Sawmill, (2)Wood Veneer and Containers, and (3) Plastics.

(ii) The Wood Veneer Subsector
Comprised of the SIC industries
2435-Hardwood Veneer and Plywood,
2436-Softwood Veneer and Plywood,
2439-Structural Wood Members,NEC,
2441-Wood Boxes,
2449-Wood Containers,NEC, and
2452-Prefabricated Wood Building and Components
The three PNIA variables for this subsector were:
(1) Logging, (2) Sawmills, and(3) Plastics.

(iii) The Pallet Subsector
Comprised of the SIC industries
2448-Wood Pallets and Skids,
2492-Particleboard, and
2499-Wood Products,NEC
The three PNIA variables for this subsector were:
(1) Sawmills, (2) Plastics, and (3) Logging.

The Models: Nine models were analysed in this study. Six models were estimated by SAS Stepwise Logistic Regression Procedure (SAS, 1985). The first 3 models were used to determine what subset of the 31 independent variables were significant (alpha=.10) in explaining the location of each of the 3 subsectors in the 368 metropolitan communities. The second 3 models were used to determine what subset of the 31 independent variables were significant (alpha=.10) in explaining the location of each of the 3 subsectors in the 730 non-metropolitan communities.

A third set of 3 models contained 62 independent variables, the 31 variables discussed above and another 31 computed by multiplying each (of those 31 variables) by a dichotomous variable, which had a value of one (1) for metropolitan communities and a value of zero (0) for non-metropolitan communities. The latter 31 variables were used to determine which of

the first 31 variables were significantly different (alpha=.10) in metropolitan and non-metropolitan communities.

RESULTS

The Aggregate Industry Effect

We examined the regression results by organizing the significant variables to highlight a comparison of the location determinants of the three subsectors (Table 1) within metropolitan and non-metropolitan communities. In general, the results indicate that the set of industrial location determinants for each of the three subsectors were different in both types of communities.

Metropolitan Community Models: Of the 11 significant variables in the three subsector models for metropolitan communities none were significant in all three models. Two variables BSERVICE, NEWENGLAND) had coefficients with the same sign in the furniture and the pallet subsectors: indicating that these firms chose New England communities with well developed service sectors. The veneer and pallets subsector were both attracted to larger communities. However, firms in the veneer subsector located in communities with higher per-capita incomes, while firms in the pallet industry located in communities with low per-capita incomes. Opposite signs on the coefficients of a significant variable (NONWHITE) was also evident in the furniture and veneer subsectors models. Here, the result suggest that firms in the furniture subsectors located in communities that had higher proportions of nonwhite residents, while, firms in the veneer subsector located in predominantly white communities.

There were 3 unique significant variables (INPUT1, ROAD, EDUCATED) for the furniture subsector, 1 unique variable (LADYLABOR) for the veneer subsector, and 2 unique variables (AIRLINES, MALELABOR) for the pallet subsector. These results suggest that firms in the furniture subsector tended to concentrate in more remote metropolitan communities with a high proportion of college graduates. On the other hand, firms in the veneer subsector tended to locate where there was a high level of female participation in the workforce. Firms in the pallet subsector located in metropolitan communities with good airline connections and a high level of male participation in the labor force. Thus, while there are some common location determinants there are also significant differences across industries.

Non-Metropolitan Community Models: Of the 16 variables significant in the three subsector models only one (POPULATION) was significant in all three models. A result which clearly indicates that larger non-metropolitan communities are most likely to be chosen by the types of firm represented in these subsectors. However, while firms in the furniture and pallet subsectors tended to locate in non-metropolitan communities where similiar firms are already established, there is no such tendency indicated for firms in the veneer subsector. Further, while firms in the furniture subsector and the veneer subsector displayed regional tendencies,

Table 1.-- Location determinants for metropolitan and non-metropolitan communities for the Furniture, Veneer, Pallet and their allied inputs industries subsectors.

	METROPOLITAN			NON-METROPOLITAN			
VARIABLE	FURN	VENR	PALL	FURN	VENR	PALL	
MARKET	.	.	.	(-)	.	(-)	*
INPUT1	(-)	.	.	(-)	.	(-)	*
INPUT2	.	.	.	.	.	(+)	
INPUT3	.	.	.	.	.	.	
FOREST	.	.	.	(-)	.	.	
STATE	.	.	.	.	.	.	
LOCAL+CNTY	.	.	.	.	.	(-)	
AIRLINES	.	.	(+)	.	(+)	(+)	*
RAILROADS	.	.	.	.	.	.	
ROAD	(+)	.	.	(-)	.	.	
HIWAY	.	.	.	.	.	.	
EDUCATED	(+)	.	.	.	.	.	
MALELABOR	.	.	(+)	(+)	.	.	
LADYLABOR	.	(+)	.	.	.	(+)	
MALEFULL	.	.	.	.	.	.	
LADYFULL	.	.	.	.	(+)	.	
SEWERS	.	.	.	.	.	.	
HBEDS	.	.	.	.	.	.	
COEDS	.	.	.	.	.	.	
MFTLABOR	.	.	.	.	.	.	
INCOME	.	(+)	(-)	.	.	.	
VACANT	.	.	.	(+)	.	.	
PROXIMITY	.	.	.	.	.	.	
POPULATION	.	(+)	(+)	(+)	(+)	(+)	*
SERVICES	.	.	.	.	.	.	
BSERVICE	(-)	.	(-)	(-)	(-)	.	*
NONWHITE	(+)	(-)	.	.	.	.	
RETIREES	.	.	.	.	.	.	
NEWENGLAND	(+)	.	(+)	(+)	.	.	*
MIDATLANTIC	.	.	.	(+)	(-)	.	
RESIDENTS	.	.	.	.	.	(-)	
COMMUNITY	368	368	368	730	730	730	
STARTS	120	44	93	145	80	131	
STARTS (%)	33	12	25	20	11	18	
SIGNIFICANT	6	4	6	10	5	8	
COMMON	<- 0 ->	<- 1 ->		<- 2 ->	<- 2 ->		
COMMON	<----- 2 ---->			<----- 4 ---->			
OVERALL		11			16		19
COMMON		3			5		6

* Significant variables (with the same sign) common to at least two subsectors in the same community.

no such tendency was displayed by firms in the pallet subsector. Firms in the veneer and pallet subsectors located in non-metropolitan communities with good airline connections while firms in the furniture industry located in non-metropolitan communities close to primary roads. A well developed service sector was important to firms in the furniture and veneer subsectors while low local and county taxes appears to be important to firms in the pallet subsector. Finally, firms in the furniture subsector tended to locate in non-metropolitan communities with high housing vacancy rates and high levels of male participation in the labor force, while, firms in the veneer and pallet subsectors located where there was a large female workforce.

The Community Size Effect

The results of the analysis for the three subsectors are presented in Table 2. Variables with coefficients which were significantly different in metropolitan and non-metropolitan communities are also indicated. In general these results indicate that the location determinants for the metropolitan communities were different from the location determinants for non-metropolitan communities.

The Furniture Subsector: Close examination of Table 2 shows that there are 10 variables which are significant in explaining the location of the furniture subsector in non-metropolitan communities, while there are 6 location determinants for metropolitan communities. There were 4 variables (MARKET, FOREST, ROAD, LADYFULL) with coefficients which were significantly different in metropolitan and non-metropolitan communities. The coefficients for one of these variables (ROAD) had opposite signs in the two models. A result which suggests that non-metropolitan communities close to primary roads are more likely to attract a new firm, while remote metropolitan communities are more attractive. This apparently contradictory result may be explained by the market orientation of the firms. Firms locating in non-metropolitan communities may plan to cater to regional markets, while firms locating in remote metropolitan communities may plan to cater to the local market. Thus, highways are important to non-metropolitan furniture plants and not important to metropolitan furniture plants.

Three of the location determinants (INPUT1, NEWENGLAND, BSERVICE) were common to the two models and had the same sign. A result indicating a preference by firms in this subsector to locate in New England communities with a well developed service sector and a sawmill output deficit (i.e. consumption of sawmill output exceeds local supplies. A phenomena Goode (Goode 1989) associated with agglomeration). The two other variables (NONWHITE, EDUCATED) in the metropolitan model suggest that firms may prefer communities with a high proportion of nonwhite and a high proportion of college educated people. The other 6 variables (MARKET, FOREST, MALELABOR, VACANT, POPULATION, MIDATLANTIC) in the non-metropolitan model suggest that these firms tended to locate in larger communities with excess output (i.e. the output from the subsector exceeds local consumption. A phenomena Goode (Goode 1989) also associated with agglomeration). Non-metropolitan communities in Mid-Atlantic states with vacant housing

Table 2.-- Variables significant (alpha=.10) in the industrial location models for the Furniture, Veneer, Pallet and their allied inputs industries subsector analysed by metropolitan and non-metropolitan communities.

	-FURNITURE-		--VENEER---		---PALLET-----		
VARIABLE	METRO	NONMETRO	METRO	NONMETRO	METRO	NONMETRO	
MARKET	.	(-)**	.	.	.	(-)	
INPUT1	(-)	(-)	.	.	.	(-)	*
INPUT2	.	.	.	.	.	(+)	
INPUT3	.	.	.	.	.	.	
FOREST	.	(-)**	.	.	.	.	
STATE	.	.	.	.	.	.	
LOCAL+CNTY	.	.	.	.	.	(-)**	
AIRLINES	.	.	.	(+)**	(+)	(+)	*
RAILROADS	.	.	.	.	.	.	
ROAD	(+)	(-)**	.	.	.	.	
HIWAY	.	.	.	.	.	.	
EDUCATED	(+)	.	.	.	.	.	
MALELABOR	.	(+)	.	.	(+)	. **	
LADYLABOR	.	.	(+)	.	.	(+)	
MALEFULL	.	.	.	.	.	.	
LADYFULL	.	. **	.	(+)**	.	.	
SEWERS	.	.	.	.	.	.	
HBEDS	.	.	.	.	.	.	
COEDS	.	.	.	.	.	.	
MFTLABOR	.	.	.	.	.	.	
INCOME	.	.	(+)	.	(-)	.	
VACANT	.	(+)	.	.	.	.	
PROXIMITY	.	.	.	.	.	.	
POPULATION	.	(+)	(+)	(+)**	(+)	(+)	*
SERVICES	.	.	.	.	.	.	
BSERVICE	(-)	(-)	.	(-)	(-)	.	*
NONWHITE	(+)	.	(-)	. **	.	.	
RETIREES	.	.	.	.	.	.	
NEWENGLAND	(+)	(+)	.	.	(+)	.	*
MIDATLANTIC	.	(+)	.	(-)	.	.	
RESIDENTS	.	.	.	.	.	(-)	
SIGNIFICANT	6	10	4	5	6	8	
OVERALL	12		8		12		19
COMMON	<- 3 ->		<- 1 ->		<- 2 ->		5

* Significant variables (with the same sign) common to subsector models in the two types of communities.

** Variables with coefficients in metropolitan models which were significantly different (alpha=.10) from coefficients in non-metropolitan models.

and a high level of male labor force participation were also likely to attract firms in this subsector.

The Wood Veneer Subsector: Examination of Table 2 shows that there were four variables (LADYLABOR, INCOME, NONWHITE, POPULATION) which help to explain the location of the wood veneer subsector in metropolitan communities. There were also four location determinants (AIRLINES, LADYFULL, POPULATION, BSERVICE, MIDATLANTIC) for non-metropolitan communities. Of these variables four (AIRLINES, LADYFULL, POPULATION, NONWHITE) had coefficients which were significantly different in metropolitan and non-metropolitan communities. One of these location determinants (POPULATION) was common to the two models. In both models the effect was positive i.e. larger communities were more likely to get a new firm than a small community, but, in the non-metropolitan communities the size effect was more important since the coefficient for this variable was significantly larger in the non-metropolitan model than the coefficient for the variable in the metropolitan model. These results indicate there is a very clear preference by firms in these industries to locate in larger communities whether they were metropolitan or non-metropolitan. However, firms locating in non-metropolitan communities tended to locate in New England and South Atlantic towns with well developed service sectors, good airline connections and high proportions of working women. In metropolitan communities, firms tended to locate in places with predominantly white populations, high female workforce participation rates, and high per capita incomes.

The Pallet Subsector: Examination of Table 2 shows that there are 8 variables (MARKET, INPUT1, INPUT2, LOCAL+CNTY, AIRLINES, LADYLABOR, POPULATION, RESIDENTS) which help to explain the location of wood veneer subsector in non-metropolitan communities, while there are 6 location determinants (AIRLINES, MALELABOR, INCOME, POPULATION, BSERVICE, NEWENGLAND) for metropolitan communities. There were 2 variables (LOCAL&CNTY, MALELABOR) with coefficients which were significantly different in metropolitan and non-metropolitan communities. A result which shows that the effect of local and county taxes were significantly more important to firms locating in non-metropolitan communities, while the male labor force participation rate was significantly more important to firms locating in metropolitan communities. Only 2 of the location determinants (POPULATION, AIRLINES) were common to the two models. A result indicating a preference by firms in this subsector to locate in larger communities served by a number of airlines. However, firms locating in non-metropolitan communities also tended to locate where there was an excess supply of plastics and a high proportion of working women. While, firms locating in metropolitan communities also tended to locate in New England towns where there were high male labor force participation rates, highly developed service sectors, and low per capita income.

In summary, while the models for the three subsectors of the forest products industry had some variables in common, each subsector model had several unique significant explanatory variables. In the metropolitan community models there were 11 significant variables, of these only three had the same sign in at least two of the subsectors. In non-metropolitan community models there were 16 significant variables, of these only five had the same sign in at least two of the subsectors. Overall, there were 19 significant variables, of these only six

had commonality across subsectors within community type. Therefore, less than a third of the determinants were common to two or more of the subsectors. Evidence which suggest that each subsector has a relatively unique set of location determinants.

SUMMARY AND CONCLUSION

This study was designed to test the hypotheses that location determinants within communities are invariant with respect to community size and industry subsector. To test these hypotheses 31 variables reflecting the socioeconomic and space specific characteristics of 1098 northeastern communities were estimated by stepwise logistic regression. The results indicate that each subsector had location determinants which were different in non-metropolitan communities and metropolitan communities. Comparison of the significant variables for the three subsectors indicate that less than a third of the determinants were common to two or more subsectors. This suggests that each subsector has a relatively unique set of location factors whether they were metropolitan or non-metropolitan community models.

The conclusions of this study are twofold. First, non-metropolitan communities have a different set of location determinants for forest products industries than small metropolitan communities in northeastern USA. Second, subsectors of the forest products industry each have a set of location requirement which are different. These results suggest that programs aimed at attracting forest products firms in northeastern USA need to be make a special effort to target the specific type of firm they are interested in while being aware of the socio-economic and space specific characteristic of the communities they are planning to develop.

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ARE WE UNDERESTIMATING THE SIZE OF OUR HARDWOOD INDUSTRIES?

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Abstract: Sawmills and planing mills (SIC code 2421) were analyzed by comparing data from the 1987 County Business Patterns, published by the U. S. Bureau of Census, and research conducted by the Ohio Cooperative Extension Service for the same year. The Ohio study and the Bureau of Census survey were comparable in industry sector definition, data collection unit and survey instrument. The Ohio research included all known sawmills and planing mills in Ohio whereas the Bureau of Census used probability sampling based on firm size with estimates made of establishments with under five employees. The Ohio research found substantial increases in number of establishments (38 percent), number of employees (88 percent) and annual payroll (82 percent) compared to Census Bureau estimates of the Ohio sawmill and planing mill industry. Foresters, forest product specialists, economic developers and others who work with the forest products industry need to be cautious when using published Census Bureau data to describe the industry. Evidence from the Ohio study and other research suggests a substantial Census Bureau underestimation of the true size of the hardwood industry.

INTRODUCTION

The central hardwood forest, which includes parts or all of 24 states, is the largest forest region in the United States. The economic and social importance of this forest region is significant when one considers that with the exception of the Pacific Coast, eastern Canada, and central Mexico, the largest concentration of population and industry in North America is located in this region (Duffield 1982).

Historically, the central hardwood forest region has been a national leader in the production of wood and paper products. Today however many states are viewing their forests from a much broader perspective. Pennsylvania, for example, has targeted the forest products industry as part of an overall statewide economic development effort. Other states such as Ohio have not formally targeted the industry for development but have increased their economic development efforts in the forested regions of the state.

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Statistics published by the U. S. Bureau of Census are frequently used as a starting point for studies involving economic impact and development potential. Economic developers, educators, planners, legislators, researchers and persons involved in the financial sector use Bureau of Census data for needs assessment, program planning and the like. Historically foresters, forest product specialists and forest industry officials have expressed concern that the Bureau of Census underestimates the true size of the forest products industry. Phelps and Smith (1985), in describing a Missouri study, conclude that Census Bureau data may underestimate industries that use wood as a raw material. Jones and Zinn (1986), report the number of establishments, number of employees and annual wages of West Virginia forest product industries to be roughly double those reported by the U.S. Bureau of Census.

Dempsey (1987) states that in 1982 the Census Bureau provided data on 751 commercial lumber producing sawmills and planing mills operating in Pennsylvania, Kentucky and West Virginia; state forest product industry directories, however, reported 1892 operational sawmills located within the tri-state area in 1984. Doud (1990) estimates the number of employees in the Pennsylvania kitchen cabinet industry to be nearly three times the Census Bureau estimate. Additional discrepancies in the area of hardwood lumber production have also been reported (Cardellichio and Binkley 1984, Luppold and Dempsey 1989).

Numerous reasons have been proposed to explain the discrepancies between the findings of statewide or regional studies and Bureau of Census surveys. One explanation is definition. The Census Bureau categorizes industries by the primary product shipped as determined by dollar value. Consequently, a combination logging and sawmill establishment is defined by the Census Bureau as either a logging establishment or a sawmill but not both. Based on definition, some establishments may be counted twice or omitted entirely in statewide and/or regional surveys.

A second possible explanation for the discrepancies between numbers reported by state and/or regional studies and U. S. Bureau of Census estimates could be due to the data collection unit. The Bureau of Census uses the individual establishment as the data collection unit. For example, "Company A" may be the non-manufacturing corporate headquarters for establishments X, Y and Z. The Bureau of Census would survey the X, Y and Z manufacturing establishments but not Company A, the corporate headquarters. However, if Company A mistakenly received, and responded to a survey instrument on "behalf" of the X, Y and Z establishments, then double counting would occur if the individual establishments also were surveyed.

Third, it is not uncommon for statewide and/or regional surveys to contact 100 percent of the known establishments. The Census Bureau, however, uses probability sampling based on firm size with estimates made of establishments with under five employees. Since the hardwood industry is characterized by numerous small firms (Haygreen and Bowyer 1989), the Census Bureau may not be adequately canvassing the entire industry.

Fourth, Census Bureau data is often compared with studies where the survey time period is different. While the time period difference may not always be a problem in itself, when

coupled with one or more of the previous explanations could contribute to the discrepancies between statewide and/or regional and Census Bureau survey estimates.

PURPOSE

The purpose of this study was to: 1) identify the discrepancy (if any) between statistics published by the U. S. Bureau of Census and a statewide study on selected variables for the 1987 Ohio sawmill and planing mill sector (SIC code 2421) and 2) quantify the extent of the discrepancy.

METHODS

Research Design

This study was descriptive in nature and utilized mail questionnaires for data collection. To have a meaningful comparison between Bureau of Census data and the Ohio survey research data, a common definition of the industry sector was used (Anon. 1987). The Bureau of Census defines sawmills and planing mills (SIC code 2421) as: 1) those establishments primarily engaged in sawing rough lumber and timber from logs and bolts, or resawing cants and flitches into lumber, including box lumber and softwood cut stock, 2) planing mills combined with sawmills, and 3) separately operated planing mills which are engaged primarily in producing surfaced lumber and standard workings or patterns of lumber. Dry kilns and mills producing railroad ties, chips and studs are also included in the Bureau of Census definition.

Since many establishments are integrated operations such as logging, sawmilling and secondary manufacturing, the Bureau of Census classification of an establishment is based upon the dollar value of the primary product shipped. As an example, a combination sawmill/pallet mill which annually sells a higher dollar value of pallets than lumber in a given year would fall into the industry sector of "wood pallets and skids" (SIC code 2448) and would not be reported in the results of this study. If the combination mill sold a higher dollar value of lumber as compared to pallets, then the mill would fit the Bureau of Census definition of a sawmill and planing mill.

Sample Population

The sample population consisted of all known Ohio establishments which potentially would fit the Bureau of Census definition of a sawmill and planing mill. The names of the establishments were compiled from a base list published in directory form by the Ohio

Department of Natural Resources, Division of Forestry (Long 1988). This directory was supplemented with additional establishments compiled from lists by the Ohio Forestry Association/Timber Industry Council, Ohio service foresters and Ohio extension agents. These sources represented the best available lists of sawmills and planing mills in the state of Ohio. The sample size, after eliminating known duplications, was 389 establishments.

Survey Instrument

A questionnaire was designed that sought information for 1987 regarding employees, payroll, capital expenditures and the quantity and value of products produced. Value is the dollar amount of products shipped and services performed at the net selling value, f.o.b. plant, to the customer, ie., after discounts and allowances and exclusive of freight charges and excise taxes (U. S. Department of Commerce 1987).

In developing the instrument the authors selected questions from the 1987 Census of Manufactures questionnaire (U. S. Department of Commerce 1987). The instructions, questions and format used in the Ohio survey instrument were as identical as possible to the Bureau of Census instrument.

The Ohio survey omitted some questions included on the Bureau of Census questionnaire. Only those questions relevant to the Ohio study were chosen. In addition, questions that required calculations by respondents were also omitted from the Ohio study, ie., average employment for the year (divide line b by 4; omit fractions). The reason "calculation questions" were omitted was respondent convenience, survey brevity and possible inaccurate calculations by the respondent. In summary, the Ohio survey instrument replicated selected questions and instructions from the Census Bureau questionnaire so as not to misidentify any firms in the sawmill and planing mill sector or inaccurately record data.

Data Collection and Analysis

The questionnaire, along with a cover letter and a postage paid return envelope, was mailed to each of the 389 establishments. Approximately four weeks following the initial mailing, a second letter and questionnaire were sent to those establishments who had not responded. One month following the second mailing there were 102 responses, or a return rate of 25.6 percent. Nine questionnaires were non-deliverable.

Of the 278 non-respondents, 55 or 19.7 percent were contacted by telephone (random sample) as a follow-up with with an additional seven having wrong or changed phone numbers or disconnected phones. A check for non-response bias was conducted by comparing respondents with non-respondents (Miller and Smith 1983). The comparison was done on the key variables of number of employees, annual payroll, capital expenditures and product value. The t-test indicated no significant difference between respondents and non-respondents at the

alpha level of .05. Thus, the results of the study were generalized to the target population under study. The analyses used were frequency distribution and percentages.

For the purpose of this paper, 1987 sawmills and planing mills was the industry sector studied. A sawmill and planing mill is defined as one which was in business during the 1987 year. This definition excludes non-sawmills and out-of-business establishments. Of the 102 mail respondents, 54 (52.9 percent) were current sawmills or planing mills. In the non-respondent follow-up group of 55, there were 28 sawmills and planing mills (50.9 percent). This leads to an estimate that the number of 1987 sawmill and planing mills from the original sampling frame of 389 was actually 200 (54 + .509 x (389 - 102)). Therefore, the response rate for 1987 sawmill and planing mills is 41 percent ((54 + 28)/200).

RESULTS AND DISCUSSION

The Ohio survey, as noted above, estimates the 1987 sawmill and planing mill sector to be comprised of approximately 200 establishments as compared to the Bureau of Census estimate of 145 establishments (U.S. Department of Commerce 1989). A second estimate of Ohio sawmill and planing mill establishments was computed via a "weighting" formula where non-responding establishments randomly selected for telephone follow-ups represented more than their own establishment. For example, a firm selected in a 20 percent random sample is essentially representing 4 firms in addition to itself and carries a "weight" of 5 (100/20 = 5). The weighting method, when applied to the Ohio survey data, resulted in an estimate of 198 sawmill and planing mill establishments. Therefore the authors are confident that 200 is a reliable point estimate of this industry sector in Ohio. This is a 38 percent increase of the figure reported by the Bureau of Census ((200-145)/145).

The Ohio survey estimated nearly double (88 percent) the number of sawmill and planing mill employees compared to the Census Bureau estimate (Figure 1). Regarding annual payroll, a similar increase (82 percent) was found in the Ohio survey (Figure 2). These rather substantial increases of 88 percent for employees and 82 percent for annual payroll clearly depict the Census Bureau underestimate.

The Bureau of Census underestimated the number of establishments in all employee size classes. The Ohio survey found a greater percentage of establishments in the larger employment size classes, especially in the 20-49 employee size class (Table 1). The larger employee size classes had the greatest underestimation. This explains how a 38 percent increase in establishments translates to a 88 and 82 percent increase in employees and payroll.

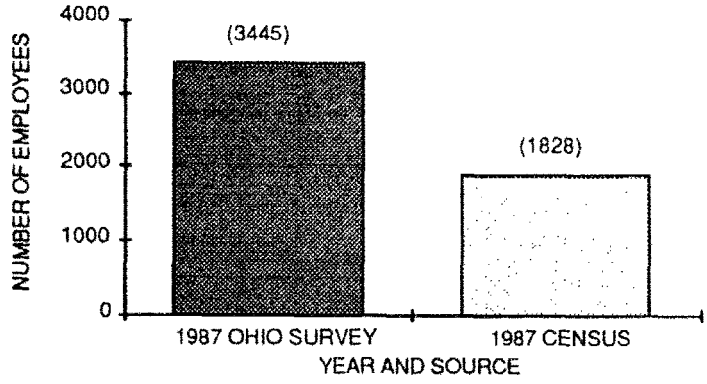

Figure 1. Estimates of sawmill and planing mill employees.

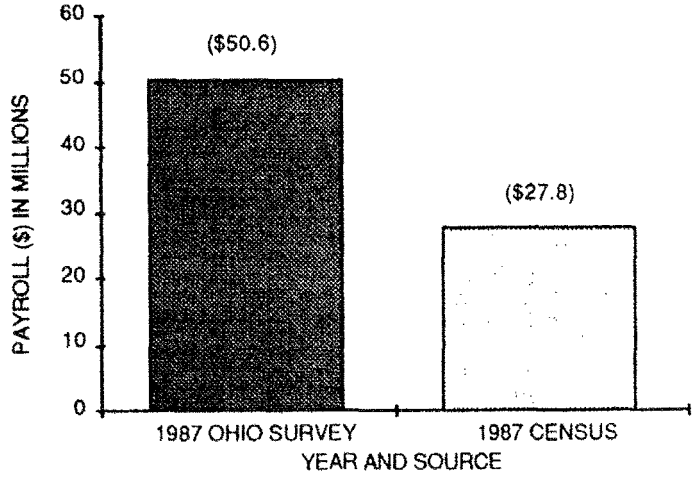

Figure 2. Estimates of sawmill and planing mill annual payroll.

Table 1.--U.S. Bureau of Census and Ohio Survey Estimates of Number of Establishments and Percentage by Employment-Size Class, 1987.

	Employment-size class													
Source	1 to 4		5 to 9		10 to 19		20 to 49		50 to 99		100+		Total	
Census	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Bureau	54	37	29	20	35	24	19	13	7	5	1	1	145	100
Ohio	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
Survey	70	35	35	18	40	20	40	20	13	6	2	1	200	100

The Ohio survey documented capital expenditures for new machinery, equipment and buildings of $18.9 million and a 1987 sawmill and planing mill product value of $355 million. As of October 1990 however, 1987 Census Bureau estimates on these two variables were not yet available. While the Census Bureau has published comparison data for 1982, to be consistent in our comparisons, 1987 data must be available. Further analysis will be done at a later date.

Based on number of establishments, number of employees, and annual payroll, the Ohio survey clearly documents a significant difference with the data published by the Census Bureau. The Ohio survey found substantial increases in number of establishments (38 percent), number of employees (88 percent) and annual payroll (82 percent) (Figure 3).

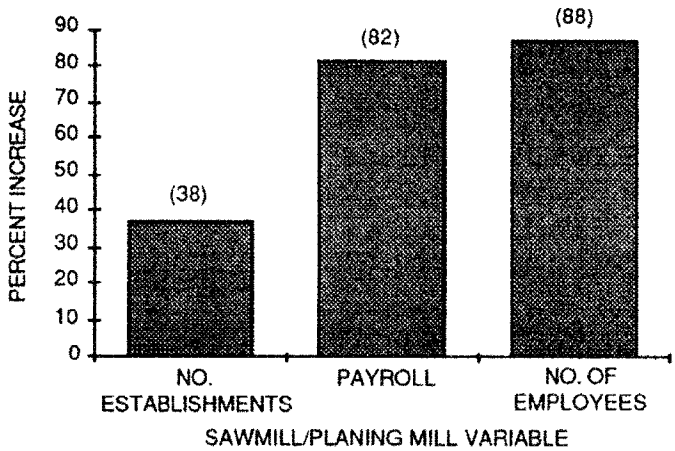

Figure 3. Percent increase of Ohio survey estimates over Census Bureau estimates.

IMPLICATIONS

Foresters, forest product specialists, economic developers and others who work with the forest products industry need to be cautious when using published Census Bureau data to describe the hardwood industry. Results from this research document that a specific industry sector in Ohio, sawmills and planing mills, is substantially larger than published Bureau of Census estimates. Consequently, economic development strategies and economic impact studies could be grossly inaccurate if based on Bureau of Census data.

In certain instances the Census Bureau underestimation could result in specific forest product industry sectors being viewed as "unimportant" from a statewide or regional perspective. Ultimately, this might cause public and private resources (dollars, personnel, etc.) to be allocated to "larger and more important" non-forest industries.

Another implication of underestimation, according to Luppold and Dempsey (1989), is the undervaluation of potential returns from quality northern forest sites. They conclude that an erroneous prediction of lower future hardwood stumpage values would discourage forest investment and ironically, could result in even higher long-term prices.

The results presented in this paper suggest that other central hardwood states could use the Ohio example as a beginning point for more accurately reporting sawmill and planing mill sector Census Bureau data. For example, the Ohio survey estimate of 200 sawmill and planing mill establishments versus the Census Bureau estimate of 145 establishments implies an "expansion factor" of 1.38 (200/145). The expansion factors for number of employees and annual payroll are 1.88 and 1.82, respectively.

While the authors feel the expansion factors might be accurate in Ohio for other primary manufacturing forest industry sectors such as logging camps and logging contractors (SIC code 241), the authors believe the expansion factors would not hold for various secondary manufacturers. In Ohio, for example, there are only three pulp mills. These mills would not "fall through the cracks" in an industry-wide canvass whereas many small sawmills are overlooked in surveys. Likewise, the expansion factors should be used with caution in other states.

The authors are hopeful that researchers in other central hardwood states would replicate the Ohio study. Other primary manufacturing industries, in addition to the sawmill and planing mill sector, need to be studied to determine if the Ohio results hold in other states and for other industry sectors.

A final comment on methodology is appropriate. Even though the results of the Ohio study support the general conclusion that others have made, ie., the Bureau of Census underestimates the size of forest product industries, the Ohio research is different. The Ohio study and the Bureau of Census survey used the same definition of "sawmills and planing mills" (SIC code 2421), surveyed the same data collection unit (individual establishments), used a comparable data collection instrument, and collected data during the same time period (1987). Consequently, the Ohio and Census Bureau data comparison is an "apples to apples" comparison.

In conclusion, no intent to discredit the U.S. Department of Commerce, Bureau of Census, is implied. The authors compliment the Census Bureau for continually providing valuable and useful data in industry sectors where accurate information is difficult to obtain.

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PISTILLATE FLOWER ABORTION IN THREE SPECIES OF OAK

Robert A. Cecich, Gary L. Brown, and Bart K. Piotter[1]

Abstract: Pistillate flower survival was monitored at weekly intervals in three species of oak (*Quercus rubra* L., *Q. velutina* Lam., and *Q. alba* L.) during the 1989 and 1990 growing seasons in central Missouri. Pollen was shed between late April and early May in both years. However, in 1989 only *Q. velutina* flowers had emerged by the time of pollen shed; in 1990 flowers of all three species were receptive. Tree-tree variation was observed in morphological development of the flowers, especially in peduncle length in *Q. rubra* and *Q. alba.*

Flower abortion was pronounced during the early part of both growing seasons. By the end of May 1989, 95 percent of the *Q. rubra* flowers had aborted; by early July of that year 98 percent of the *Q. alba* flowers were dead. In 1990 those values were about 65 and 75 percent, respectively, with 98 percent mortality observed in *Q. alba* acorns by the end of the growing season. Forty to fifty percent of the *Q. velutina* flowers aborted by early July in both years, with little mortality thereafter.

Weevils destroy a large portion of an acorn crop. But, most oak flowers abort before reaching the acorn stage. If we look at the potential crop as a function of the number of pistillate flowers at the time of pollination, it is apparent that weevils are not the primary causal agent of variable acorn crops. What happens to the flowers?

We are currently exploring the hypothesis that pistillate flowers are destroyed by insects, primarily those in the family Membracidae, the treehoppers. Adults of these true bugs or sucking insects are active in the crowns of *Q. alba* just after the flowers emerge. Adults were observed with their stylets inserted into the stigmas. The flowers turned from green to brown within a week and aborted. The most abundant species observed on *Q. alba* was *Atymna querci* (Fitch.). The adult is present from early May to early June when most of the pistillate flower abortion occurs.

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MEASUREMENT OF FOREST CONDITION AND RESPONSE ALONG THE PENNSYLVANIA ATMOSPHERIC DEPOSITION GRADIENT

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Abstract: Research in the oak-hickory forest of northcentral Pennsylvania is being conducted to detect anomalies in forest condition that may be due to atmospheric deposition, with the intent that such anomalies will be further studied to determine the role, if any, of atmospheric deposition. This paper presents the status of research along a 160-km gradient of sulfate/nitrate deposition across northern Pennsylvania begun in 1986 by a multidisciplinary group of researchers at Penn State University and Ohio State University. Four general objectives of the study are: (1) estimate atmospheric deposition loadings across the gradient and at the specific study sites, (2) locate ecologically analogous intensive study sites across the deposition gradient to minimize extraneous variability in forest response, (3) measure and relate forest responses to environmental factors, including atmospheric deposition, and, (4) estimate effects of ambient ozone concentrations on tree seedling growth along the deposition gradient by use of open-top chambers.

The study region lies within the southern portion of the Allegheny Plateau physiographic province, a strongly dissected, large unglaciated tableland with elevations of 500-700 m. Forest types within the region include oak-hickory, mixed deciduous, and northern hardwoods, depending on aspect, slope position, and other factors. Thirteen ecologically analogous stands, ranging from 7 to 58 ha, were selected for intensive measurement of forest response across the deposition gradient from an initial set of 53 candidate stands. Selection procedures included qualitative evaluations to ensure that minimum criteria were met, followed by statistical comparisons of soils and amounts of canopy species to establish similarity on the basis of factors unlikely to have been affected by atmospheric deposition (nonresponse variables). The stands were distributed approximately equally among four uniformly-spaced core areas across the 160-km gradient. They are ridgetop northern red oak-dominated stands, 70-80 years of age, with no evidence of intermediate cutting, severe defoliation or other major disturbance. Soils are course-textured, stony, acidic, and low in base saturation.

Bulk deposition estimates based on intensive deposition monitoring at ten sites across the gradient indicate that annual sulfate deposition (wet plus dry) averages 57 kg/ha at the western end and 38 kg/ha at the eastern end. A coincident gradient of nitrate and other ions also exists. The gradient monitoring also points out the large spatial variability and importance of intensive monitoring for accurate assessment of causal relationships. Surfacing

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techniques employing the Pennsylvania monitoring network data from 1982-1987 were used to estimate average deposition of various ions at the forest response study sites. These estimates are being used to study relationships between deposition and forest response.

Forest community response to sulfate/nitrate deposition is hypothesized to occur earliest within the herb stratum. Particular emphasis is therefore being placed on measures of herb-layer biomass, species richness, and elemental status of selected species in relation to forest overstory, soil and deposition factors. Numbers and size of woody species in other strata were also determined. Correlation/regression analysis of community parameters with deposition estimates and soil/site factors are being determined.

Soils were intensively sampled by horizon, and comparisons of chemical and physical properties in relation to deposition and other site/forest community parameters are underway. Forest floor mass and humus metals loadings are undergoing similar comparisons.

Tree growth relationships are being studied using standard dendroecological procedures to model red oak, white oak and tuliptree tree-ring width response to climate, site and deposition. Chronologies for host (oaks) and non-host (tuliptree) species will be compared to develop techniques for detecting and assessing past impacts of major oak insect defoliators. Red oak height growth for selected time periods based on stem analysis data is being used to model relationships with soil, site and deposition factors.

Forest health assessments include crown transparency and twig dieback surveys, as well as bole evaluations, within all study stands. Leaf symptoms are being identified and quantified on annual samples of over 14,000 leaves collected from these three species. Ancillary to the leaf assessment program, an expert computer system was developed as a training aid for symptom identification and rating. Crown and bole assessments for each of the 13 stands indicated no unusual tree health conditions. Certain foliar disorders (e.g., galls) appear to be related to deposition patterns.

A lichen survey revealed that lichen richness was comparatively greater on the low sulfate deposition portion of the gradient. Concentrations of Al, Fe, Cr, and Cu in *Hypogemnia physodes* thalli were greater on the high-deposition portion of the gradient. These findings are suggestive of an air pollution effect.

Red maple sap chemistry was monitored for 2 years at seven sites along the gradient to determine the usefulness of sap constituency as a biomonitor of soil and atmospheric deposition chemistry. Preliminary analyses indicate that elemental content of red maple sap may be a valuable tool to indicate biological effects of chronic atmospheric deposition along the gradient, but may not be useful in detecting short-term effects of artificially added sulfate.

Open-top chamber studies at three remote sites along the deposition gradient are underway to assess the foliar and growth impacts of ozone concentrations representing ambient, half-filtered, and full-filtered levels. Ozone levels in 1988 exceeded the standard of 120 ppb numerous times; the standard was not exceeded in 1989. An ozone gradient coincident with the sulfate/nitrate deposition gradient was found. Ambient ozone levels induced foliar

symptoms on black cherry and tuliptree (sensitive species), but slight to no symptoms on more tolerant red maple and red oak. Increasing basal diameter and height of black cherry during the growing season was negatively correlated with ozone dose. Ozone stimulated premature fall coloration and defoliation on black cherry.

IMPACT OF SMALL MAMMALS ON REGENERATION OF NORTHERN RED OAK

Colleen A. DeLong, and Richard H. Yahner[1]

Abstract: The impact of small mammals on regeneration of northern red oak (*Quercus rubra*) was studied from October 1989 to December 1990 in Huntingdon County, Pennsylvania. Acorns were planted in two replicates each of three silvicultural treatments: 20% shelterwood, 70% improvement, and untreated mature forest. Four hundred acorns were planted in a 0.8-ha study site in each replicate, giving a total of 2400 acorns in each of six trials (Nov-Dec, Mar-Jun). One-half of the total acorns were direct-seeded 2 cm below the soil surface, and one-half were surface-seeded in a shallow depression on the soil surface. Acorn loss was compared between autumn (Nov-Dec) and spring (Mar-Jun), among treatments and between acorn depths. Most acorn loss was attributed to white-footed mice (*Peromyscus leucopus*). Total acorn loss (direct-seeded, surface-seeded) in the 20% shelterwood ranged from 28% to 68% in autumn and from 96% to 100% in spring. Total loss in the 70% improvement ranged from 44% to 84% in autumn and from 94% to 100% in spring. Total loss in the untreated mature forest ranged from 67% to 88% in autumn and from 99% to 100% in spring. Loss of direct-seeded acorns ranged from 17% in the 20% shelterwood during autumn to 60% in the 70% improvement during autumn. Loss of surface-seeded acorns ranged from 40% in the 70% improvement during autumn to 83% in the 20% shelterwood during autumn. Preliminary evidence indicated that acorn loss was lower in autumn than in spring, and acorn loss in autumn was greater in untreated forest sites than in treated sites.

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HARDWOOD STUMPAGE PRICE TRENDS IN NEW ENGLAND

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Abstract: Stumpage price trends in New Hampshire and Vermont varied considerably among species and products. Real stumpage price trends, expressed in 1988 dollars using the Producer Price Index to remove the effect of inflation, are reported for selected species and products. Long-term (1964-1989) trends in average annual prices are reported for New Hampshire and short-term (1981-1989) trends in average quarterly prices are reported for Vermont.

Real prices for red oak stumpage increased at a remarkable rate. These prices have increased at an average annual rate of 11.3% in New Hampshire and 7.0% in Vermont, since 1981. These rates represent the average rate of price change that occured over and above inflation, which averaged 1.2% during the period. Real prices for white pine, another commercially valuable species, also outpaced inflation annually by 2.1% in New Hampshire and 2.0% in Vermont. Real sugar maple prices declined in Vermont at an average annual rate of -1.6% and declined slightly in New Hampshire since 1981.

Stumpage prices for hardwood pulp and fuelwood did not keep pace with inflation since 1981. It appears that the sharp upturn in fuelwood prices that occured in the late 70's and early 80's has ended. The average annual decline in real fuelwood prices was -6.7% in New Hampshire and -4.3% in Vermont. The inventory of low-quality hardwoods has increased substantially over the past few decades. Real prices for softwood pulp remained stable in Vermont and increased slightly in New Hampshire since 1981.

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PREDICTING TREE MORTALITY FOLLOWING GYPSY MOTH DEFOLIATION[1]

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Abstract: Appropriate application of gypsy moth control strategies requires an accurate prediction of the distribution and intensity of tree mortality prior to defoliation. This prior information is necessary to better target investments in control activities where they are needed. This poster lays the groundwork for developing hazard-rating systems for forests of the Appalachian Plateau (AP) and the Ridge and Valley (R&V) by comparing the impact of gypsy moth defoliation in these two provinces.

METHODS

Field plots were established in defoliated and undefoliated stands of both provinces from 1984-1986. Two hundred and twenty-seven 1/10-acre circular plots were located primarily on State Game Lands in Somerset County, Pennsylvania, and 158 plots were located at Green Ridge State Forest in Allegany County, Maryland. All plots were located along the leading edge of gypsy moth infestation and represented a range of site and stand conditions. On each plot, tree variables (e.g. species, height and d.b.h.) and site characteristics (e.g. site index, slope inclination and aspect) were measured. From 1984-1989, each tree was evaluated for defoliation and vigor annually. In 1989, all variables measured during plot establishment were remeasured. Z-tests were used to test for differences in initial stand conditions and in tree mortality between the two provinces.

RESULTS

Initial Stand Conditions

Pre-defoliation stand conditions were similar for the two provinces. On average, plots were located in fully stocked mixed-oak stands that had an average diameter of 8 inches. Initial stocking ranged from 72% to 91% and average basal area ranged from 101 to 109 square feet per acre. Stands in the R&V province contained a higher proportion of oak. Oaks in undefoliated stands of the R&V were evenly divided between northern red oak, black/scarlet oak, white oak and chestnut oak. In defoliated R&V stands, white oak and the black/scarlet oak group accounted for 81% of the total stand basal area. No non-host species accounted for a significant proportion of the R&V stands. In the AP, chestnut oak and northern red oak

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dominated the oak composition. Red maple was the most abundant of the non-host species present in the AP.

Defoliation History

Defoliation histories differed between the two provinces due to differences in land management philosophies. In the AP, lands managed by the Pennsylvania Game Commission were not treated following defoliation. Plot defoliation in the AP (weighted by d.b.h.) averaged nearly 60% in 1985 and 1986, 23% in 1987 and less than 10% in 1988 and 1989. The gypsy moth management strategy at Green Ridge State Forest was to limit defoliation by aerial application of Dimilin. The data suggest that our research areas were sprayed following a single year of heavy defoliation in 1985 (ave. defoliation = 55%). The following year, average defoliation had dropped to < 2%.

Tree Mortality

As expected from the differences in defoliation history, tree mortality was greater in the AP (34%) than in the R&V (16%) even though R&V stands contained more oak. In both provinces, as the amount of oak in stands increased, so did the amount of mortality. This increase was more noticeable in the AP than in the R&V due to the larger variability in species composition of AP stands.

Mortality also increased with the number and intensity of defoliations. Undefoliated stands had less than 10% basal area loss. A single defoliation increased mortality to between 16% (R&V) and 24% (AP); two, three and four defoliations resulted in 34, 45, and 77% mortality in the Appalachian Plateau. When the average annual defoliation over the five-year period was less than 20%, basal area loss was less than 20% in both provinces. In the R&V, which suffered one severe defoliation in five years (i.e. ave. annual defol. always < 20%), only one plot exceeded 25% mortality. In the AP, when average annual defoliation over the five-year period was greater than 25%, basal area loss exceeded 29%. When the average defoliation was greater than 40%, at least 56% of the stand basal area died.

Slope inclination, aspect, and site quality also appear to influence tree mortality following gypsy moth defoliation. In the R&V, mortality was greatest (30%) on fair sites (NROSI=60-70) and lowest (11%) on the poorest sites (NROSI < 60). In the AP, mortality was greatest on the poor and fair sites (32 and 35% respectively) and lowest (9%) on the good sites (NROSI>70). In the AP, slopes greater than 20% had the greatest mortality (31-46%) while there was no relationship between slope inclination and tree mortality in the R&V. In the AP, mortality was greatest on southern and southeastern aspects (41 & 55%) and lowest on southwestern and eastern aspects (< 10%). In the R&V, mortality was greatest on northeastern through southeastern aspects (26, 20, 29%) and lowest on northern through western aspects (8, 13, 10%).

It is difficult to accurately predict tree mortality following defoliation because of the complex interaction of host vigor, insect populations, weather, secondary organism populations and site conditions. However, the results indicate that the proportion of oak and the level of

defoliation in a stand are the strongest foretellers of tree mortality. Several site conditions also appear to be related to mortality; however, these relationships may be driven by species composition. The testing of these interactions will need to be completed as part of the process of developing a gypsy moth hazard-rating system for Appalachian hardwood stands.

INVASION OF A PARTIALLY CUT OAK STAND BY HAYSCENTED FERN

John W. Groninger and Larry H. McCormick[1]

Abstract: Hardwood forests in Pennsylvania frequently develop a dense understory of hayscented fern (*Dennstaedtia punctilobula* (Michx.) Moore)) following partial overstory removal. Seedlings of desirable hardwood species are unable to develop in these understories. A study was conducted in a central Pennsylvania mixed oak stand to determine how hayscented fern becomes established following partial cutting.

Hayscented fern is capable of reproducing both sexually through the production of spores and asexually through the extension of a perennial rhizome. While rhizome extension and transportation by logging equipment have traditionally been considered the primary mechanisms of fern reproduction and invasion, these processes can also be the result of development from spores. Spores are disseminated throughout late summer and early fall and can emerge within days after release or during the following spring when soil conditions are favorable. Rhizomes grow and fronds are produced throughout the growing season. Individuals are capable of reproducing sexually three years after development from spores.

The study area is a 100-year-old stand dominated by northern red oak (*Quercus rubra* L.), black oak (*Quercus velutina* Lam.), yellow-poplar (*Liriodendron tulipifera* L.), and red maple (*Acer rubrum* L.) located on state forest lands 7 miles south of State College, PA. The site occupies a lower slope position and has a southeasterly aspect. Soils range from poorly to well drained. The stand received an improvement shelterwood cut during the spring of 1989 in which the basal area was reduced to 80 sq. ft. per acre. The stand contained a few isolated clumps of hayscented fern before logging. A previously partially cut stand adjacent to the study area contained dense fern understories.

Hayscented ferns arising from spores were observed in the study area during the spring one year after cutting. Both gametophytes and sporophytes were noted. These individuals are characterized by a dense clumping of small fronds generally less than 4 inches tall. A small rhizome (< 0.5 inches long) was usually present. These newly developing ferns appeared to be restricted to areas with high soil moisture usually growing from moss patches. Sexually

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reproduced ferns were most commonly associated with microsites produced by logging-related soil disturbance; where mineral soil was exposed through intensive log skidding and on the uphill banks of skid roads where high soil moisture is maintained by subsurface drainage. Ferns also grow frequently at the base of rocks or fallen logs where water runoff is concentrated and high soil moisture is maintained. We have occasionally observed spore origin ferns in microsites not associated with logging disturbance. These include soil mounds resulting from windthrown trees and wet areas associated with seeps. In contrast, new ferns have not been observed on well-drained mineral soil, areas with thick litter cover or on compacted skid roads. Dense shade does not appear to limit fern development under these conditions. Instead, shaded conditions may favor the growth of young ferns by maintaining high soil moisture.

Based on the findings of this study, sexual reproduction is the primary mode by which hayscented ferns invade previously fern free areas. Once these individuals become established, asexual reproduction through rhizome extension becomes the primary means of reproduction. Reducing the impact of log skidding on wet sites would also help prevent sexual reproduction of hayscented ferns. The herbicide sulfometuron (Oust®) effectively controlled hayscented fern spore emergence in a greenhouse study and may also prevent the development of spore origin ferns if applied following timber harvesting.

MICROCOPPICE: A NEW STRATEGY FOR RED OAK CLONAL PROPAGATION

Duane E. Harper and Brent H. McCown[1]

Abstract: The great demand for red oak (*Quercus rubra* L.) has forced plant propagators to consider viable methods of mass clonal propagation for the species. A process called 'microcoppicing' is presently being developed to help meet such needs. The advantage of this technique is that it proposes to work with oak's natural growth characteristics. The 'microcoppice' hypothesis capitalizes on the well-known ability of oak to form epicormic shoots. This concept should be capable of providing a large number of plants without being overly hampered by oak's episodic growth tendencies. This theory is being developed by utilizing seedlings, stump sprouts, and grafted scions from mature plants. Plant material will be disinfected, cultured on an agar-based media, and rooted *in vitro*. The plants will then be put through an *in vitro* coppicing phase, thus producing a multiplication effect. The derived microshoots will then be rooted *ex vitro*. After acclimation, it is believed that the plants could again go though a coppicing series for further multiplication. This process should be capable of producing a large quantity of plants from mature stock, a goal that has eluded plant propagators working with oak species.

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FIELD TESTING A SOIL SITE FIELD GUIDE FOR ALLEGHENY HARDWOODS

Stephen B. Jones[1]

Abstract: A site quality evaluation decision model, developed for Allegheny hardwoods on the non-glaciated Allegheny Plateau of Pennsylvania and New York, was field tested by International Paper (IP) foresters and the author, on sites within the region of derivation and on glaciated sites north and west of the Wisconsin drift line. Results from the field testing are presented along with the decision model as modified for both the glaciated and non-glaciated conditions.

Within the region of derivation on the non-glaciated Allegheny Plateau, field testing warranted only a minor modification of the slope criteria for discriminating between the four topographic classes. North and west of that region, lesser topographic variability seems to obviate the need for four distinct sets of site quality decision criteria.

The models serve as practical field guides for foresters, and rely on field determinable decision criteria, including: soil texture, soil stoniness, aspect, shade angle, slope shape, and effective rooting depth. IP foresters and management have adopted the field guide as a principal criterion for forestry investment decisions. A documentation of site potential using the field guide is requisite to budget authorization for individual land management actions.

Suggestions are offered for developing similar field guides elsewhere in the Central and Eastern Hardwood Regions.

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COMPARISON OF NORTHERN GOSHAWK NESTING HABITAT IN APPALACHIAN OAK AND NORTHERN HARDWOOD FORESTS OF PENNSYLVANIA

J. Timothy Kimmel and Richard H. Yahner[1]

Abstract: The Northern Goshawk (*Accipiter gentilis*) is a rare to uncommon woodland raptor in Pennsylvania. Although it is primarily a boreal species, the goshawk nests in Northern Hardwoods and Appalachian oak forests along the southern margin of its range in Pennsylvania. This study compared the nesting habitat of goshawks in Appalachian oak and Northern Hardwoods forests in Pennsylvania during the 1989-90 field seasons.

Vegetative and physiographic habitat variables were quantified at both the nest site (microhabitat) and landscape (macrohabitat) levels. Preliminary results indicate that conifers may be more important for goshawks nesting in Appalachian oak forests. We suggest that microclimatic factors associated with conifer stands in oak forests may create a more favorable nesting environment for this northern raptor. Results of this study will be important in developing management strategies for maintaining critical nesting habitat for the goshawk in Pennsylvania.

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RESPONSE OF CHESTNUT OAK AND RED OAK TO DROUGHT AND FERTILIZATION: GROWTH AND PHYSIOLOGY

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Abstract: Chestnut oak (*Quercus prinus* L.) and red oak (*Quercus rubra* L.) seedlings were grown for two seasons under two nutrient regimes: **fertilizer +** (NPK) and **fertilizer -** (No NPK). Beginning two weeks after budbreak, water was withheld for 10 weeks during the second growing season. Leaf water potentials, gas exchange measurements and growth measurements were made on a subset of plants on alternate weeks (5 sample weeks).

Red and chestnut oak growth was positively influenced by the **fertilizer +** treatment. Over the ten week treatment period, seedling diameter, height, and shoot weight were all significantly greater in the **fertilizer +** treatment, with the greatest differences measured during weeks 8 and 10. Red oak shoot and root weights were significantly greater in the **water +** treatment. Budbreak of red and chestnut oaks in the **fertilizer +** treatment was on average, 3 days earlier than for individuals in the **fertilizer -** treatment. Based on growth over the ten weeks, the treatment rankings for both red and chestnut oak were: $H_20+/NPK+ > H_20-/NPK+ > H_20+/NPK- > H_20-/NPK-$.

Over the 10 week treatment period, measures of red and chestnut oak carbon gain rates, stomatal conductance, transpiration rates and water use efficiency were all significantly reduced by the **water -** treatment. The greatest reduction in carbon gain rates occurred during weeks 8 and 10. By week 10 chestnut oak carbon gain rates were significantly reduced in the **water -** treatment (27% reduction) as compared to the **water +** treatment. Although red oak exhibited a greater reduction in carbon gain rates than chestnut oak (37% reduction), this was not significant due to the greater variation among the seedlings.

For chestnut oak, significant reductions in carbon gain rates occurred before significant reductions in leaf water potentials occurred. Although predawn leaf water potentials and mean diurnal leaf water potentials in the **water -** treatment were not significantly lower until week 10, carbon gain rates, water use efficiency, stomatal conductance and transpiration rates were all significantly reduced by week 8 in the **water -** treatment.

The **fertilizer +** treatment did not ameliorate carbon gain rates for seedlings of red or chestnut oak in the **water -** treatment. In both the **water +** and the **water -** treatments, unfertilized seedlings had significantly greater carbon gain rates, stomatal conductance, transpiration rates, predawn and diurnal leaf water potential than fertilized seedlings. Based on

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the measures of carbon gain rates during the final week of drought, the treatment rankings for red oak were: H_2O+/NPK- > H_2O+/NPK+ > H_2O-/NPK- > H_2O-/NPK+ and the treatment rankings for chestnut oak were: H_2O-/NPK- > H_2O+/NPK+ > H_2O+/NPK- > H_2O-/NPK+.

PHYSIOLOGICAL AND STRUCTURAL FOLIAR CHARACTERISTICS OF FOUR CENTRAL PENNSYLVANIA BARRENS SPECIES IN CONTRASTING LIGHT REGIMES

Brian D. Kloeppel, Mark E. Kubiske, and Marc D. Abrams[1]

Abstract: Four central Pennsylvania barrens species, black oak (*Quercus velutina*), chestnut oak (*Quercus prinus*), red maple (*Acer rubrum*), and sassafras (*Sassafras albidum*), in the sapling size range were tagged and monitored in juxtaposed understory and full sunlight conditions. Five times during the 1990 growing season diurnal gas exchange measurements were collected along with stomatal and tissue leaf structure on all species in both light regimes. Concurrently, tissue pressure-volume (P-V) analysis and soil moisture analysis were conducted to compare inter-site and inter-species water relations parameters. One sampling date was conducted at the end of a mild drought period to determine if adjustments had occured in water relations parameters. Leaf structure data indicated that guard cell length and stomatal density were fixed over the growing season, but differences existed between the contrasting light regimes. Also, the full sunlight treatment leaves were relatively thicker than the understory leaves. Species diurnal gas exchanges measurements were similar within light regimes, but differences in species diurnal patterns existed. Sassafras usually peaked soon after full sunlight conditions existed and then tailed-off markedly; whereas all three other species reached a plateau in mid-morning and maintained moderate levels of net photosynthesis during the afternoon. Soil moisture did not decrease to drought conditions at anytime during the growing season. However, the fourth diurnal measurement on August 3, 1990 showed a 50% decrease in soil moisture to 6%. This decrease in soil moisture did not significantly affect pre-dawn leaf water potentials or the calculated parameters from the P-V analysis. However, the P-V analysis did show the high capacitence and relatively high wilting point exibited by sassafras compared to the other three species.

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EFFECT OF STAND AGE AND SOILS ON FOREST COMPOSITION AT SPOTSYLVANIA BATTLEFIELD, VIRGINIA

David A. Orwig and Marc D. Abrams[1]

Abstract: Woody vegetation was surveyed in 28 forest stands at the Spotsylvania Battlefield, Virginia to examine forest composition and structure in relation to stand age and edaphic features. Pioneer stands consisted primarily of *Pinus virginiana*, which represented 50% of the overstory importance value total, whereas mid-successional stands contained a mixture of pine and hardwood species including *Quercus alba*, *Liriodendron tulipifera*, and *Liquidambar styraciflua*. Late successional stands were dominated by *Quercus* and *Carya* species, as well as *Cornus florida* and *Nyssa sylvatica*. Although *Q. alba* was the leading dominant in presettlement forest data and in half of the surveyed stands, lack of oak reproduction in the oldest stands casts doubt as to the future dominance of the species, possibly due to fire exclusion. Pine stands were found on deep, well-drained eroded soils while hardwood stands were found on both well-drained and poorly-drained soils. Radial growth analysis indicated that all stands were initiated within the last 150 years. Many stands were even-aged and appeared to be in a prolonged stem exclusion stage, with little or no recruitment of species into the tree size category. Stand age, past land use, and edaphic characteristics were the primary factors in determining the present vegetative composition and structure within Spotsylvania Battlefield.

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FIELD RESPONSE OF RED OAK, PIN CHERRY AND BLACK CHERRY SEEDLINGS TO A LIGHT GRADIENT

Mark R. Roberts[1]

Abstract: The objective of this study is to determine the relationship between light conditions and the growth of natural seedlings of red oak (*Quercus rubra* L.), pin cherry (*Prunus pensylvanica* L.) and black cherry (*P. serotina* Ehrh.) growing under a range of canopy densities in northwestern Pennsylvania. Annual height growth, total height and photosynthetically active radiation (PAR) are being monitored for two growing seasons (1990-1991) on 1-year-old natural seedlings. Experimental plots were located in mature oak stands where understory trees (<5.3" dbh) were removed and the remaining overstory trees represented 100%, 60% and 40% residual relative densities. The areas also were fenced to exclude deer and eliminate the impact of browsing on seedling growth rates. The plots were variable in size up to a 50 foot radius, and contained at least six healthy seedlings of one of the target species. Ten plots that represented a range of canopy densities from complete canopy cover to large openings were established for each species. The plots were stratified into three canopy density levels: large openings, partial canopy, and complete canopy. In each plot, the six tallest 1-year-old seedlings of each species were selected for measurements. Only seedlings that were free of physical damage and that were free-to-grow (not overtopped by surrounding vegetation) were selected. Total integrated PAR was measured over a 24-hour period at least once in each plot in September, 1990, using six Li-Cor quantum sensors attached to a Li-Cor LI-500 integrator. Each sensor was placed on a platform directly above one of the six seedlings. All radiation values will be expressed as a percent of full sunlight received in the open. At the end of the 1990 growing season, the second year of seedling growth, stem elongation in the first and second year were measured on each seedling. Total seedling height was also measured. For red oak seedlings, the number of flushes in each year was recorded. These measurements will be continued during the 1991 growing season.

Preliminary results dealing with total seedling height as related to canopy density class are presented in this poster. Average total height was similar for the three species under the complete canopy, but differences among species became more pronounced as canopy density decreased. The height of red oak seedlings increased only slightly from the complete canopy to the large openings (0.7 ft. to 1.1 ft.), with no significant differences among canopy density classes ($p>0.05$). The mean heights of black cherry were 0.9, 2.7, and 5.9 ft. for the complete, partial and open canopy classes, and the heights of pin cherry were 1.2, 4.4, and 9.8 ft. for the three canopy density classes, respectively. For both pin cherry and black cherry, the

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differences among canopy density classes were significant ($p<0.05$). These results indicate that heavy cutting does not stimulate height growth of red oak seedlings, but does stimulate growth of the competing cherry species. The dramatic increase in height growth of pin cherry and black cherry under the partial and open canopy conditions creates intense competition for red oak seedlings. Under the full canopy, red oak seedlings would not be suppressed by pin cherry and black cherry, but seedling vigor is low and may result in poor long-term survival. If natural red oak regeneration is desired, limited overstory removal combined with control of competing vegetation will probably be required. The detailed measurements of PAR, when complete, will help define more precisely the light and canopy conditions that will favor the growth of red oak regeneration.

PIONEER MOTHERS' MEMORIAL FOREST REVISITED

Richard C. Schlesinger, David T. Funk, Paul L. Roth, and Charles C. Myers[1]

Abstract: The area now known as Pioneer Mothers' Memorial Forest was acquired by Joseph Cox in 1816 from the public domain. In 1944, a portion of that property, including the area referred to as Cox Woods, was established as a National Forest Research Natural Area. This beech-maple forest, located in the Knobs area of southern Indiana, is considered to be one of the few remaining remnants of the original forests in the region. Although there is no known record of cutting trees in the stand, portions of it were pastured prior to it's acquistion by the Forest Service in 1941. Also, a tornado in 1897 blew down most of the larger trees in a strip about 160 m wide through a portion of the stand. Otherwise, the forest appears essentially undisturbed.

Following the 1978 growing season, permanent plots were established in the stand on a 50 m by 50 m grid. All trees 15 cm dbh and larger were measured and mapped on a 0.1 ha circular plot, and trees between 5 cm and 15 cm were measured and mapped on a 0.01 ha circular plot in the center of the main plot. These plots were remeasured following the 1989 growing season. Two of the 153 plots were located in a pine planting, 15 plots were bordered by private lands (open pasture and harvested forest), and 15 plots were in old pasture areas. Thus, the following descriptions are based on the data from the 121 remaining plots, representing 30.25 ha.

The total number of trees has declined from 620 per ha in 1978 to 522 in 1989. The basal area (sq. m per ha) increased slightly from 27.1 to 27.8, while the overall stocking percent went from 95 to 93. Seventy-six trees per ha grew passed the 5 cm minimum dbh threshold, and 175 trees per ha died during the 11 year period between measurements. A total of 32 species were represented by at least one individual in the 1978 sample; in 1989, there were 33 species.

Sugar maple (*Acer saccharum* Marsh.) was by far the most prevalent species in both 1978 (48 percent of the trees) and 1989 (55 percent). Dogwoods (*Cornus florida* L.) were a distant second at 8 percent in 1978. In 1989, the second most numerous species was beech (*Fagus grandifolia* Ehrh.) at 8 percent. In terms of basal area, sugar maple was 25 percent and 27 percent, respectively, in 1978 and 1989, followed by beech at 15 percent in 1978 and yellow poplar (*Liriodendron tulipifera* L.) at 16 percent in 1989.

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Fifty-two percent of the ingrowth trees were sugar maples. Of the 12 other species that were represented by ingrowth, dogwood was the next most numerous at 14 percent. However, more stems of these two species died than of any others. Sugar maple was 26 percent of the mortality, while dogwood was 16 percent.

The visually-dominant portion of this old growth stand, those trees at least 51 cm dbh and larger, increased from 31 trees per ha in 1978 to 34 trees in 1989. Basal area per ha increased from 11 sq m to 12 sq m, representing 41 percent of the total basal area in 1978 and 44 percent in 1989. Of the 19 species composing this portion of the stand, beech was most numerous in 1978 (24 percent of the total number), followed by yellow poplar at 13 percent. Sugar maple was the sixth most numerous at eight percent. In terms of basal area, the pattern was similar. Beech was 28 percent of the total, followed by yellow poplar at 13 percent, and sugar maple was seventh at seven percent.

During the 11 year study period, mortality of these large trees amounted to 5.5 trees per ha and 2 sq m of basal area. Fifty-two percent of the trees lost were beeches (60 percent of the basal area). Black walnuts (*Juglans nigra* L.) and sugar maples were 11 percent each.

By 1989, yellow poplars were the most numerous large trees (19 percent of the total number), with beeches now second at 15 percent. The basal area represented by these two species was nearly equal (18 percent and 17.5 percent respectively). Sugar maples were still sixth in number (eight percent) and moved to sixth in basal area (six percent).

The most notable change from 1978 to 1989 is the loss of the large beech trees. Thirty-eight percent of the large beech trees that were present in 1978 died. During the same period, ingrowth into the large tree size class was sufficient to replace only 12 percent of the mortality. The largest of the dying beeches was 104 cm dbh, while several others were over 80 cm. Thus, several large gaps in the canopy were created.

Another important change in the overstory is the increase in number of yellow poplar trees. Overall, eight new trees per ha grew passed the 51 cm threshold. Thirty-two percent of these were yellow poplars. The next most numerous recuits were black oaks (*Quercus velutina* Lam.) at 13 percent, followed by white oaks (*Q. alba* L.) and northern red oaks (*Q. rubra* L.) at 11 and 10 percent, respectively. Sugar maples were the fifth most numerous recuits at eight percent.

During this relatively short study period of 11 years, there have been several significant changes in what was thought to be a relatively stable community. The total number of live trees dropped by 16 percent, while the basal area and stocking percent remained relatively constant. The number of large trees increased by eight percent, while at the same time the most numerous large tree species in 1978, beech, was represented by 34 percent fewer trees. If such stands are to be used as benchmarks representing the original forests, it will be necessary to describe not only the composition and structure at a particular point in time, but also the expected amount and type of variation over time.

SURVIVAL AND GROWTH OF DIRECT-SEEDED AND NATURAL NORTHERN RED OAK AFTER CLEARCUTTING A MATURE RED PINE PLANTATION

R.D. Shipman and D.B. Dimarcello[1]

Abstract: Initiated in 1985, a study was designed to evaluate the effects of site preparation (rototilling) and logging slash on 5-year survival and growth of natural and direct-seeded northern red oak (*Quercus rubra* L.) after clearcutting a mature, 45-year-old red pine (*Pinus resinosa* Ait.) plantation in central Pennsylvania. The study area, approximately 2.2 ha in size, is flanked on the northeast and southeast by dense stands of Norway spruce (*Picea abies* (L.) Karst.) and on the southwest by 60-70 year-old mixed oak stands. Soils supporting the red pine plantation are mainly well-drained, moderately acid (pH 4.5-5.6) silty clay loams, derived from weathered shale and shaly limestone.

A 100 percent, before and after harvest inventory of all naturally occurring economically important tree seedlings, noncommercial shrubs and herbaceous species was conducted during September, 1984 and April, 1985 respectively. Following inventory, all natural (advanced) red oak seedlings beneath the red pine overstory were hand-sheered back to the groundline to facilitate later identification of direct-seeded red oak seedlings. An uncut "control" block was inventoried, but received no additional pre-harvest treatments.

Four duplicate site preparation treatments, each approximately .04 ha in size were established on the study area: (1) Rototill-no slash (2) Rototill-slash (3) No rototill-no slash and (4) No rototill-slash. In preparation for oak seeding, one-half of the treatments received a mechanical pre-harvest scarification of the forest floor and surface soil layers with a 4 h.p. gasoline engine rototiller between 8-foot spaced red pine tree rows. On the remaining blocks, "fresh" slash (tops and branches) 0.5 to 1.2 m thick, was left undisturbed on the forest floor after removal of the merchantable pine logs. Previously stratified red oak acorns, collected from five trees of the same seed source were planted on April 6, 1985. Acorns were sown in each treatment between consecutive red pine "stump" rows, 1.8 m apart. Within each row, acorns were spaced .45 m apart at a depth of 2.5 to 5.0 cm using a metal "V"-tipped planting pole, creating holes in the mineral soil. Two acorns were sown in each hole, covered by soil and surface litter, and tramped over by foot. Shoot emergence of the germinating seed first occurred in mid-May, 1985.

Variation in survival and growth of direct-seeded and naturally occurring northern red oak seedlings was evaluated after the first and fifth growing seasons. Chi-square analysis and pairwise comparisons were used to test significant differences among and between site preparation treatments. After the first growing season, survival of both direct-seeded and

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naturally occurring red oak seedlings with the rototill/slash and no rototill/slash treatments were significantly higher (P=0.05) than the rototill/no slash and no rototill/no slash treatments. However after five growing seasons, scarifying with a rototiller, in combination with intact logging slash, showed significantly greater total numbers of seedlings/ha than the remaining treatments. Mean 5-year height growth of acorns sown on slash-covered areas with or without rototilling were both significantly superior to seedlings grown on plots without logging slash (Fig. 1). Germination and early survival of direct-seeded acorns was most pronounced on rototilled blocks. Although the presence of slash also enhanced germination and survival, an added benefit of slash cover was to protect young red oak seedlings from browse damage.

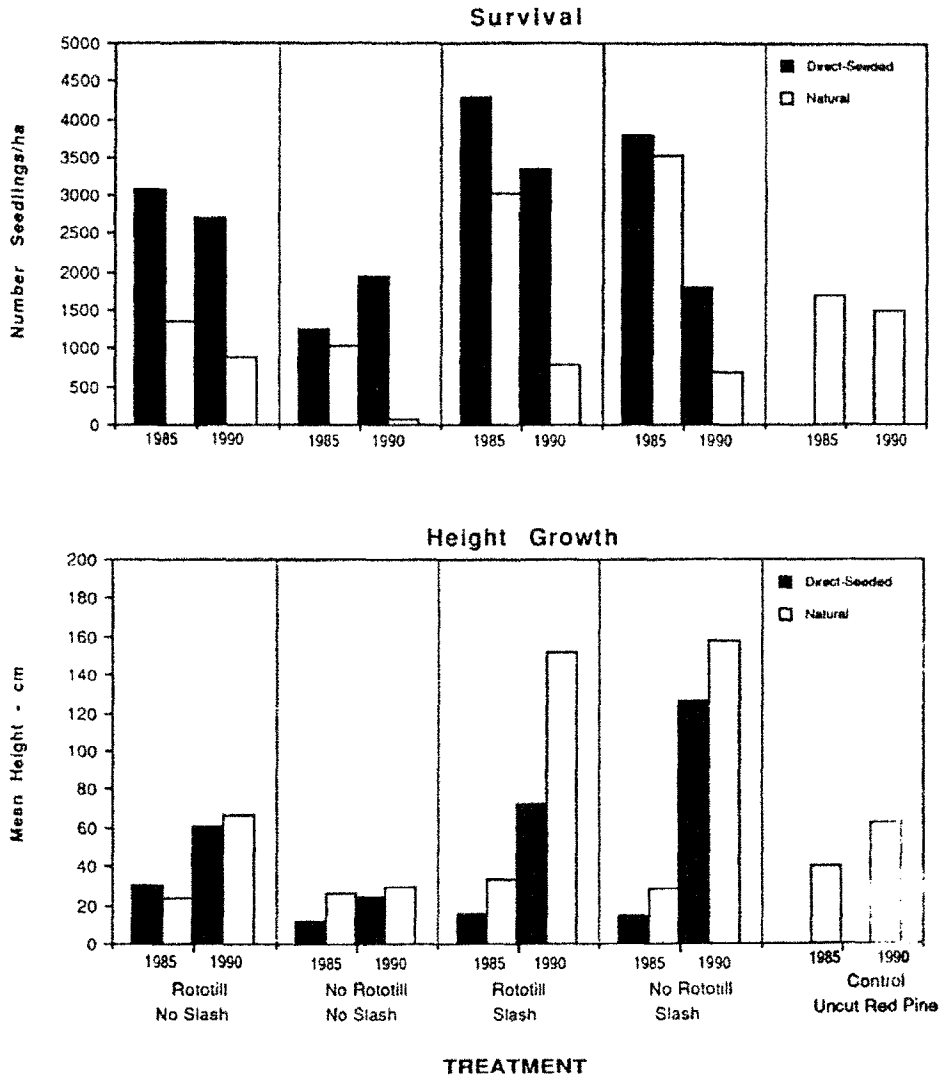

Figure 1. Effects of site preparation on northern red oak seedlings after clearcutting red pine.

TREEGRAD: A GRADING PROGRAM FOR EASTERN HARDWOODS

Jeffrey W. Stringer and Darryl W. Cremeans[1]

Abstract: Assigning tree grades to eastern hardwoods is often a difficult task for neophyte graders. Recently several "dichotomous keys" have been developed for training graders in the USFS hardwood tree grading system. **TREEGRAD** uses the Tree Grading Algorithm (TGA) for determining grades from defect location data and is designed to be used as a teaching aid. The program takes individual tree inputs and determines the best grade for the tree as well as the location and the length of the grading section giving the best grade. The program can be used to objectively determine grades from field data of defect location and size as well as for instructional purposes to show the effect of defect positioning on grade.

After the introduction screen the user is prompted by the following screen:

```
IS THIS A BASSWOOD OR ASH TREE?

ENTER TREE DBH IN INCHES AND TENTHS (FORMAT XX.X)

ENTER DIAMETER INSIDE BARK AT TOP OF GRADING SECTION

ENTER PERCENT CULL DEDUCTION FOR SWEEP AND CROOK

ENTER PERCENT CULL DEDUCTION FOR ROT
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Inputs are provided for each of the prompts and the following screen appears:

```
YOU MAY NOW ENTER UP TO 7 DEFECTS AND THEIR SIZES

IF 2 DEFECTS DO NOT HAVE A CLEAR TWO FOOT SECTION
BETWEEN THEM, COUNT IT AS 1 DEFECT

ENTER HEIGHT TO DEFECT IN FEET AND TENTHS (XX.X)

THEN ENTER THE THICKNESS (from bottom to top)
OF THE DEFECT IN FEET AND TENTHS

do not let the top of the highest defect be more than 14 feet

hit any key when you understand these instructions
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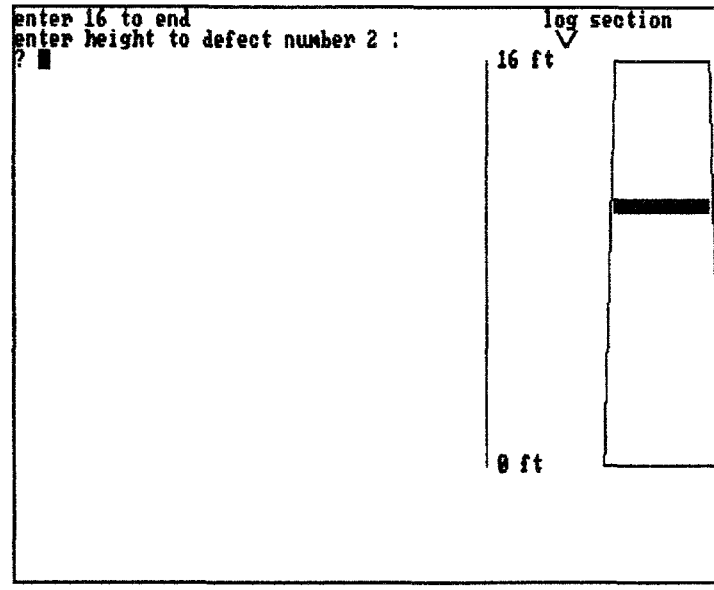
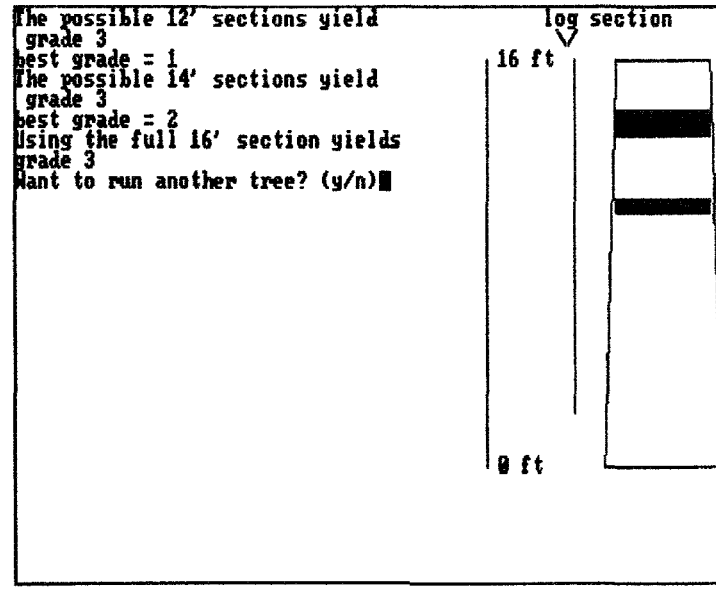
[1]Research Silviculturalist and Scientific Analyst Programmer, Department of Forestry, University of Kentucky, Lexington, KY. 40546-0073.

After the previous screen has been viewed the first graphic screen appears.



In this example screen the location and thickness of the first defect has been entered and the program is prompting the user for the second defect location which it will plot on the grading face to the right of the screen.

After the user has input defect location and size TREEGRAD then advances to the following screen.



The user can watch the program analyze each possible, 12 ft, 14 ft, and 16 ft grading section. The program then lists the best possible grade for each length grading section.

TREEGRAD uses 128K of RAM and runs on any IBM or compatible with any color monitor.

WHITE OAK SEEDLING SURVIVAL AND VIGOR FOLLOWING ACORN REMOVAL AND WATER STRESS

Eugene R. Thorn and Walter M. Tzilkowski[1]

Abstract: A lack of viable acorns, due to rodent depredation, may be the primary cause of advanced regeneration failure of oak in Pennsylvania. White oak (*Quercus alba*) acorns germinate immediately upon falling. Within three weeks, 30-50% of the nutrients in the cotyledon are transferred into the upper taproot; removing the cotyledon during winter may not affect survival and growth. Our objective was to determine whether nondormancy of white oak acorns contributed to seedling survival. Thirty-three or 34 sound white oak acorns were randomly assigned to each of six perforated trays (95 x 46 x 10 cm) filled with a mixture of 1/2 peat moss and 1/2 sterilized sand. Two weeks after acorns were planted at a depth of 2.5 cm in 8 equally spaced rows, cotyledons were carefully removed from the growing radicles in three randomly chosen trays, simulating removal by small mammals. Remaining acorns were used as controls. For the first nine weeks, the germination phase, trays were watered three times weekly until the soil mixture was saturated. Beginning with week 10, the water stress phase, each tray received only 0.5 1 of water/week, until week 21, the resprout phase, when water was provided at the initial intensity. After eight weeks of greenhouse conditions, 68% of intact acorns germinated into seedlings, whereas only 53% of acorns without cotyledons germinated. After 10 weeks of water stress shoot mortality was observed. Seven weeks after watering was resumed, 17% of seedlings with cotyledons and 33% of seedlings without cotyledons resprouted. Seedling survival (with or without cotyledons) differed within the germination ($P < 0.0001$), water stress ($P < 0.0001$) and resprout phase ($P < 0.0001$). Variation in seedling survival within either the germination, water stress or resprout phase was accounted for primarily by time. Survivorship of seedlings that lose the acorn food reserve was lower initially; however, after stressing seedlings until the shoots died back, seedlings with cotyledons removed resprouted and survived at double the rate of control seedlings. Recovery from cotyledon loss evidently prepared these seedlings for the next stressful situation. Our results suggested a potential for establishment of vigorous seedlings from white oak acorns, even if cotyledons are removed from the radicle by small mammals during late winter-spring.

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UNDERSTORY COMPOSITION OF HARDWOOD STANDS IN NORTH CENTRAL WEST VIRGINIA

Mark J. Twery[1]

Abstract: Understory composition was measured on 960 10.5 m^2 plots in 16 stands on the West Virginia University Forest in north-central West Virginia. The overstory composition was dominated by oaks (*Quercus* spp.) on 50% of the stands and by a mixture of oaks and yellow-poplar (*Liriodendron tulipifera* L.) on 50%. All stands were without recent disturbance and ranged in age from 60 to 100 years. All woody stems under 7 cm dbh were counted by size class and percent cover was estimated for woody and herbaceous vegetation.

Ferns dominated the understory on 32% of the plots and tree species dominated on 30% of the plots. Dominance by ferns was correlated with more mature stands in both forest types. Woody vines such as greenbrier (*Smilax* spp.) were the dominant form on most of the remaining plots (26% of tthe total) in the mixed stands, while only 9% of the understory plots were dominated by shrub species such as blueberry (*Vaccinium* spp.). Total number of species on the 10.5 m^2 plots ranged from 1 to 25, while stand averages ranged from 7 to 14 species per plot (Figure 1).

A total of 38 different woody species were found on the study plots. The most common woody understory species (Figure 2) included red maple (*Acer rubrum* L.) (43% of total stems), black cherry (*Prunus serotina* L.) (17% of total stems), and sassafras (*Sassafras albidum* (Nutt.) Nees) (14% of total stems). Red maple was present on 94% of sample plots, black cherry on 79%, and yellow-poplar on 69%. Red oak (*Quercus rubra* L.), although not as abundant, was also well distributed, as shown by its presence on 54% of the study plots.

Significant differences were not found in Shannon's Diversity Index (H') for woody species between cover types, although the mixed oak-yellow poplar stands tended to have slightly higher diversity. Conversely, Hill's Evenness Index showed somewhat greater values for the oak stands.

Species abundances of the larger stems differed from the overall total, indicating differential abilities of woody species to survive early seedling stages. The dominance of cherry among the stems over 30 cm tall implies the possibility that it may well dominate the next stand. All areas are well-stocked with advance regeneration of commercial tree species and should respond well to future disturbances.

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[1]Research Forester, USDA Forest Service, Northeastern Forest Experiment Station, Morgantown, WV 26505-4360.

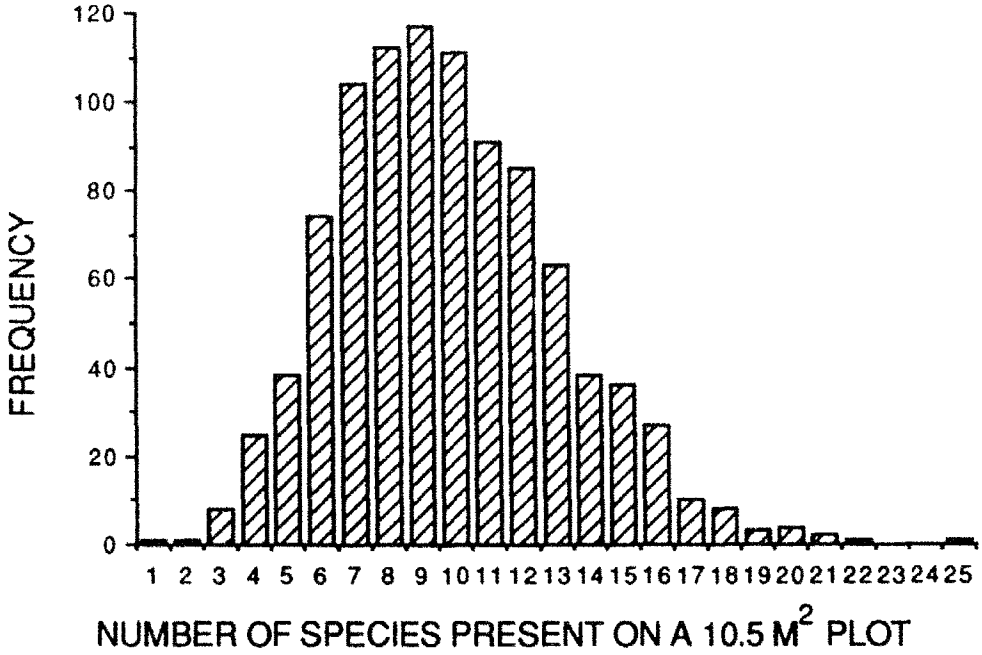

Figure 1. Species richness distribution on 960 understory plots in oak and mixed hardwood stands on the West Virginia University Forest.

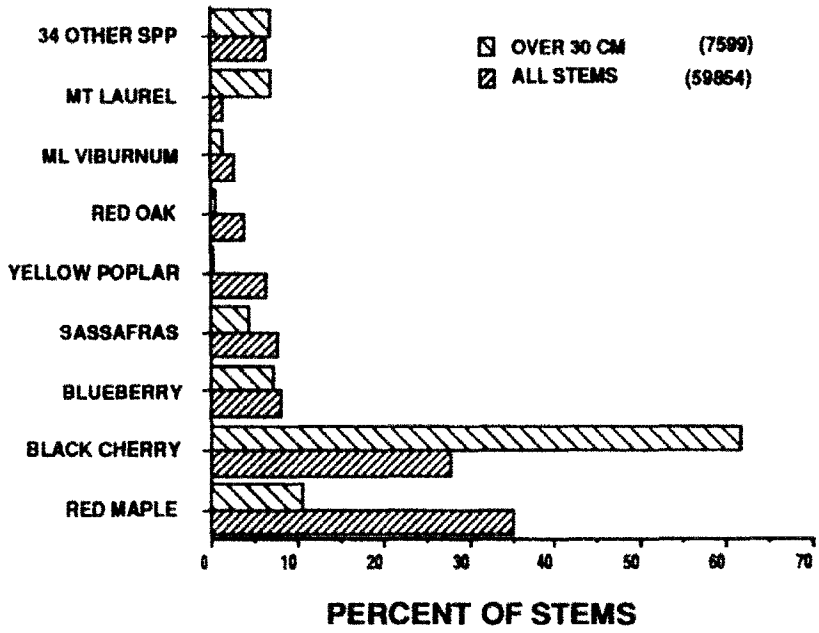

Figure 2. Abundances of common woody species on 960 understory plots in oak and mixed hardwood stands on the West Virginia University Forest.

HARDWOODS ARE NOW BEING HARVESTED AT RECORD LEVELS

Richard H. Widmann[1]

Abstract: Recent canvasses by the USDA Forest Service of the sawmills and pulpmills in the central hardwood region show large increases in the harvests of hardwood species. In Kentucky, the production of hardwood sawlogs rose from 457 million board feet in 1974 to 775 million board feet in 1986, a 70 percent increase. In West Virginia, hardwood sawlog production also increased. In 1987, hardwood sawlog production in the Mountaineer State totaled 566 million board feet, an increased of 39 percent over the 399 million board feet produced in 1979.

A variety of species make up the sawlog harvests in these two states. In West Virginia, northern red oak lead all other species with 129 million board feet cut for sawlogs followed by yellow-poplar with 113 million board feet. In Kentucky, yellow-poplar was the top species harvested with 109 million board feet; white oak was a close second with 108 million board feet. As a group, the oak species represented 52 percent of all hardwoods harvested for sawlogs in these states.

The harvest of hardwoods for pulpwood also has increased in these states. In 1988, 413,000 cords of hardwood pulpwood were harvested in Kentucky and West Virginia versus 171,000 cords harvested in 1978.

Increased activity at sawmills in Kentucky and West Virginia has made available more residue chips for pulpmills to use for furnish. Between 1978 and 1988, the use of hardwood residue chips for pulpwood more than doubled, from 338,900 cord equivalents to 757,500 cord equivalents in these two states.

Timber inventories in these states have been building over many years. The ratio of timber growth to removals is 3.7 to 1 West Virginia and 2.1 to 1 in Kentucky. Because of these favorable ratios and the large inventories currently available for cutting, it is likely that forest industry will continue to expand in these states to take advantage of existing opportunities.

[1]Forester, USDA Forest Service, 5 Radnor Corporate Center, 100 Matsonford Rd., Suite 200, Radnor, PA 19087.

PLANTING NORTHERN RED OAK: A COMPARISON OF STOCK TYPES

J. J. Zaczek, K. C. Steiner, and T. W. Bowersox[1]

Abstract: Height and survival values of northern red oak (*Quercus rubra* L.) were compared three years after outplanting as functions of: stock types (direct-seeded, 1-0, 2-0, 1-1, 2-1, and 2-year-old seedlings grown in 7.9-liter pots), presence or absence of undercutting in the nursery, and presence or absence of top-clipping when field planting. In all, 33 or more completely randomized single-tree plots for each of 17 different treatments or treatment combinations were represented at recently clear-cut sites in northern, central, and southern Pennsylvania. The same seed source was used in all seedling treatments. Seedlings were protected from white-tailed deer browsing by 6-strand electric fences and competing vegetation was removed.

After three growing seasons, survival ranged from 94% to 92% at the northern and central plantings, where there were no obvious treatment differences, to below 70% at the southern site. At the southern site, treatment survival percentages ranged from a high of 97 for unclipped containerized stock to a low of 48 for one of the unclipped 1-0 stock treatments. The only discernable pattern in survival at this site was that, for 2-0 and 1-0 stock treatments, undercutting resulted in an average 19% survival advantage.

Germination of direct-seeded acorns was 90%, 63% and 20% for the northern, central, and southern sites, respectively. Pilferage of acorns by animals accounted for only a 3% loss at all three sites combined. Germination differences were most likely due to soil physical properties and weather.

Site means for total height were statistically different ($p<0.0001$) at 62, 86, and 134 cm for the southern, northern, and central plantings, respectively. There was a statistically significant site x treatment interaction, but 41% of this interaction is attributable to the uneven performance of just two treatments across sites. The direct-seeded and 2-1 unclipped treatments performed relatively better (compared to other treatments) in the shorter, southern plantation than in the central and northern plantations. With these exceptions, the treatment rankings indicated by the data below are generally representative of individual site results.

Considering all sites together, treatment differences in total height after three years in the field were highly significant ($p<0.0001$). Of all treatments, two-year-old containerized seedlings were the tallest at 151 cm (162 and 141 cm, unclipped and top-clipped, respectively). Of all remaining treatments, the 2-0 seedlings were tallest at 115 cm, and these were 62% taller than 1-0 seedlings. Transplanted seedlings (2-1 and 1-1) were smaller than non-transplanted 2-0 seedlings. Undercutting in nursery beds produced variable results: it

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improved the height of 2-0 seedlings by 10% (P=0.05) but reduced the height of 1-0 seedlings, though not significantly. Except for containerized stock, top-clipped seedlings were generally taller than unclipped seedlings, but none of the differences were statistically significant. Seedlings arising from from direct-seeded acorns were not significantly different in height from 1-0 planted seedlings.

In summary, transplanting in the nursery did not result in improved field performance after three years, and undercutting gave variable results. The containerized seedlings performed best overall but their growth advantage may have been more than offset by the added costs and efforts of production and planting. Among all other treatments, 2-0 bareroot seedlings (especially if undercut in the nursery) unquestionably produced the tallest seedlings and had good survival. In most comparisons, top-clipped seedlings performed slightly better than unclipped seedlings, and this treatment facilitates handling. Perhaps most surprisingly, direct-seeded plants were as tall as seedlings from 1-0 stock, suggesting the possibility of a considerable savings in the cost of artificial regeneration if acorn viability is good and predation is minimized.

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Two invited papers, forty-five volunteer papers, and twenty volunteer poster summaries presented at the 8th Central Hardwood Forest Conference. Presentations were on economics, forest amenities, harvesting, utilization, physiology, genetics, ecology, regeneration, silviculture, protection, management, hydrology, soils, nutrient cycling, and hardwood markets of central hardwood forests.