



Forest Service
U.S. DEPARTMENT OF AGRICULTURE

Northern Research Station | General Technical Report NRS-228 | June 2025

Managing Your Woodland: Forestry Research Translated for Landowners

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Granstrom, Maren; Kenefic, Laura S.; Crandall, Mindy S.; Stockwell, Sally; Giffen, R. Alec; Rogers, Nicole S. 2025. Managing your woodland: forestry research translated for landowners. Gen. Tech. Rep. NRS-228. Madison, WI: U.S. Department of Agriculture, Forest Service, Northern Research Station. 47 p. <https://doi.org/10.2737/NRS-GTR-228>.

Abstract

A long-term study of forest management, like the one established in the 1950s by the U.S. Department of Agriculture, Forest Service at the Penobscot Experimental Forest in Maine, provides a unique opportunity for landowners to learn about different approaches to management and their outcomes. After more than 70 years of research at the Penobscot Experimental Forest, it has become apparent that the management approaches applied have changed the species composition, tree quality, wildlife habitat, carbon storage, productivity, and financial value of the forest. The side-by-side comparisons included in the long-term experiment provide photos and data that clearly demonstrate the outcomes of uneven-aged and even-aged silviculture and exploitive harvesting. This guide provides background information about forest ecology and silviculture (the science and art of managing forests for the outcomes we want) for landowners and others who are not forestry experts, then explains several types of management and the benefits and challenges associated with each. Finally, additional resources are provided to help landowners move forward and make informed decisions about the future of their woodlands.

Keywords: silviculture, forest landowners, northern conifers, long-term study, experimental forest, education

Cover photo: Penobscot Experimental Forest, 2019. Courtesy photo by Scott A. Sell.

Published by:
USDA Forest Service
One Gifford Pinchot Drive
Madison, WI 53726
June 2025

Visit our website at <https://research.fs.usda.gov/nrs>

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Acknowledgments

This work was made possible with funding from the U.S. Department of Agriculture, Forest Service, Northern Research Station; University of Maine, School of Forest Resources; Northeastern States Research Cooperative; and Maine Outdoor Heritage Fund. Thank you to our reviewers, Lloyd Irland, Andy Shultz, Jessica Leahy, and Alexandra Kosiba, for lending their time and expertise.



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Introduction



A recently harvested stand on the Penobscot Experimental Forest, 2020. USDA Forest Service photo by Laura Kenefic.

Welcome

As a woodland owner you might be interested in managing your forest but not know where or how to start. Information might be overly technical or hard to find, especially if you have multiple goals such as wildlife habitat, recreation, and timber. This guide introduces a few common approaches to forest management and outlines some pros and cons of each based on 70 years of research conducted by the U.S. Department of Agriculture, Forest Service, at the Penobscot Experimental Forest in Maine. Different types of management applied in 20-acre experimental areas have been studied by doing inventories of the sites every 5 to 10 years and before and after harvests to document how the forest changes over time. Tree species, size, quality, and amount of wood harvested have all been tracked since 1952, and habitat quality

for some bird species has been considered. This guide summarizes the findings of that research. The following pages help to explain how a forest might respond to different types of management, setting you on a path toward successfully managing your own woodland.

A 26-minute film accompanies this guide. For a virtual tour of research at the Penobscot Experimental Forest and to hear from forestry experts, scan the QR code or visit <https://www.youtube.com/watch?v=eykwZkKrYKg> to watch “Forestry for the Future: Lessons in Sustainable Management from Maine” on the University of Maine YouTube channel.



Why Forestry?

Forestry is the study and management of forests. It helps us assess the condition of a forest and achieve our goals through careful management. Those goals might include improving wildlife habitat, timber production, water quality, recreation, and many other forest values. Knowledge of forestry cannot tell you what those goals are but can help you achieve them.

A critical part of forestry is silviculture, the science and art of managing forests for the outcomes we want to achieve. Silviculture usually involves some kind of harvesting, but the focus is on the future of the forest. When practicing silviculture, the trees that will grow and be harvested many decades in the future are just as, if not more, important than those that are removed in the present.

How Did We Get Here?

The forests of the northeastern United States have been shaped by human activities for millennia, including the use of trees for shelter, fuelwood, cultural purposes, timber harvesting, and clearing for farming and pasturing. The very small amount of forestland in the region that was not harvested in the past few hundred years is mostly in steep or remote areas (33).

Some clues to past human activity are easy to find, such as old stumps and stone walls running through the woods. Others are more subtle: clumps of trees that sprouted from cut stumps, many acres of trees of the same age, or a lack of large downed logs. In addition, nonnative pests and diseases introduced to the region by humans continue to influence forests by altering the species that are present, almost eliminating mature American chestnut and American elm and posing a threat to ash and eastern hemlock (see appendix 1 for a list tree and wildlife species mentioned in this guide).

In Europe, foresters have worked for centuries to provide a sustained flow of wood products from limited forestland area. But when European colonial settlers first arrived in North America, the forests appeared endless. It was not until the true scarcity of the resource became apparent in the early 1900s that forward-thinking forest management, not just exploitive harvesting, began (19).

Markets and harvesting technology have evolved together over time, from people and oxen or horses removing just the biggest trees to large machinery cutting small-diameter trees for biomass production. Even in the past 50 years, the relative values of different tree species have changed. In some parts of the northeastern United States, spruce and balsam fir were historically more desirable than hardwoods (i.e., deciduous, broadleaved trees) for making paper and so were favored through management, but changes in markets have created incentives to grow a wider range of species in the forest today (11).

Because of environmental and human influences, forests are continually changing. Not everything lies within our control, but careful management can help forests be more resilient to environmental and market changes in the future.



Harvesting operation, 1950s. USDA Forest Service photo.



Harvesting operation, 1990s. USDA Forest Service photo .

Understanding Trees and Forests

The terms that foresters use to talk about trees and forests can be confusing to people who are not experts in the field. Knowing the definitions of some commonly used terms can help you understand and communicate about management of your woodland (see sidebar).



Spruce forest in coastal Maine. Courtesy photo by Maren Granstrom.

Some Key Forestry Terms and Concepts

Silviculture—The science and art of growing, tending, and regenerating trees to achieve the forest conditions we want (15). This can involve activities such as harvesting, thinning (cutting some trees to provide more growing space for others), and pruning (cutting off low branches), but always with a plan for future growth and improvement. A silvicultural system is a planned series of such activities carried out over time that will shape both the current and future forest.

Stand—A contiguous area of forest with common characteristics, defined by natural boundaries, manmade boundaries, or a combination of both (15). Usually refers to an area that will be managed as a single unit.

Regeneration—The new generation of young trees. Advance regeneration is already growing under the canopy of mature trees before a harvest (15).

Even-aged stand—A stand in which all the trees are roughly the same age and often of similar size (15). Trees in the stand started growing around the same time in response to a large disturbance, such as a severe windstorm or large harvest. Even-aged silvicultural systems are used to manage even-aged stands.

Uneven-aged stand—A stand in which there are at least three age classes of trees (15), usually arranged in an understory, midstory, and overstory, with foliage at all height levels. In an uneven-aged stand, individual trees or groups of trees started growing at different times in response to small disturbances, such as single or small groups of trees dying or harvests of scattered trees. Uneven-aged silvicultural systems are used to manage uneven-aged stands. The term multi-aged is broader and is often used to describe stands with two or more age classes of trees.

Diameter at breast height (DBH)—The diameter of the tree stem (also called bole or trunk) at 4.5 feet above the ground. A standard measurement of tree size used by foresters.

Basal area (BA)—The cross-sectional area covered by tree stems at breast height. (Imagine every tree cut off at 4.5 feet above the ground; BA is the surface area of the tops of the stumps). This is a common way of describing how much growing space is occupied in a stand.

Why Do Trees Grow Where They Do?

Each tree species has different requirements for regeneration and growth. Some must grow from seeds, while others, like red maple, are also able to sprout several stems from a recently cut stump or, like aspen, from roots of existing trees. Some species grow well in full sunlight, and others in shade. By creating certain conditions in the forest, we can give an advantage to some species over others.

One of the most important things that harvesting and silviculture affect is light (31). When regenerating a forest, the amount of light helps to determine which species will successfully grow, especially in the northeastern United States where precipitation is abundant year round. For some tree species, light requirements for seedlings are different than the amount of light needed as the trees grow larger.

Species such as paper birch and aspen regenerate and grow well in large openings with full sunlight. These

species are shade intolerant. Species like sugar maple, red spruce, balsam fir, and eastern hemlock tend to regenerate best in partial shade and grow well in partial sun (Fig. 1). These species are shade tolerant. Northern red oak and eastern white pine grow well in partial shade when they are seedlings, but after a few years grow best in full sun. These species have intermediate shade tolerance (6).

Soil and site conditions can also influence species composition. Factors such as soil type, depth, and moisture can vary even within a small property, and determine which tree species are likely to be most successful in the long run. Site conditions can vary on a very small scale, known as a microsite. For example, a yellow birch or red spruce seedling might grow on the moist microsite provided by a decaying stump even if the surrounding ground is too dry.



Figure 1.—Red spruce seedlings growing in a gap created by a fallen tree. Courtesy photo by Maren Granstrom.



Figure 2.—Tree species did not differ across this area before it was divided for research in 1950. Species composition changed after harvesting due to different types of management (uniform shelterwood silviculture on the left and opportunistic harvesting on the right, see pages 15 and 29). Today, eastern white pine and red spruce are more abundant on the left and red maple, birch, and aspen are more abundant on the right. Courtesy photo by David Sandilands.

After a Harvest, What Determines Which Species Will Grow Back?

Many harvests in the northeastern United States cause seedlings and saplings already growing beneath the canopy to grow more vigorously and become the next main forest canopy. These small trees can shape the future species composition of the forest. In addition, large trees left after a harvest not only continue to grow but also provide seeds and shade; in this way they too play an important role in the composition of the future forest (Fig. 2). Harvests can also influence species composition by altering the ground condition. For example, eastern white pine regenerates well on exposed soil (i.e., soil not covered by leaves, moss, etc.). If eastern white pine regeneration is desired, harvest operations can provide an opportunity to scuff the surface of the forest floor if the ground is not frozen or covered with snow (40).

Unfortunately, some factors can make it difficult to grow desired species. White-tailed deer browse on small trees and other plants and can reduce or even eliminate some species in areas where deer populations are high. Understory plants and shrubs, especially those that are invasive, can outcompete tree seedlings (25). Beech bark disease, a disease complex that affects American beech trees, can lead to an abundance of small beech trees that take up nearly all the growing space and present serious challenges to creating a diverse forest or a forest with large, healthy trees. Foresters and scientists are researching and testing creative solutions to these issues.

Forest Types

There are several distinct forest types in Maine and the surrounding region. Forests can be classified in many ways, but in this publication we have chosen to group forests into three broad categories based on whether the most abundant species are softwoods (coniferous, needle-leaved trees), hardwoods (deciduous, broad-leaved trees), or a mixture of the two (mixedwoods). While the Penobscot Experimental Forest and the examples included in this guide are representative of the northern conifer forest type, many of the principles and outcomes discussed are applicable to other forest types as well, particularly if shade-tolerant species are abundant. This includes many areas of the northeastern and upper midwestern United States and adjacent parts of Canada.

In the northeastern United States, the major forest types include these common tree species (45):

Northern conifer—At least 75 percent of tree volume in the forest is softwood species. These stands may be dominated by red, white, or black spruce, balsam fir, eastern hemlock, and northern white-cedar (Fig. 3).

Northern hardwood—At least 75 percent of tree volume in the forest is hardwood species. These stands may be dominated by sugar and red maple, yellow birch, American beech, and white ash (Fig. 4).

Mixedwood—Hardwoods and softwoods are found together, with neither exceeding 75 percent of tree volume. Oak – pine is a common and important mixedwood in the region, in which northern red oak and eastern white pine are the dominant species (Fig. 5). Other mixedwoods in the northeastern United States include maples, birches, aspen, and beech, in mixture with eastern hemlock, spruce species, balsam fir, and northern white-cedar.



Figure 3.—Northern conifers in coastal Maine. Courtesy photo by Maren Granstrom.



Figure 4.—Northern hardwoods in central Maine. Courtesy photo by Maren Granstrom.



Figure 5.—Oak – pine mixedwood in central Maine. Courtesy photo by Maren Granstrom.

Silviculture: What Works in the Northeastern United States?

Foresters learn how to manage trees and forests based on observations of nature and studies of how trees grow under different conditions. Because different environmental conditions favor different tree species, appropriate methods of management need to incorporate both the environment and the characteristics of the desired species.

Disturbances resulting from wind, fire, and native insects are a natural part of forest ecosystems. These disturbances affect environmental conditions such as light, water, and temperature and, in this way, favor some tree species over others. Silviculture and forest management use knowledge of environmental conditions and disturbances to guide the growth of particular stands of trees to achieve desired outcomes. For example, if a forester wants to grow a species in a particular location, then they would need to maintain conditions, such as light and temperature, that are suitable for that tree species.

Regions where natural disturbances tend to disrupt large areas at once (for example portions of the western United States where fires of moderate to high severity were historically common) may have even-aged forest stands where most of the trees originated after one event and grow in full sun (2). In the northeastern United States, natural disturbances that kill most of the trees in a large area do not often occur (48). Common tree species tend to be those that grow well in small gaps created when just one or a few trees die or blow down. This results in a multi-aged forest with many shade-tolerant species. Successful silvicultural practices for intermediate and shade-tolerant species in the region often create conditions similar to those resulting from natural disturbances.

Silviculture is not just about regenerating a forest, either by seeds or sprouts or through planting, but also about tending the forest as it grows and matures. Foresters use a range of approaches to affect the growth, quality, and composition of a forest. Practices such as thinning and pruning focus on improving the growth and quality of existing trees.



Natural gap in an unmanaged forest in Maine. Courtesy photo by Scott A. Sell.

How Do We Value a Forest?

Depending on interests and goals, different landowners assess the quality and value of each tree, stand, or forest in different ways. It is helpful to think about what is important to you when deciding on management strategies.

Financial Value

Many commercial products come from forests. These include nontimber products such as balsam fir tips for wreaths, mushrooms, and other plants used for food and medicine. Yet wood from trees remains the primary source of income from forests of the northeastern United States. Wood products from trees include firewood, biomass (for heat or electricity), pulpwood (for paper manufacturing), sawtimber (for lumber), and veneer (for plywood or paneling). Certain species of trees are suitable for some uses but not others. The value of each species and product can change dramatically from one year to the next depending on consumer demand, technology, and other market variables.

Trees are sold for different uses based primarily on species, size, form (how straight the trunk is), and presence of defects like rot or dead branch stubs. The stumpage price (the take-home value for the landowner) can increase dramatically as a tree grows into different product categories (Table 1). Trees sold for sawtimber need to exceed a minimum diameter and straight log length, and those sold for veneer also need to be free of any defects. A forester or logger can explain the intricacies.

More information about wood markets and how they relate to management strategies can be found in the article “Fifty Years of Maine Stumpage Prices: Trends, Surprises and Lessons” by Lloyd Irland in Northern Woodlands magazine (16).

Ecological Value

An individual tree can be ecologically important, even if it is not valuable for timber. A good example is an American beech tree with a large crown and smooth bark that is resistant to the beech bark disease. Large, healthy beech trees that produce many nuts are declining on the landscape. This is

Table 1.—Examples of differences in dollar value for two common species in the northeastern United States in 2023

	Northern Red Oak	Eastern White Pine
Biomass, per ton	\$2.00	\$2.00
Pulpwood, per ton	\$9.00	\$2.00
Firewood, per cord	\$28.00	Not used for this product
Sawtimber, per thousand board feet	\$285.00	\$229.00
Veneer, per thousand board feet	\$650.00	Not used for this product

Source: 2023 Maine Stumpage Price Report, statewide averages (29).

an important tree to leave growing in the forest, as it provides a food source for wildlife and may pass on its disease-resistant genes. Similarly, trees with cavities that provide homes for wildlife are good to keep in managed forests even if their commercial value is low.

Aesthetic Value

Certain trees, or areas of a forest, are aesthetically beautiful and special to landowners. Some people prefer the look of the large, straight trees that are most valuable for timber, but an old gnarled red maple, not worth more than a few dollars for pulpwood, might be right along a path and look beautiful each fall.

If you spend a lot of time in your woodland, make sure that management and harvesting are visually acceptable to you before undertaking those activities. Almost any harvest will leave behind some slash (treetops and branches), but these will slowly decay over time and become less visible in future years. It is helpful to visit another property where similar management has taken place and see if you like the result. A good resource is “What Will My Woods Look Like?”, a publication from the Maine Forest Service showing before and after photos from several kinds of harvests, with landowner, forester, and logger commentary (30).

Forestry for Wildlife

Identifying and Improving Key Habitat Features

Elements of forest structure, such as amounts of softwoods and hardwoods, density and height of the canopy, and amount of dead or dying trees, affect habitat quality for many wildlife species. Many landowners are interested in hunting game species like white-tailed deer or ruffed grouse, viewing rare or migrant birds, and protecting threatened and endangered species. Guides such as the “Landowner's Guide to Wildlife Habitat: Forest Management for the New England Region” are available for those interested in managing a woodland to promote certain types of wildlife (9). Your state forestry or wildlife agency might also have more information.

In “Forestry for Maine Birds,” experts from Maine Audubon and other state and private organizations provide habitat guidelines for 20 forest bird species of high conservation concern (10). These species were chosen based on declining populations, future threats, high proportions of their populations found in northeastern forests, and relative ease of identification by sight or song. These are not the only species of importance, but their habitat needs include the needs of many other animals. The guide includes a habitat assessment that was applied to forest stands at the Penobscot Experimental Forest. Some results from those assessments are included in the following pages.

Careful forest management can increase beneficial habitat features for desired species and can take into account the role of a particular forest stand in a larger landscape context. It is important to look beyond your own property before deciding which habitat features might be lacking. While no one forest stand can or needs to provide habitat for all species, your property can meet habitat needs of species important to you or provide habitat features that might be missing in the surrounding landscape. A forester or wildlife biologist can help to determine what habitat types are missing.

Some important habitat features identified by Maine Audubon include:

- Multiple layers of forest floor plants, shrubs, and trees of different ages and sizes that provide a range of places to nest, find food, and hide from predators.
- Snags (dead standing trees) for woodpeckers and the many birds and mammals that later use their cavities.
- Downed dead wood (logs and branches) for hiding, drumming, feeding, and perching.
- Canopy gaps between one quarter and two acres in size that encourage young trees and shrubby conditions needed by several bird and mammal species.
- Large trees that are used by some species for feeding and nesting.

Maine Audubon provides a list of priority forest birds and the forest types and key habitat features with which they are associated (Table 2). In addition, you can visit the Maine Audubon Forestry for Maine Birds website for more information (28). Similar resources for some other New England states are listed on page 35.



American woodcock. Licensed photo by Rhododendrites/
Wikimedia Commons.

Table 2.—Maine Audubon’s list of priority forest birds and the forest types and key habitat features with which they are associated (10)

Bird species	Forest type ^a	Key habitat features
American woodcock	Northern mixedwood	Small clearings, dense undergrowth
Bay-breasted warbler	Northern mixedwood, northern conifer	Dense conifers
Black-backed woodpecker	Northern conifer	Large dead and dying trees
Blackburnian warbler	Northern conifer, oak–pine	Tall trees, large eastern hemlock trees
Black-throated blue warbler	Northern hardwood, northern mixedwood	Dense shrubby understory
Black-throated green warbler	Northern mixedwood	Eastern hemlock trees
Boreal chickadee	Northern conifer	Snags
Canada warbler	Northern mixedwood	Wet areas with small gaps
Chestnut-sided warbler	Northern hardwood	Gaps with regeneration
Eastern wood-pewee	Northern mixedwood, oak–pine	Small gaps
Magnolia warbler	Northern conifer	Dense conifer regeneration
Mourning warbler	Northern hardwood	Dense regeneration
Northern flicker	Oak–pine	Snags, open forest
Northern parula	Northern conifer	Moist forest, bearded lichen ^b
Olive-sided flycatcher	Northern conifer	Gaps and snags
Ovenbird	Northern hardwood, oak–pine	Mature forest, dense leaf litter
Scarlet tanager	Northern hardwood, oak–pine	Forest interior, tall trees
Veery	Northern hardwood, oak–pine	Sapling patches and riparian areas
Wood thrush	Northern hardwood, oak–pine	Tall trees, dense leaf litter
Yellow-bellied sapsucker	Northern hardwood, northern mixedwood	Snags, especially aspen and birch

^aMaine Audubon recognizes two types of mixedwoods: northern mixedwood (eastern hemlock, spruce species, and balsam fir in mixture with hardwoods) and oak–pine.

^b*Usnea longissima*

Forests and Carbon

Changes in patterns and extremes of precipitation and temperature affect our forests and other natural systems. Forests can help mitigate these changes and their impacts by providing ecosystem services like intercepting rain or sequestering and storing carbon, but are also stressed by the changes as they occur (27). For this reason, forests' contribution to services like carbon storage will be most successful if they are able to withstand or adapt to future disturbances and growing conditions. The concepts of mitigation, vulnerability, resilience, and adaptation are useful to know when considering forests and carbon (see sidebar).

The same type of management might not achieve high levels of both sequestration and storage. In some cases, unmanaged forests have the highest carbon storage, but intensively managed forests have the highest sequestration rates. Balancing mitigation, resilience, and adaptation goals might require some compromises.

For further reading, the New England Forestry Foundation's webpage about exemplary forestry includes a section about forests and carbon storage (35). Alexandra Kosiba's "A Guide to Forest Carbon in the Northeast" is also an excellent resource (27). Or, explore the "New England and Northern New York Forest Ecosystem Vulnerability Assessment" from the U.S. Forest Service, which includes ideas for adaptation (17, 8).



Research plot at the Penobscot Experimental Forest. Courtesy photo by Maren Granstrom.

Some Key Forestry Concepts

Carbon sequestration—This is the rate at which carbon is being accumulated in a tree or forest.

Carbon storage—The amount of carbon stored in the forest at a given time (7). Carbon storage (also called stock) is in different parts of the forest: live and dead trees, the forest floor, and soil. In managed forests, carbon can continue to be stored in harvested wood products for as long as they are used.

Mitigation—Forests can reduce (mitigate) effects of excess carbon dioxide (CO₂) in the atmosphere by sequestering CO₂ and storing carbon in the live and dead trees, forest floor, and soil. Forest management can contribute to mitigation, and using wood products for building can both store carbon in that wood and replace more carbon-intensive materials like steel, concrete, and plastics (18). Managing forests for improved health and productivity, ecosystem functioning, and wood production for building can enhance mitigation.

Vulnerability—This is the degree to which a forest is susceptible to and unable to recover from disturbances. Different species and ages of trees have different stress tolerances and susceptibility to disturbances (27).

Resilience—This is the capacity of a forest to recover or adapt following disturbances or stress. Resilient forests typically have diverse tree species and ages, allowing them to accommodate change and continue as forests after experiencing disturbances or stress (27).

Adaptation—Preparing for and responding to anticipated impacts of disturbances by reducing vulnerabilities and advancing forest resilience is called adaptation (27). In the northeastern United States, scientists predict warmer temperatures, more extreme weather events, variable precipitation, and increasing impacts of pests and diseases (17). Some tree species are expected to adapt to these changes better than others, and those species can be favored during management.



Figure 6.—Sign at the Penobscot Experimental Forest, 1956. USDA Forest Service photo.



Figure 7.—A forester measuring tree diameter at the Penobscot Experimental Forest, 1954. USDA Forest Service photo by Arthur C. Hart.

Experimental Forests: Research for the Long Term

At research sites around the country, U.S. Forest Service scientists and collaborators have been studying ecological systems for over 100 years. Today, 81 experimental forests provide the opportunity to learn and share valuable scientific information about many vegetation types in the United States. The Penobscot Experimental Forest in Bradley and Eddington, Maine, is one of these (Fig. 6).

Trees grow slowly and can live for centuries; a forest's time scale is much longer than a human life. Long-term research can help us understand how harvesting and other types of human activities impact a forest not just in our own lifetime, but in the next generation's as well (Fig. 7). With that knowledge we can make the best decisions possible.

Studies on the U.S. Forest Service's experimental forests have increased our knowledge of how forests impact water quality, fire behavior, wood supply, carbon dynamics, endangered species recovery, habitat provisioning, and much more (1). Information about each experimental forest and range along with research results from decades of studies are free and available to all. To learn more about the Forest Service network of Experimental Forests and Ranges and the Penobscot Experiment Forest, scan the following QR codes:

<https://research.fs.usda.gov/forestsandranges>



<https://research.fs.usda.gov/nrs/forestsandranges>



<https://research.fs.usda.gov/nrs/understory/penobscot-experimental-forest>



Research Results in this Guide

Research at the Penobscot Experimental Forest has compared different types of silviculture and harvesting in a northern conifer forest for more than 70 years. Continuous, long-term studies like this are rare in forestry research, despite the importance of time in shaping forests.

This guide incorporates research from several studies, but the focus is on results of a U.S. Forest Service experiment called the Compartment Management Study that started in Maine in 1952 (Fig. 8) (5). Nine variations of management and harvesting were applied across several hundred acres, with at least two examples of each treatment in different areas of the experimental forest.

The treatments were chosen for the study because they were promising silvicultural systems with the potential to provide consistent timber over time, or as examples of exploitive harvesting practiced in the region at the time. Exploitive harvests aim only to maximize short-term financial gain, and unlike silvicultural systems, do not have the explicit goal of creating or sustaining specific forest values for the future.

Permanent sample plots were established in each treatment area, and harvests have taken place at predetermined intervals since the research began. Data collected on the sample plots every 5 to 10 years, as well as before and after every harvest, tell us how individual trees and the stands in which they are growing have changed in response to various management strategies. With these data, researchers can determine how different silvicultural treatments and exploitive harvests affect species composition, tree size, timber quality, growth rates, financial returns, structural diversity, carbon sequestration and storage, and more.

Because the treatments were applied side-by-side in the same forest, it is possible to walk around and see the changes after decades of management. The Compartment Management Study area at the Penobscot Experimental Forest once looked similar across its breadth, but you will see in the coming pages and the accompanying video (see page 1 for link) how it has been altered over 65 years.

WORKING PLAN FOR COMPARTMENT MANAGEMENT STUDY

Spruce-Fir Management

Penobscot Experimental Forest

THE PROBLEM

There need be no shortage of pulpwood of spruce, fir, and associated species in the spruce-fir region. If all the wood that is grown were used, the supply would be adequate for current demands and could probably continue to supply demands for many years to come.

Figure 8.—A portion of the working plan for the Compartment Management Study on the Penobscot Experimental Forest, 1962. Wood supply was a priority, but the focus of the research changed over time to include other values.

How this Guide Works

The decisions we make today can impact a forest for centuries. The tree species in a forest, their size, the soil conditions, and much more are altered by forest management choices, including the choice to do nothing (sometimes called passive management). Those changes might not become fully apparent for years, or even decades. That is what we have been studying at the Penobscot Experimental Forest and are now sharing with you. Sustaining all the values that forests provide requires a long-term view.

So why practice such careful management? Because we care not just about our own needs or enjoyment but want to sustain or improve the forest and continue to provide high-quality wood products and ecosystem values for those who come after us.

The previous pages gave an introduction to the science of forest ecology and management in the northeastern United States. The next section delves more deeply into the specific treatments and their outcomes at the Penobscot Experimental Forest by summarizing research results from the Compartment Management Study over the first 65 years (11). In the following pages, several kinds of silviculture as well as some common kinds of exploitive harvesting are explained.

It is important to remember that outcomes of these types of management might vary when applied in another forest type or in a stand with different starting conditions than the examples in this guide. A forester can provide guidance or clarification.

We All Have Different Goals and Values For Our Land

Your priority might be financial returns, wildlife habitat, climate change mitigation, recreation, or, most likely, a combination of these and more. No one type of management is the best at meeting all goals. The images and explanations in this guide will help you consider your priorities and various options for managing your property to make sure you achieve the best results possible and enjoy your forest for years to come.

How Do Different Kinds of Management Measure Up?

We present research findings from the Penobscot Experimental Forest so that you can understand and compare how different types of management might affect your property over time. We briefly explain some financial, ecological, and aesthetic outcomes that long-term research suggests you could expect. A comparison table (see Table 9 on page 46) helps you view important outcomes side by side, and the data and figures in appendix 2 provide numbers to support the outcomes described in each treatment section.

What If I Decide Not to Manage My Forest?

Choosing to do no management is an active decision that comes with its own outcomes. Forests will continue to change whether we manage or not; how they will change without management depends on the starting condition of the woodland.

If rare habitats or ecological communities are present, or if a forest contains species of plants or animals that are especially sensitive to disturbance, preserving a woodland can provide great benefit. In other cases, no management can prolong an unnatural or degraded forest condition that came about because of past land use. A forester or ecologist can help assess a forest and provide guidance on what types of management may help achieve your goals.



Oyster mushrooms. Courtesy photo by Maren Granstrom.

Even-Aged Silviculture

Uniform Shelterwood

Shelterwood silvicultural systems can be used to create an even-aged forest when the species you are trying to grow, such as eastern white pine, red spruce, or balsam fir, regenerate in partial shade. Uniform shelterwood refers to an even-aged system where the trees left to shelter the new generation are distributed evenly throughout the stand (Fig. 9).

The first step is to harvest many of the overstory trees from a mature stand, leaving behind some to provide seed and shade for the next generation. Once seedlings are established, usually 5 to 10 years later, most or all of the remaining overstory trees can be removed. The new age class is left to grow (and may be thinned) until the trees are large enough to harvest. Then the process begins again.

Financial

By controlling the seed source and amount of light during the period when new seedlings are established and later through thinning, shelterwood allows greater control of species composition than some other methods of naturally regenerating a stand. Because all trees are about the same age, they may be ready to harvest at around the same time (11). This creates more straightforward management and harvests and can provide a large flow of cash when trees are mature. However, unless it is possible to conduct a commercial thinning (see page 17) before the next harvest of mature trees, income may be many decades in the future.

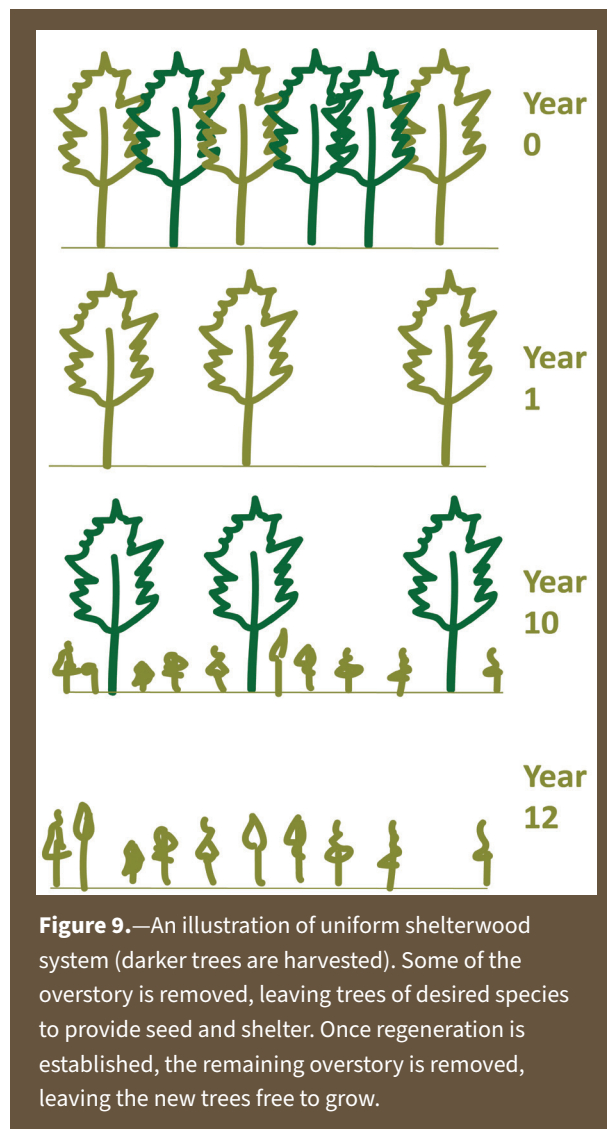


Figure 9.—An illustration of uniform shelterwood system (darker trees are harvested). Some of the overstory is removed, leaving trees of desired species to provide seed and shelter. Once regeneration is established, the remaining overstory is removed, leaving the new trees free to grow.



Dense trees create a shaded understory in an unthinned uniform shelterwood stand. Courtesy photo by Scott A. Sell.

Ecological

Uniform shelterwood silviculture is often applied in a way that creates a uniform condition, making it easy from a management standpoint, but less structurally diverse at any given time than a multi-aged stand (Fig. 10). Findings from a “Forestry for Maine Birds” assessment in the uniform shelterwood stands at the Penobscot Experimental Forest suggest that you might find magnolia warblers, or other birds and mammals that specialize in young softwood environments, in the first 5 to 15 years after overstory removal (10). Several decades later, as the shelterwood stand grows, the understory becomes dense and shaded, and small plants will disappear.

Selecting some large trees to remain in the stand following final harvest (called legacy or reserve trees) can reduce some of the declines in structural diversity and habitat that occur with even-aged management. This creates a two-aged stand and is a type of irregular shelterwood (see page 19).

Tree basal area changed over time in response to harvesting in the uniform shelterwood stands at the Penobscot Experimental Forest (Fig. 11). Dramatic changes in basal area like these impact how the forest looks and grows at different points in time.



Figure 10.—A uniform shelterwood stand. Note the similarity of tree sizes and shaded understory. Courtesy photo by Maren Granstrom.

Carbon

Shelterwood silviculture can result in high rates of **carbon sequestration** in fast-growing trees in the decades after seedlings are released from overstory shade (i.e., exposed to full sun for faster growth). However, the **carbon storage** in live trees in the stand will drop to near zero after the harvests of the overstory trees that initiate the next cycle of the shelterwood system (Figs. 12 and 13).

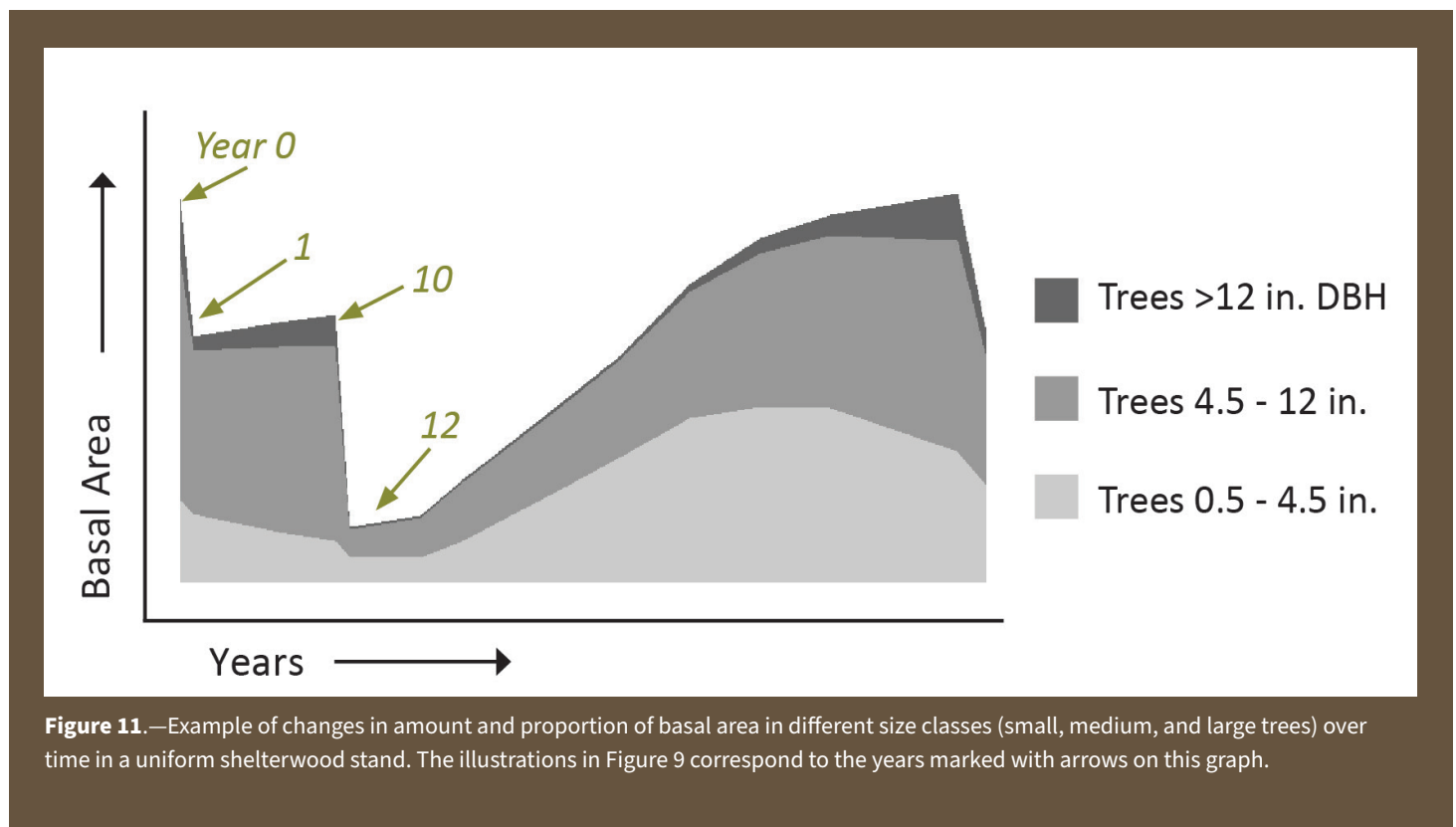




Figure 12.—Young trees in a uniform shelterwood stand at the Penobscot Experimental Forest, 15 years after overstory removal. USDA Forest Service photo.

To thin or not to thin?

Thinning removes some trees to provide conditions that concentrate growth on the trees that remain in the stand and may also favor certain species over others. Precommercial thinning means cutting down some trees that are too small to be sold to favor certain trees or species and create more space for faster growth on remaining trees. Commercial thinning has the same goals but takes place when the trees removed are merchantable. The tree size threshold for merchantability varies, and the markets in an area at a given point in time will determine if a thinning is precommercial or commercial by dictating which sizes and species of trees can be sold, and for how much. The stand in Figure 14 has been precommercially and commercially thinned, while the stand in Figure 15 has not been thinned. As a result, there are fewer but larger trees in the thinned stand, even though the trees in both photos are the same age. The cost of precommercial thinning may or may not pay off financially in terms of greater future value, though it may mean an earlier final harvest because the trees reach merchantable size sooner.



Figure 13.—A uniform shelterwood stand at the Penobscot Experimental Forest, 45 years after overstory removal. Courtesy photo by Maren Granstrom.



Figure 14.—A uniform shelterwood stand at the Penobscot Experimental Forest that has been precommercially and commercially thinned. Note the more open spacing and larger tree size. Courtesy photo by Maren Granstrom.



Figure 15.—Dense stems and smaller tree size in an unthinned uniform shelterwood stand at the Penobscot Experimental Forest. USDA Forest Service photo by Laura Kenefic.

Why choose uniform shelterwood?

- If you have a long-term profit-driven focus, shelterwood silviculture can sustainably produce predictable forest products, particularly if stands are thinned.
- As seen at the Penobscot Experimental Forest, the stand structure is relatively simple (11), and removing large volumes of wood in a few harvest entries makes this operationally efficient.

What are the challenges?

- Uniform shelterwood stands may be dominated by one or two species, and all trees may be ready to harvest at the same time. Findings from the Penobscot Experimental Forest show that this will work well if timber markets are favorable, but can be risky if markets change so that the value of those species is lower than expected (11, 16).
- In stands where just one or two tree species are encouraged, a forest may be more susceptible to pests and diseases that attack those few species (50).
- If trees are not thinned as they grow, dense stands of similar-sized trees with narrow trunks and small crowns can result (51). These trees are not especially stable on their own, so when some trees in the stand are later harvested to reduce canopy cover and increase light on the forest floor to encourage new regeneration, the remaining trees may be more likely to blow over.
- Many intensively managed stands lack dead standing and down trees. Consider leaving some large trees to die and remain in the forest as snags and large logs, two important habitat features for many species of wildlife.



Eastern white pine can be managed with shelterwood silviculture. Courtesy photo by Maren Granstrom.



A cable skidder in an eastern white pine harvesting operation. Courtesy photo by Maren Granstrom.



Recently thinned shelterwood stand of red spruce, balsam fir, and eastern white pine. USDA Forest Service photo by Laura Kenefic.

Multi-Aged Silviculture

Irregular Shelterwood

Irregular shelterwood is a form of multi-aged silviculture that can be used to create stand structures and species compositions similar to those resulting from natural disturbances common in the northeastern United States. Instead of creating a forest that emphasizes sustained production and species control based primarily on social or economic priorities, harvesting patterns are based in part on the type and intensity of natural disturbances. In the region where the Penobscot Experimental Forest is found, research suggests that small blowdowns affect about 1 percent of forest area on average each year, creating small gaps in the canopy (48). An irregular shelterwood might be used to approximate that disturbance rate over the long term, for example by harvesting a portion of the volume at intervals (Fig. 16).

Irregular shelterwood silviculture can be used to encourage species diversity and maintain a mix of younger and older trees at all times. Rather than harvesting entire age classes of trees at one time, this type of management responds to the current condition in the woods. A forester may choose to release young trees or thin dense areas while leaving some old, large trees standing (Fig. 17). This works well for mixed stands of species with varying shade tolerances (39). Less rigid than the other silvicultural systems in this guide, irregular shelterwood is where the “art” of silviculture is fully apparent.

Further explanation of how irregular shelterwoods are applied in a forest is provided in a presentation by University of Maine Professor Emeritus Robert Seymour, “Exploring Silvicultural Strategies in Northern New England – Irregular Shelterwood” available online (46).



Figure 16.—A small gap created by harvesting in an irregular shelterwood stand at the Penobscot Experimental Forest. Courtesy photo by Robert Seymour.



Figure 17.—A harvested gap with retention trees in an irregular shelterwood stand at the Penobscot Experimental Forest. Courtesy photo by Robert Seymour.

Some variations of irregular shelterwood

Variations of irregular shelterwood have been described for the northeastern United States, including silvicultural systems that maintain continuous canopy cover and systems that create gaps (39). Some approaches may be more suitable than others in a given forest, depending on the species compositions and structures that exist now and that are desired in the future.

Extended irregular shelterwood—Instead of harvesting all overstory trees after new regeneration is established as in uniform (regular) shelterwood, some older trees are kept for decades or even permanently, creating a two-aged structure with some diversity in tree heights.

Continuous cover irregular shelterwood—Several ages of trees are maintained at all times, but not necessarily with a regular structure or schedule. Even-aged silvicultural practices, such as thinning, harvesting the overstory trees, and releasing patches of regeneration, are applied at the same time in different parts of a stand, but some degree of canopy cover is maintained.

Expanding gap irregular shelterwood—In much of the forest in this region, small gaps are naturally created by mortality of one or a few trees from wind or other causes. These gaps expand over time as trees on the edges blow down or die and younger trees become established in the gap center. To create conditions similar to this using irregular shelterwood, small gaps can be created by harvesting a few overstory trees in areas where trees are dying or where there is regeneration below the canopy. A decade or more later, trees on the edges of those gaps can be harvested. The gaps continue to be expanded through periodic harvests until multiple gaps converge and the forest is fully regenerated. After a few decades the trees in the original gap reach maturity, and the process can begin again.

In 1995, the University of Maine established the Acadian Forest Ecosystem Research Program (AFERP) at the Penobscot Experimental Forest (3). Designed to explore long-term trends and outcomes from forest management, this experiment tests variations of expanding gap irregular shelterwood.

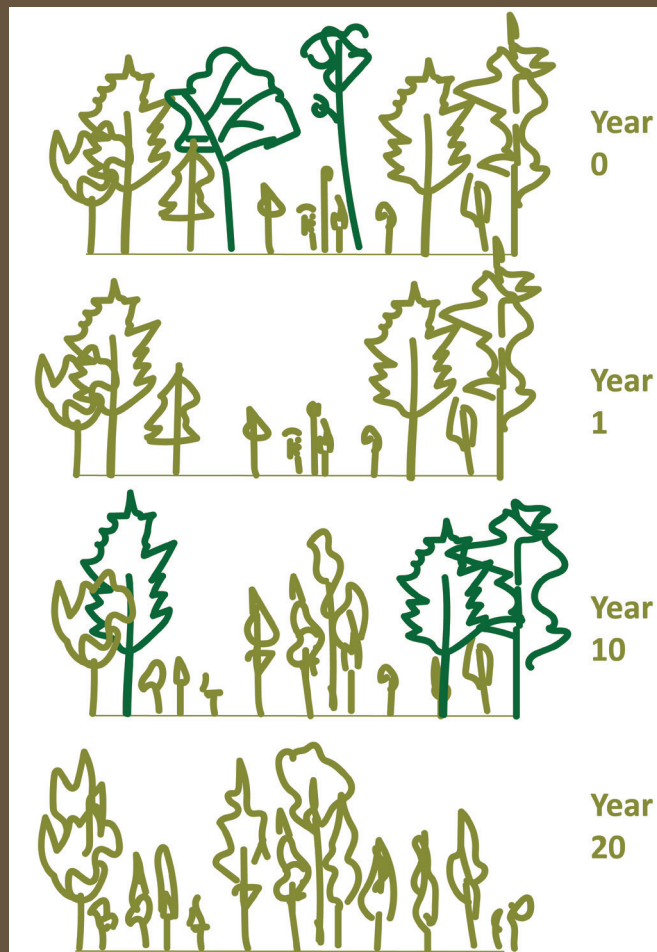


Figure 18.—An illustration of expanding gap irregular shelterwood system (darker trees are harvested). Small gaps are created by harvesting mature trees; subsequent harvests expand those gaps once regeneration is established. Some large legacy trees are left (reserves), similar to the conditions resulting from natural disturbances.

In the AFERP experiment, gap creation and expansion occur through periodic harvests made every 10 years, with a few trees left to grow and die in place in each gap (Fig. 18).

The three variants of irregular shelterwood included here were described by researchers in Quebec (39). Other variants exist and have a long history of use in Europe. A forester can help you determine which treatments might be suitable for achieving your goals.

Why choose irregular shelterwood?

- In the northern conifer forest, this type of management is more similar to the natural disturbance regime than some other silvicultural systems. This might allow plant and animal species to thrive, while also providing some income from timber harvesting (13).
- This is a flexible system that can be used in stands that have variable species compositions and tree sizes due to past harvesting (4).
- The mix of gaps and closed canopy areas are visually diverse and viewed by some as aesthetically pleasing.

What are the challenges?

- Though irregular shelterwood has been around for a long time, it is new to some foresters. Treatments may vary more within and between stands than they do for some other systems, so make sure that you and your forester are on the same page.
- Because of the potential for a greater variety of tree species to be left as seed sources, precommercial thinning may be necessary to control species composition and tree density.
- Where populations of white-tailed deer are high, a mix of gaps and closed canopy areas can lead to heavy browsing of young trees in the gaps and cause regeneration failures.
- The expanding gap approach requires careful planning and follow-through to harvest every 10 to 20 years in a specific pattern. Working with the same forester, or creating a detailed management plan, will be helpful.



Trees regenerating in an expanding gap irregular shelterwood stand. Courtesy photo by Robert Seymour.



Recently harvested continuous cover irregular shelterwood stand on the Penobscot Experimental Forest. USDA Forest Service photo by Laura Kenefic.

Single-Tree Selection

Single-tree selection is a form of multi-aged silviculture suited for species that grow well in partial shade. It maintains a variety of tree ages and sizes and increases the quality of standing trees over time (11, 23, 44).

In this multi- (or uneven-) aged silvicultural system, harvesting removes some trees from all size classes, leaving some trees of several ages in the forest at all times (11, 47). Trees are harvested throughout the stand, creating small openings in the forest canopy (Fig. 19). These small openings release shade-tolerant understory trees and thin out poor quality and low vigor trees so better trees are favored. Typically, single-tree selection harvests are done at a predetermined interval, called a cutting cycle. At the Penobscot Experimental Forest, selection harvests occur on 5 to 20 year cutting cycles in different parts of the forest. The more frequent the harvests, the less wood is removed in each harvest.

Financial

By removing only a small portion of trees at any one entry, a single -tree selection harvest might not generate a large amount of income. However, research results show that by leaving plenty of good quality trees to grow, a similar volume can be harvested again in a decade or two, though financial returns will depend on markets at the time of harvesting (11).

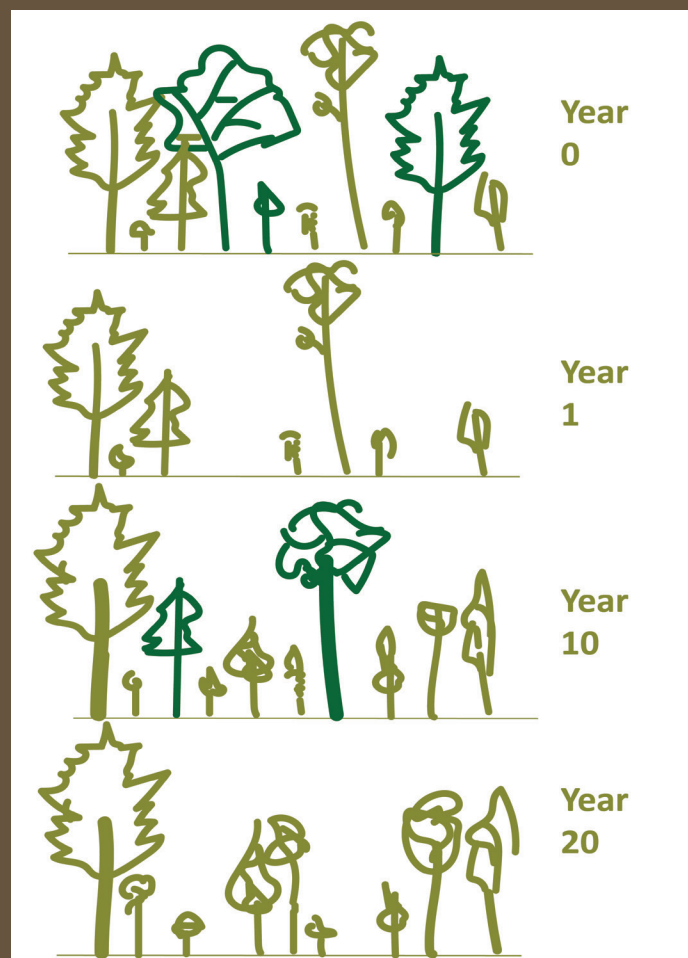


Figure 19.—An illustration of single-tree selection system (darker trees are harvested). Individual trees are harvested throughout the stand at specified time intervals to provide more resources to desired trees, remove trees before they die, and allow new trees to grow. This approach maintains a variety of tree sizes and ages in the forest at all times.



Selection stand at the Penobscot Experimental Forest, after 12 harvests, 2019. Courtesy photo by Maren Granstrom.

Ecological

Selection silviculture creates a structurally complex forest with a mix of trees of many sizes. Depending on the frequency and intensity of harvesting, this approach can create small canopy gaps similar to some gaps that result from natural disturbances in the northeastern United States (Fig. 20). This can create many types of habitat features for birds and other wildlife to use for nesting, feeding, hiding, and raising young, whether they prefer the understory, midstory, or overstory.

Regardless of whether a stand is managed with even-aged or uneven-aged silviculture, the size of the largest trees is determined by the forester's or landowner's decisions about when the final harvest of any given tree will occur. An important characteristic of the selection system and other types of uneven-aged silviculture is that some of the largest trees produced are present in the forest at all times, as opposed to being present just before the final harvest in even-aged systems such as uniform shelterwood. Stands in which large trees are continuously present generally have structures more similar to those resulting from natural disturbances in our region than even-aged stands managed with uniform shelterwood (32, 48). Assessments at the Penobscot Experimental Forest suggest that birds like the northern parula (Fig. 21), bay-breasted warbler, blackburnian warbler, or boreal chickadee could do well in single-tree selection stands in northern conifer forests (10).

Tree basal area changed over time in response to harvesting in the selection stands at the Penobscot Experimental Forest (Fig. 22). The data in this graph are from stands where single-tree selection harvests were conducted every 10 and later 20 years. Both the overall basal area and the proportion of basal area in large trees increased over time.

Carbon

Research at the Penobscot Experimental Forest suggests that single-tree selection silviculture increases the proportion of large, vigorous trees in a forest over time (23, 11). Accounting for carbon stored in trees and harvested wood products, selection silviculture has both high sequestration (rate of carbon uptake) and high carbon storage over time relative to the other treatments studied (38, 11).



Figure 20.—A mix of tree sizes and ages in a stand at the Penobscot Experimental Forest, a desired outcome of single-tree selection system. Courtesy photo by Maren Granstrom.



Figure 21.—Northern parulas are one bird species that uses forest stands with continuous canopy cover and large trees, such as stands resulting from single-tree selection. Licensed photo by Andy Reago and Chrissy McClarren/Flickr.

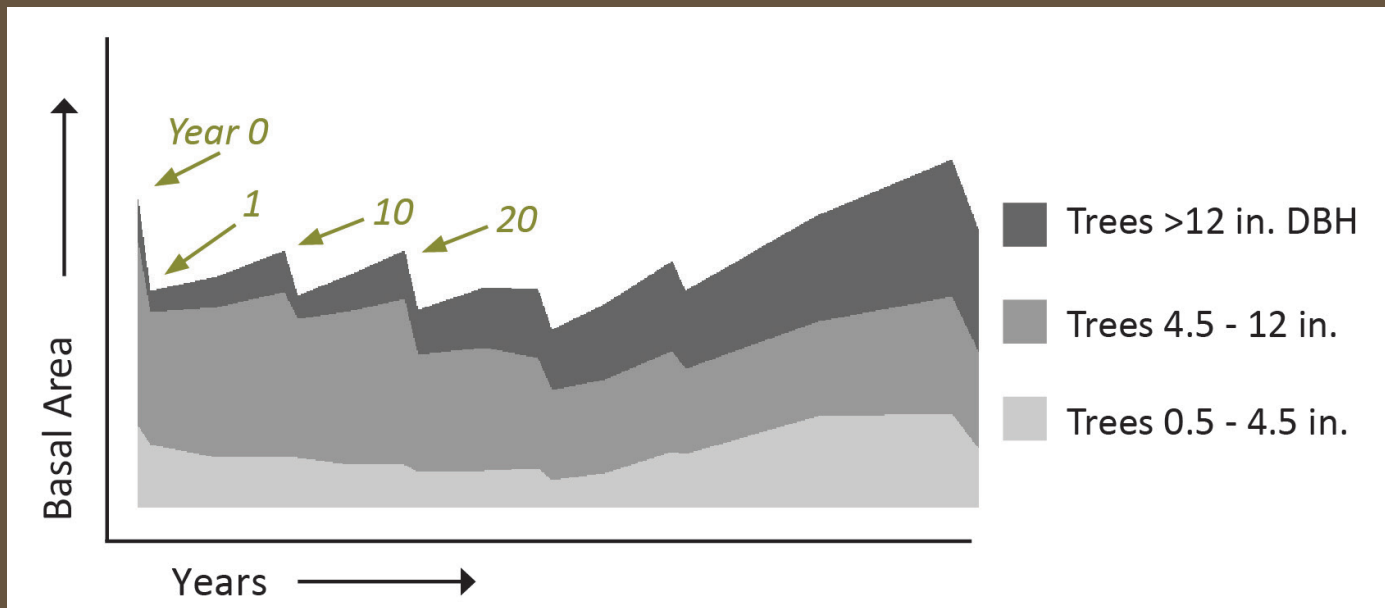


Figure 22.—Example of the changes in amount and proportion of basal area in different size classes (small, medium, and large trees) over time in a single-tree selection stand. Harvests occurred every 10 or 20 years in this stand. The illustrations in Figure 19 correspond to the years marked with arrows on this graph.

How often to harvest?

Harvest every 5 years? Every 10? Every 20? Depending on the cutting cycle you choose, the management will be a bit different. Because it costs money to transport and run machinery and to transport wood, short cutting cycles with low harvest volumes (less than 8 to 10 cords per acre) may mean that the costs of harvesting exceed the value of the wood unless only the largest, most valuable trees are removed. Research at the Penobscot Experimental Forest showed that removing only the largest, most valuable trees degraded the forest over time (22, 23), so low-volume, high-frequency harvests may only be possible if a landowner does the cutting themselves.

Characteristics of a shorter cutting cycle:

- More frequent revenue, but higher per-unit harvesting costs due to lower volume removed.
- Better opportunity to harvest trees in decline before they lose financial value (43).
- Less dramatic change in the look of the forest because fewer trees are removed, but more frequent harvests can lead to a constantly “messy” forest floor because logging slash does not fully decay before the next harvest.
- More vehicle movement on roads and trails, and possibly more chances to damage trees left standing.

Characteristics of a longer cutting cycle:

- Higher income with each harvest and lower per-unit harvesting costs due to higher volume removed.
- Longer time between harvests may mean some trees decline and die before they can be harvested for financial value. From an ecological perspective, these dead and declining trees often hold high value for wildlife and carbon storage.
- Heavier cuts open the canopy more and may encourage more tree species diversity (43).



The risk of damaging trees near machinery trails can be minimized with careful logging. USDA Forest Service photo by Laura Kenefic.

Why choose single-tree selection?

- Single-tree selection is more likely to work if your forest already has a mix of several tree ages (if not, consider irregular shelterwood if you want to manage for a multi-aged condition).
- If you want to generate periodic income while leaving a more visually intact forest with some mature forest characteristics for wildlife, recreation, or other uses, single-tree selection could be a good fit.
- In sensitive areas such as those near water courses or vernal pools where maintaining shade and limiting exposed soil are crucial for maintaining cool, clean water needed by fish such as brook trout and other wildlife, single-tree selection provides site protection by always maintaining some mature forest canopy.

What are the challenges?

- Selection silviculture is sometimes misapplied, resulting in only the largest and most valuable trees being harvested (see the Exploitive Harvesting section on page 28). Research at the Penobscot Experimental Forest has shown a big difference between always selecting and removing the most valuable trees (known as selective harvesting) and an approach where some poor quality trees are harvested and some good ones are left behind (11, 23). Working with a forester can help to make sure your property stays on a good trajectory.
- Frequent harvests that remove poor vigor trees can reduce some habitat features, such as living trees with cavities, or dead and down trees. Leaving some large trees to die and remain in the forest as snags and large logs can provide important habitat for many wildlife species.
- Removing scattered individual trees creates small gaps that might not open the canopy enough for regeneration of anything but shade-tolerant species (43, 52).
- Keep species diversity in mind. A forester can provide guidance about creating small gaps with group selection (see next section).
- Selection silviculture requires following a plan for many decades, including carefully controlling harvesting to meet tree size and species goals. This plan may need to be adapted as the forest changes, to make sure goals are met.



Researcher Arthur C. Hart in a selection stand at the Penobscot Experimental Forest after one harvest, 1954. USDA Forest Service photo.



Trees with cavities like this northern white-cedar contribute importantly to wildlife habitat. USDA Forest Service photo by Laura Kenefic.

Group Selection

Though group selection silviculture was not included in the Forest Service's study at the Penobscot Experimental Forest, it is a common approach to multi-aged forest management. Group selection has similar goals to single-tree selection, but harvests remove trees in small groups, creating gaps with more sunlight for regeneration and growth of tree species that are of intermediate shade tolerance (42).

Like single-tree selection, group selection harvesting removes some trees in all size classes, so trees of several ages remain in the forest at all times (Fig. 23). Unlike single-tree selection, harvested trees are grouped in the stand, creating openings that are at least one to two tree heights wide (Fig. 24). This creates gaps in the forest canopy that not only release shade-tolerant tree species but regenerate mid-tolerant and intolerant tree species. Typically, harvests occur periodically on a predetermined cutting cycle. At each entry, new gaps are created in different areas of the stand, and eventually, perhaps over the course of 100 years, the whole stand will have been harvested. In addition to cutting trees in small groups, the areas of the stand between those gaps may be lightly harvested to remove trees of poor vigor (41). The intention of harvesting between the gaps is to maintain healthy trees of desired species throughout the stand, not to regenerate new trees everywhere at once.



Figure 24.—A small gap created in a group selection stand in a University of Maine study at the Penobscot Experimental Forest. Courtesy photo by Robert Seymour.

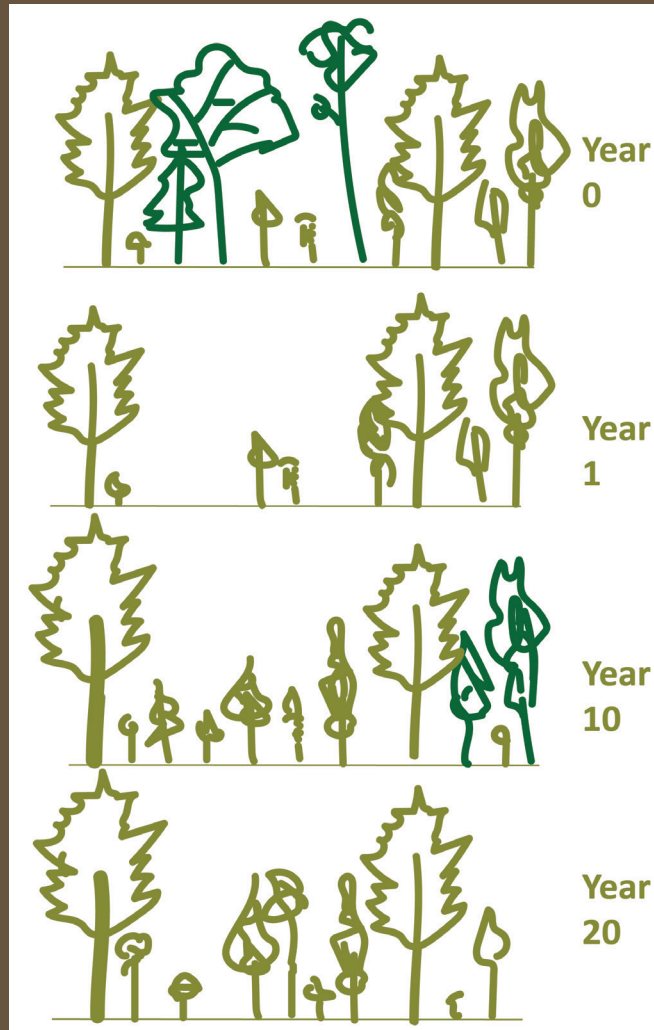


Figure 23.—An illustration of group selection system (darker trees are harvested). Like single-tree selection system, trees are harvested at specified intervals to provide more resources to desired trees, capture mortality, allow new trees to grow, and maintain a variety of tree sizes and ages in the forest at all times. Unlike single-tree selection system, trees are harvested in small groups rather than singly.



Northern parula. Courtesy image by Maine Audubon.

Why choose group selection?

- Group selection maintains a multi-aged stand with some large trees present at all times.
- Group selection may encourage a greater diversity of tree species than single-tree selection, as gaps provide varying light conditions (42).

What are the challenges?

- Creating some gaps can help regenerate a more diverse species mix than single-tree selection, but success is not guaranteed. Factors beyond light availability, including limited seed source, seed predation, competing vegetation (including advance regeneration of shade-tolerant species), and browsing by white-tailed deer or snowshoe hare (24) can affect stand growth.
- Although it is more time-consuming to lay out gaps based on stand conditions rather than in a geometric pattern, gaps are most effective if located in areas where there is already advance regeneration, groups of mature trees, or natural boundaries. Gaps that are perfectly round, the same size, and evenly spaced are unlikely to reflect natural stand conditions.



Group selection openings can be used to grow tree species with a range of shade tolerances in the same stand. USDA Forest Service photo by Laura Kenefic.



The openings in group selection stands can be similar in size to those that occur naturally when a few trees die or blow down. USDA Forest Service photo by Laura Kenefic.



A forwarder loading logs during a harvesting operation. Laying out gaps and machinery trails in advance helps to ensure desired outcomes. USDA Forest Service photo by Laura Kenefic.

Exploitive Harvesting

Why would we include examples of poor management in this guide? The following pages show examples of harvesting done without considering the condition of the remaining or future trees (Fig. 25). Because the focus is on what is removed and not what is left to grow, research shows that these harvests tend to leave a forest in worse condition than it was before (22). Tree quality and growth rates can decrease over time, and less financially valuable species can increase, especially with repeated harvests of this type (23). Because of the potential for high initial financial returns, as well as some misunderstanding about the long-term effects, exploitive harvests are still widely practiced in the northeastern United States and elsewhere (22, 34). Researching and documenting the outcomes from such practices are important and provide useful educational tools.

The examples included here are part of the long-term U.S. Forest Service research at the Penobscot Experimental Forest and serve as a caution of what can happen, especially over the long term, if a forest is harvested in this way. In addition, many landowners have forests that were exploitively harvested in the past, so it is important to be able to recognize these conditions and the need for rehabilitation to improve forest condition and increase future value.



Figure 25.—A clump of poorly formed red maple stump sprouts in an exploitively harvested northern conifer stand at the Penobscot Experimental Forest. These sprouts are unlikely to become merchantable trees of sufficient diameter and quality to be profitably harvested. Courtesy photo by Scott A. Sell.



Exploitive cutting has been happening since the 1800s and has been studied by the Forest Service since the 1900s. Photos from the former Paul Smith Experimental Forest in New York taken in 1956 (left; USDA Forest Service photo) and the Penobscot Experimental Forest taken in 2025 (right; Courtesy photo by Maren Granstrom) show examples of exploitive harvesting.

Opportunistic Harvesting

Opportunistic harvesting removes all trees that can be sold in current markets, leaving behind trees that are too small, of poor quality, or of undesired species (Fig. 26). The sole objective is to maximize current revenue in a single harvest.

Even though all trees that can be sold are harvested, this is not a **silvicultural clearcut** done as part of an even-aged silvicultural system in which the trees are harvested to create conditions for regeneration from sprouts (coppice), seed, or planting. Long-term research shows that poor quality, low vigor, and low value trees left behind after exploitive harvesting degrade the future forest (Figs. 27 and 28).

Financial

The first harvest generates the maximum income possible at the time of harvest. Future harvests may be many decades in the future and may be much less lucrative.

Ecological

Wildlife species that need shrubby, early-successional habitat can benefit for the first few years after a harvest of this type. Assessments completed at the Penobscot Experimental Forest suggest that once trees grow to sapling or pole size, the simple structure and lack of large trees, understory vegetation, or canopy gaps can mean that fewer bird species and fewer individuals of each species can find a home in these forests (Fig. 29). This holds true for other wildlife species as well. For example, American marten prefer

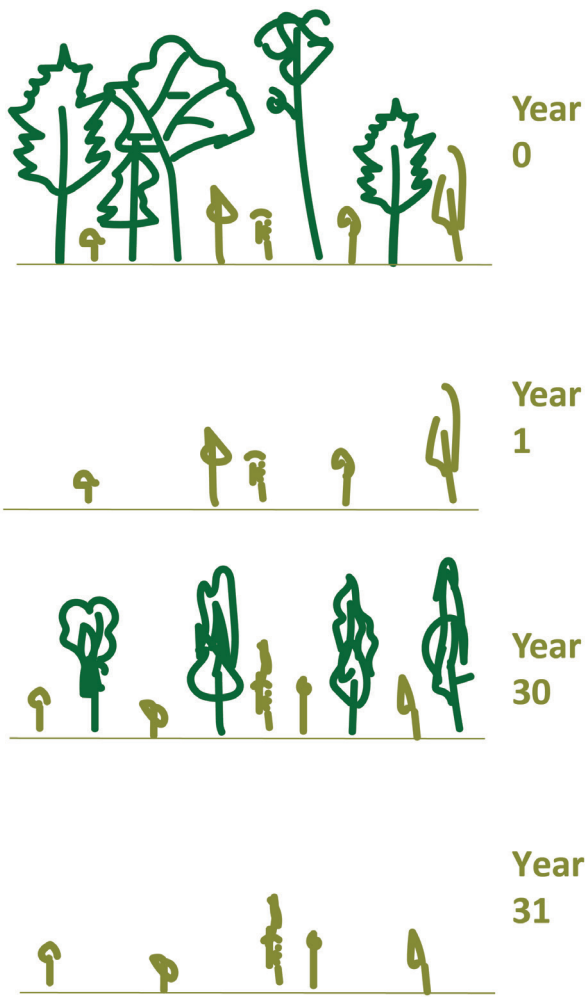


Figure 26.—An illustration of opportunistic harvesting (darker trees are harvested). Trees of value are harvested when feasible, without regard for the composition or structure of the future stand. Over time, regeneration is likely to be concentrated in undesired species and growth will accrue on unhealthy or non-merchantable trees.



Figure 27.—A stand on the Penobscot Experimental Forest 1 year after the first opportunistic harvest, 1955. USDA Forest Service photo by Arthur C. Hart.



Figure 28.—The same stand 30 years after the second opportunistic harvest, 2018. Courtesy photo by Maren Granstrom.

forests with a high canopy cover and complex physical structure, conditions not typically met in these forests (10).

Harvesting most trees in a forest without first regenerating new trees, as is done with shelterwood silviculture, lets in a lot of light. This can lead to a transition away from species like red spruce, eastern hemlock, and eastern white pine. Instead, researchers have found that sun-loving or competitive (and often short-lived) species like aspen, birch, red maple, and balsam fir predominate (Fig. 30) (20, 43).

Carbon

Removing all merchantable trees without well-established regeneration greatly reduces carbon storage in the forest (37). Trees will grow back, but species like gray and paper birch and aspen that often grow up in large openings are short-lived and will not store carbon in living trees in the forest as long as some other species (25).

What are the challenges?

- Trees will grow back, at least in the northeastern United States where precipitation is abundant year-round, but the species might not be desirable from a commercial or ecological standpoint.
- Regenerating aspen or another sun-loving species is best accomplished by using an intentional silvicultural system. A forester can recommend types of management to use.



Figure 29.—Shrubby, open conditions without large trees often result from opportunistic harvesting in stands like this one at the Penobscot Experimental Forest. Courtesy photo by Maren Granstrom.

If your woods were cut like this in the past

It is possible to rehabilitate stands where all the large, high quality trees have been removed, though the work involved is often a long-term investment. A rehabilitation treatment initiated at the Penobscot Experimental Forest did result in improved species composition and growth rates compared to a nonrehabilitated stand (20, 36, 43). To apply a rehabilitation treatment, pick crop trees (trees with good timber potential that will be grown to maturity) that are straight and of desired species, and then remove the lower quality or poor vigor trees around them to increase available light and improve their growth (20). Planting might be necessary if a desired species, such as red spruce, was harvested and no seed source is present.



Figure 30.—Sprouting red maple and fast-growing shade-intolerant species tend to dominate opportunistically harvested northern conifer stands like this one at the Penobscot Experimental Forest. Courtesy photo by Scott A. Sell.

Diameter-Limit Harvesting

In diameter-limit harvesting, all merchantable trees larger than a specified diameter are removed (Fig. 31). Poor quality, suppressed, small trees are often left to grow. Unlike silviculture in which large trees are removed to allow young trees to grow freely, the trees left behind in diameter-limit harvesting are not necessarily young, but instead might be stunted or unhealthy. Research at the Penobscot Experimental Forest shows that over time, growing space in stands where this approach to harvesting was used is taken up by low quality trees, and the productivity and value of the forest declines (11).

Financial

The first harvest can generate a large income because the largest, most valuable trees are all cut. Research at the Penobscot Experimental Forest shows that average tree value declines and stand value goes down with repeated harvests (11, 21).

Ecological

At the Penobscot Experimental Forest, researchers found that the genetic pool is changed when large, healthy trees are removed from the forest (14). The overall quality of the forest may go down over time as the fastest-growing, well-formed trees are no longer available to produce seed.

Forestry for Maine Birds assessments at the Penobscot Experimental Forest suggest that removing the largest trees can be harmful to many wildlife species that rely on high, dense overstory vegetation and large snags for nesting and roosting (10).

This type of harvesting can produce a somewhat uneven-aged forest with some diversity of species and structure (11, 49), but species and structure are variable and are difficult to reliably predict.

Carbon

Research has shown that diameter-limit harvesting at the Penobscot Experimental Forest led to lower carbon sequestration in living trees than some shelterwood and selection treatments (38). Reducing the proportion of large trees also led to lower carbon storage relative to stands managed with single-tree selection silviculture (11).

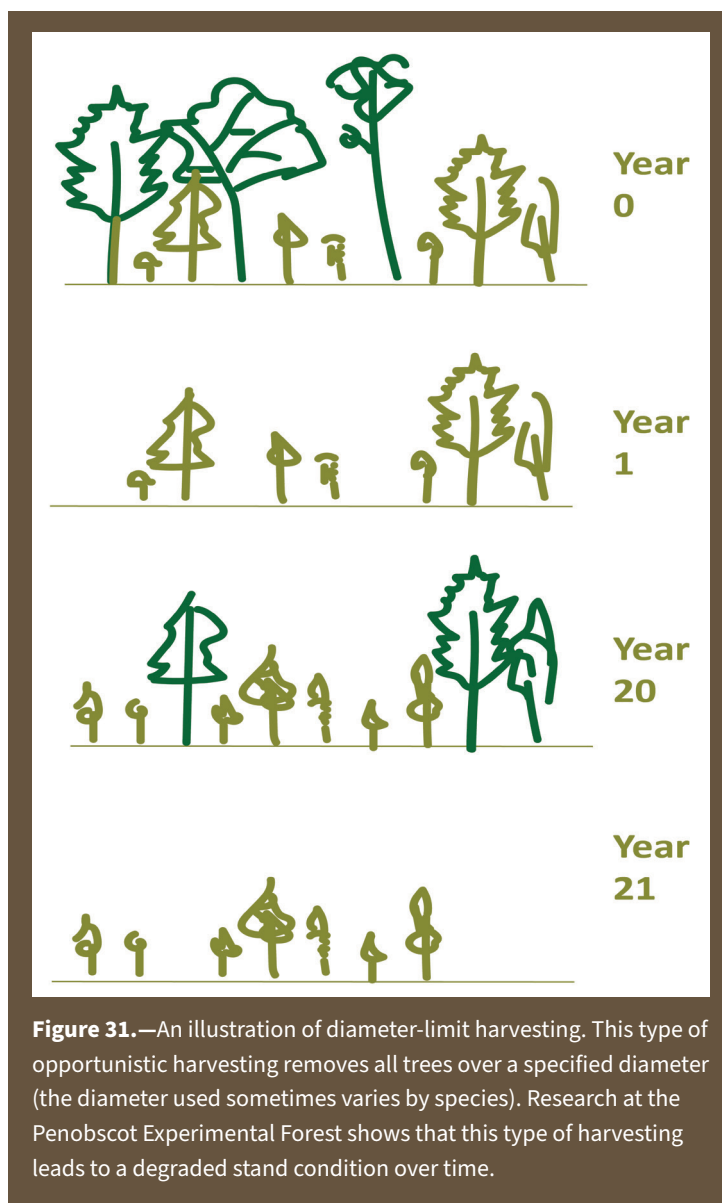


Figure 31.—An illustration of diameter-limit harvesting. This type of opportunistic harvesting removes all trees over a specified diameter (the diameter used sometimes varies by species). Research at the Penobscot Experimental Forest shows that this type of harvesting leads to a degraded stand condition over time.

What are the challenges?

- Similar to opportunistic harvesting, diameter-limit harvesting is a form of “high-grading” or removing only valuable (high grade) trees (i.e., taking the best, leaving the rest).
- While diameter-limit harvesting may result in a forest that can be harvested again, it still is exploitive because future tree quality and species composition are not part of the decision-making process when planning a harvest.
- If someone tells you, “we’ll cut the big trees to leave more space for the small ones to grow,” ask more questions. Are the small trees indeed younger, or are they poor quality, slow growing trees that will not respond well to release? Are they desirable species for your future forest? Is the goal only to generate current revenue, or to sustain the forest for the future?

Forest Management Summary

More than 65 years of repeated measurements at the Penobscot Experimental Forest demonstrate possible outcomes from different types of silviculture and harvesting. The results that are described in this guide are summarized in Figure 32, and data supporting these conclusions are in appendix 2. Analyses and results are detailed in “Northern Conifer Forest Management: Silvicultural, Economic, and Ecological Outcomes From 65

Forest Management Changes Species Composition

These graphs show results from long-term research at the Penobscot Experimental Forest. While the basal area and species composition were fairly similar throughout the forest before the study began (on the left of each graph), each kind of management removed different volumes and species of trees at different frequencies and changed the species composition over time.

One noticeable difference among treatments is the amount of eastern hemlock (dark green). Harvests that removed almost all of the trees at one time, such as opportunistic harvesting treatments, let in a lot of light and removed seed sources for eastern hemlock, a very shade-tolerant species. As a result, eastern hemlock mostly disappeared from those stands. The opposite is true in the single-tree selection areas, where harvests removed just a few trees and left plenty of shade.

Retaining a portion of the overstory trees for seed and shade for close to 20 years resulted in stands dominated by shade-tolerant softwoods after the overstory was removed.

Diameter-limit harvesting reduced the amount of red spruce and increased amount of balsam fir but did not otherwise greatly change composition.

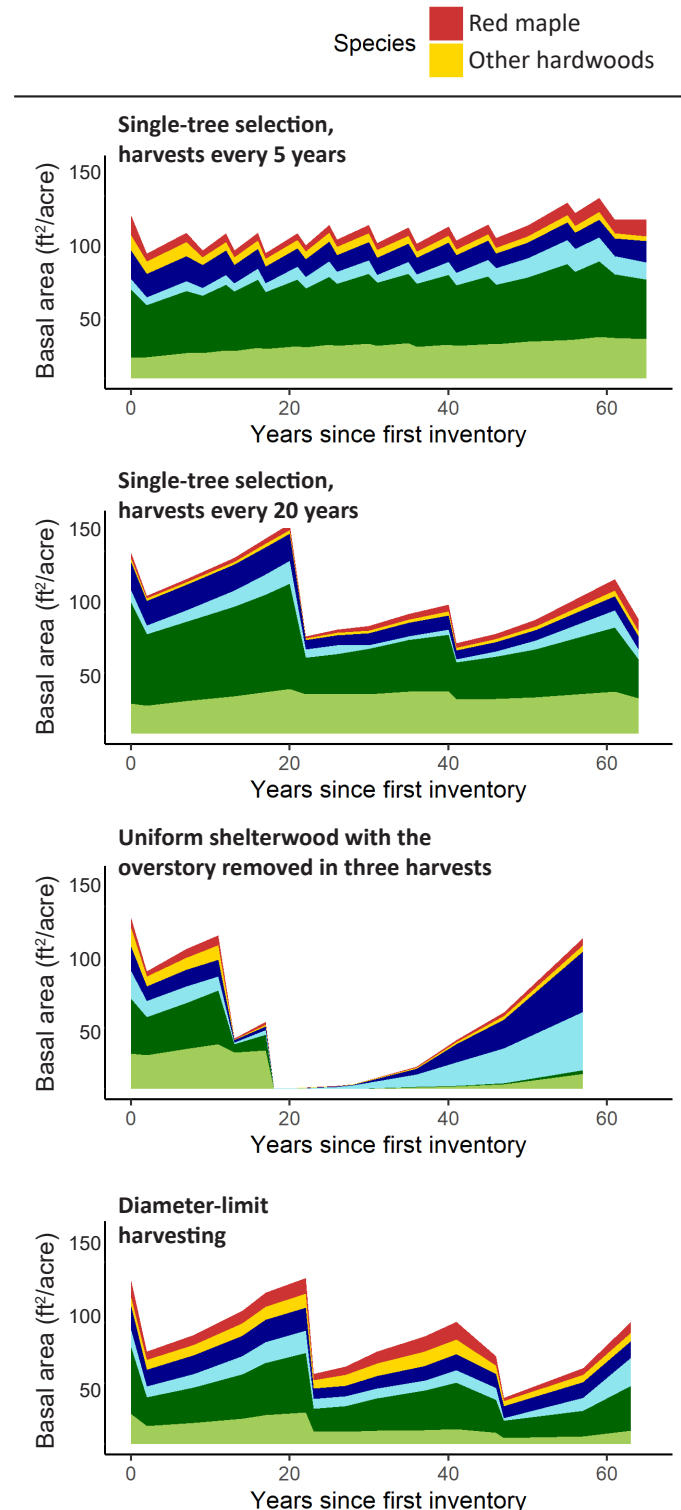
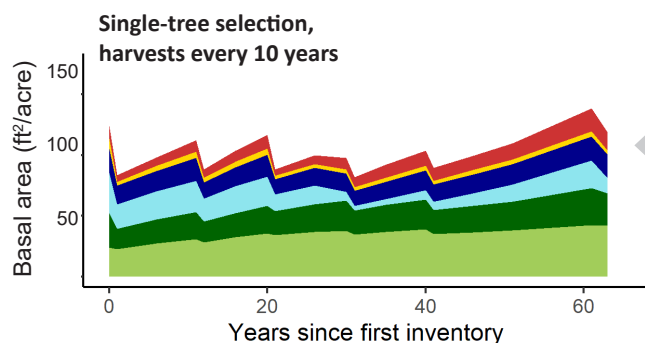


Figure 32.—Basal area of live trees >4.5 inches diameter at breast height (DBH) over time, by species, for all treatments in the Compartment Management Study at the Penobscot Experimental Forest.

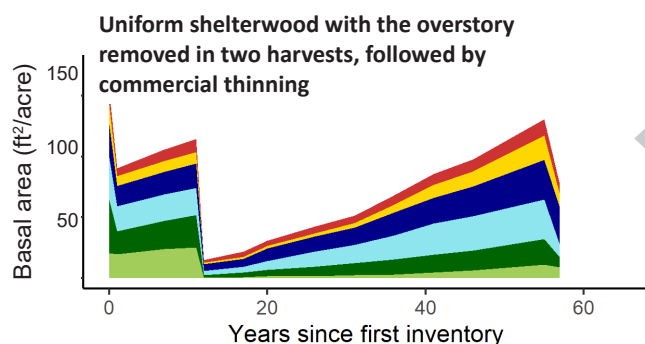
Years of Study” (11). (Scan the QR code to the right or got to <https://digitalcommons.library.umaine.edu/etd/3125> to access a PDF file of this study.) Note that irregular shelterwood and group selection silvicultural systems mentioned in this guide are not included in this table because they were not in the Compartment Management Study.



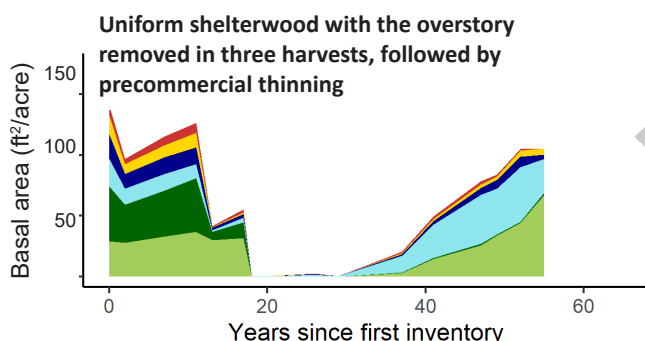
Other softwoods Eastern hemlock
Balsam fir Red spruce



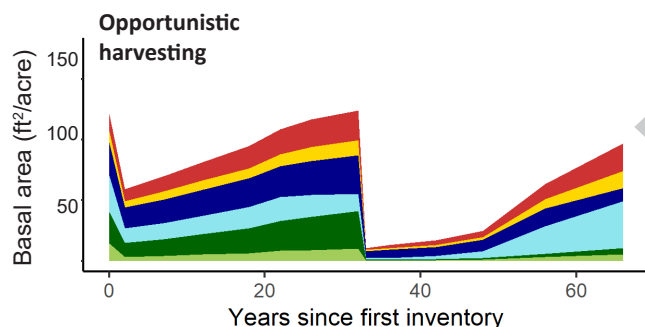
Species composition remained fairly consistent over time in all three single-tree selection treatments.



An incomplete final overstory removal around year 10 resulted in more hardwoods and eastern hemlock left to grow than in other uniform shelterwood treatments.



The precommercial thinning 12 years after overstory removal increased the proportions of red spruce and balsam fir and removed most other species.



Opportunistic harvesting almost eliminated red spruce and eastern hemlock and increased the amount of hardwoods and balsam fir.

Moving Forward on Your Woodland

What Can a Forester Do for You?

A forester can develop a management plan for your property, and if you decide to harvest, they can work with a logger to meet your forest management goals. Foresters can do any or all of the following:

- Conduct an inventory of your woodland to determine volume and value of timber, areas of importance for wildlife, streams and vernal pools, and much more.
- Work with you to write a management plan, usually for a 10-year period (often with a 25 to 50 year outlook and an update every 10 years). This can be for your own planning or to meet requirements of a state tax program and will include recommendations for harvesting or other activities to meet your short-term and long-term goals.
- Help you find technical and financial assistance from state and federal agencies to write and implement a management plan, stewardship plan, or habitat restoration plan.
- Coordinate activities that can receive financial assistance from state or federal programs, such as thinning young trees and removing nonnative invasive plants.
- Plan and oversee harvests by coordinating with a logger, marking trees to cut, monitoring integrity of water resources and soils, and managing legal regulations and requirements.
- Help you to set up and keep records needed for state and federal tax filings, as well as paperwork needed for any public programs you implement.



Loading wood for transport. Courtesy photo by Maren Granstrom

Keep in Mind

- Every woodland is in a different condition, and the species, tree sizes, and structure will determine management options. It may take decades to achieve the condition you want.
- There are laws and regulations that affect forest management—a forester can help you figure out which apply to you.
- There may be potential to receive compensation for maintaining high levels of stored carbon (carbon storage) on your land. While most carbon projects require a minimum number of acres, the carbon market is emerging and changing. Ask a forester for more details.

Interested in Learning More?

Next steps could include the following:

- Contact your state forestry agency. Your local district or county forester can come walk your property and address questions you have about the current condition of your forest, your short-term and long-term goals, and various options to meet those goals.
- Find a local consulting forester. Ask your neighbors or your state forestry agency for the names of foresters in your area, so you can talk to a few different foresters. You may be working with this person for many years, so you want to find someone who is a good match, in terms of personality and understanding your vision, to help you reach your goals.
- Ask to visit other woodlands your forester has managed so you can see for yourself what might be possible on your land. It can also be helpful to see a logger's work on another property before they harvest on yours so you know what to expect.
- Join a state organization of small woodland owners.

Additional Resources

Scan the QR codes or visit the webpages listed here to access additional resources.

- Information from the Maine Natural Areas Program about invasive plants: https://www.maine.gov/dacf/mnap/features/invasive_plants/invasives.htm
- Forestry for the Birds: Guidebooks that help landowners, loggers, and foresters learn about important habitat features for birds and other wildlife, and how to enhance habitat for them in the woods. Similar guides have been created in several states, and many states host workshops for foresters and landowners to learn more, or offer habitat assessments for individual properties.



- ◊ Vermont: <https://vt.audubon.org/conservation/foresters-bird>



- ◊ Maine: <http://www.maineaudubon.org/ffmb>



- ◊ Massachusetts: <https://www.mass.gov/guides/foresters-for-the-birds-assessing-your-woods-for-bird-habitat>



- ◊ Connecticut: <https://www.audubon.org/connecticut/projects/audubon-forester-training-and-endorsement-ct>



Measuring tree diameter during timber inventory. Courtesy photo by Maren Granstrom.



A forwarder collecting cut logs. Courtesy photo by Maren Granstrom.

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Appendix 1

Table 3.—Trees species mentioned in this guide, ordered from most to least based on the merchantable volume of growing stock trees on forest land in the state of Maine in 2022

Common name	Scientific name
Red spruce	<i>Picea rubens</i>
Eastern white pine	<i>Pinus strobus</i>
Balsam fir	<i>Abies balsamea</i>
Red maple	<i>Acer rubrum</i>
Eastern hemlock	<i>Tsuga canadensis</i>
Northern white-cedar	<i>Thuja occidentalis</i>
Sugar maple	<i>Acer saccharum</i>
Yellow birch	<i>Betula alleghaniensis</i>
Aspen	<i>Populus species</i>
Paper birch	<i>Betula papyrifera</i>
Northern red oak	<i>Quercus rubrum</i>
American beech	<i>Fagus grandifolia</i>
White ash	<i>Fraxinus americana</i>
Gray birch	<i>Betula populifolia</i>
American elm	<i>Ulmus americana</i>
American chestnut	<i>Castanea dentata</i>

Data from USDA Forest Service, Forest Inventory and Analysis Program. (Scan QR code or visit <https://apps.fs.usda.gov/fiadb-api/evaluator>.)



Table 4.—Wildlife species mentioned in this guide

Common name	Scientific name
American marten	<i>Martes americana</i>
American woodcock	<i>Scolopax minor</i>
Bay-breasted warbler	<i>Setophaga castanea</i>
Black-backed woodpecker	<i>Picoides arcticus</i>
Blackburnian warbler	<i>Setophaga fusca</i>
Black-throated blue warbler	<i>Setophaga caerulescens</i>
Black-throated green warbler	<i>Setophaga virens</i>
Boreal chickadee	<i>Poecile hudsonicus</i>
Brook trout	<i>Salvelinus fontinalis</i>
Canada warbler	<i>Cardellina canadensis</i>
Chestnut-sided warbler	<i>Setophaga pensylvanica</i>
Eastern wood-pewee	<i>Contopus virens</i>
Magnolia warbler	<i>Setophaga magnolia</i>
Mourning warbler	<i>Geothlypis philadelphia</i>
Northern flicker	<i>Colaptes auratus</i>
Northern parula	<i>Setophaga americana</i>
Olive-sided flycatcher	<i>Contopus cooperi</i>
Ovenbird	<i>Seiurus aurocapilla</i>
Ruffed grouse	<i>Bonasa umbellus</i>
Scarlet tanager	<i>Piranga olivacea</i>
Snowshoe hare	<i>Lepus americanus</i>
Veery	<i>Catharus fuscescens</i>
White-tailed deer	<i>Odocoileus virginianus</i>
Wood thrush	<i>Hylocichla mustelina</i>
Yellow-bellied sapsucker	<i>Sphyrapicus varius</i>

Appendix 2

Supporting Data

Treatment descriptions

The treatment descriptions and outcomes described in this guide are based on results from long-term research at the Penobscot Experimental Forest in east-central Maine. Selected results are presented here, but refer to Granstrom (2019) and Granstrom et al. (2022) for detailed methods and additional information (11, 12).

The following codes are used for each treatment tested:

- S05** Single-tree selection, harvests every 5 years
- S10** Single-tree selection, harvests every 10 years
- S20** Single-tree selection, harvests every 20 years
- SW2** Uniform shelterwood with the overstory removed in two harvests, followed by commercial thinning
- SW3** Uniform shelterwood with the overstory removed in three harvests
- SW3p** Uniform shelterwood with the overstory removed in three harvests, followed by precommercial thinning
- FDL** Diameter-limit harvesting
- CC** Cutting all trees with value (opportunistic harvesting)

Table 5.—Average value of Shannon’s Diversity Index and average number of trees per acre for trees >12 inches diameter at breast height (DBH), calculated for 2-inch DBH classes and 6-foot height classes at study midpoint. Higher numbers indicate greater diversity (i.e., there are many size classes, trees are more evenly spread out among size classes, or both.) For example, S05 is more diverse than SW3 based on Shannon’s Diversity Index.

Treatment	Diameter-class diversity	Height-class diversity	Live trees per acre
			>12 inches DBH at the end of the 65-year study period
S05	2.00	2.02	81
S10	1.86	1.86	62
S20	1.92	1.83	55
SW2	1.64	1.71	27
SW3	1.44	1.52	2
SW3p	1.55	1.52	2
FDL	1.80	1.72	28
CC	1.65	1.52	4

Table 6.—Average value of trees before treatment, value of all harvests, and value of trees at most recent inventory (presented in dollars per acre in constant 2017 dollars, using stumpage prices from year in which harvest or inventory took place). Estimated costs of marking trees for harvest, and cost of precommercial thinning in SW3p, have been deducted from harvest totals.

Treatment	Value of standing trees at first inventory (\$/acre)	Value of trees harvested over 65 years (\$/acre)	Value of standing trees at most recent inventory (\$/acre)	Sum of harvested and standing value at 65 years (\$/acre)
S05	\$743	\$1,193	\$1,296	\$2,489
S10	\$711	\$856	\$1,182	\$2,038
S20	\$821	\$1,165	\$743	\$1,908
SW2	\$810	\$1,213	\$414	\$1,627
SW3	\$711	\$892	\$673	\$1,565
SW3p	\$711	\$474	\$768	\$1,242
FDL	\$676	\$1,155	\$381	\$1,536
CC	\$575	\$810	\$355	\$1,165

Table 7.—Average carbon storage in aboveground live and dead trees at a recent inventory (approximately 2015), and average annual net change in carbon in live and dead trees and harvested wood products (carbon sequestration) (37, 38)

Treatment	Carbon storage in live and dead trees in the forest U.S. tons per acre	Annual carbon sequestration in live and dead trees and harvested wood U.S. tons per acre per year
S05	36.4	0.31
S10	39.9	Not included in analysis
S20	34.5	0.40
SW2	26.2	0.17
SW3	38.7	0.18
SW3p	Not measured	0.37
FDL	27.6	0.14
CC	28.5	0.18

Table 8.—Definition of outcomes in summary (Table 9), after 65 years of treatment

Variable	Description
Number of large trees	What was the prevalence of large trees (>12 inches diameter) over time?
Structural complexity	What was the variation in tree diameter and height at any single point in time during the 65-year study period?
Habitat for priority birds	What is the variety of Forestry for Maine Birds priority bird species that could have their habitat needs met based on the species and structure in the forest at the end of the study period? Habitat needs include things like number of large trees, structural complexity, dead standing trees, and down logs (10).
Harvest revenue	What was the cumulative total harvest revenue over the 65-year study period?
Standing value	What was the value in trees still growing at the end of the 65-year study period?
Tree quality for timber	What was the quality of the standing trees in terms of form (straightness), vigor, and potential for future high-value products at the end of the study period?
Carbon storage	What was the level of carbon storage in live and dead trees at the end of the study period?

Table 9.—Comparison of outcomes from selected treatments in the Compartment Management Study at the Penobscot Experimental Forest, after 65 years

	Uniform shelterwood system	Single-tree selection system	Opportunistic harvesting	Diameter-limit harvesting
Number of large trees	High just before harvest, low after harvest	High	Low	Moderate
Structural diversity	Low	High	Moderate	Moderate
Habitat for priority birds in Maine^a	A few young-forest specialists in the decade after harvest, low after that	High	A few young-forest specialists in the decade after harvest, low after that	Moderate
Revenue from 65 years of harvests	Moderate	Moderate	Low ^b	High ^b
Value of standing trees after 65 years	Moderate	High	Low	Low
Tree quality for timber	High	High	Low	Low
Carbon storage in live and dead trees	High just before harvest, low after harvest	High	Low	Low

^aRating based on habitat quality assessed for 20 priority bird species identified in Maine Audubon’s “Forestry for Maine Birds” guide (10).

^bOpportunistic harvesting is usually practiced because it brings maximum income in the short term, but we would expect lower income in the long term as tree vigor and quality are reduced. This might take longer to occur in stands treated with diameter-limit harvesting because fewer trees are removed in each harvest (11).

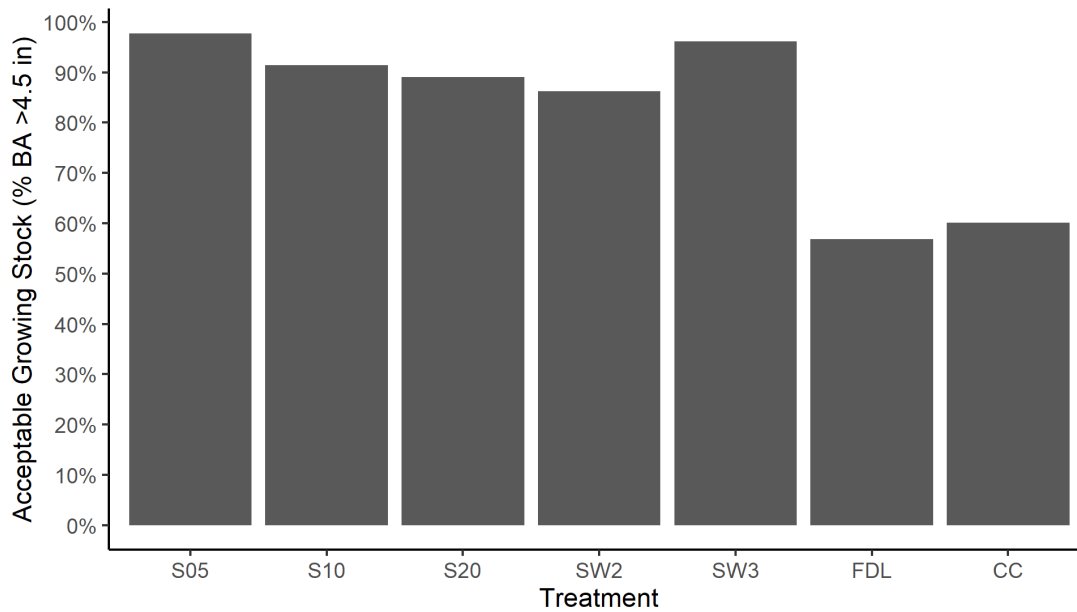


Figure 33.—Relative abundance of good-quality trees after 60 years in stands with different approaches to management at the Penobscot Experimental Forest. Trees were considered acceptable growing stock if they were expected to increase in volume or value before the next harvest, based on assessment of tree form, vigor, damage, decay, or disease. Presented as a percentage of total basal area (BA); data were averaged across two stands (replicates) of each treatment.

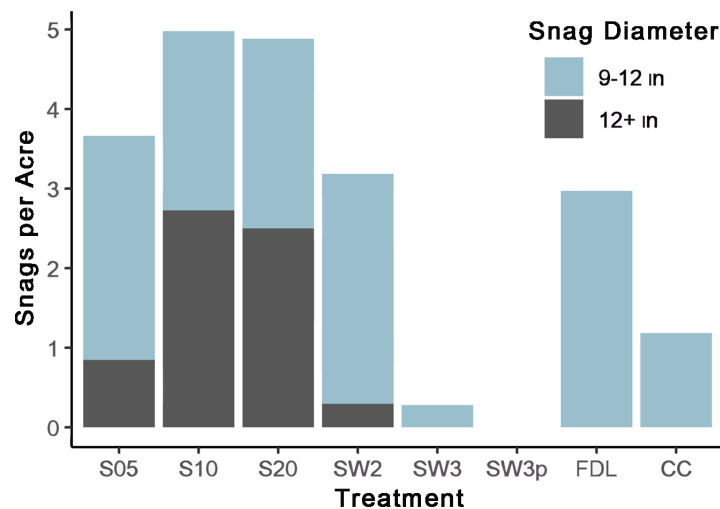


Figure 34.—Average number of snags (standing dead trees) 9 to 12 and >12 inches DBH in a recent inventory (approximately 2015) in stands with different approaches to management at the Penobscot Experimental Forest. Maine Audubon recommends at least six snags or live cavity trees per acre, with one >18 inches DBH and three >12 inches DBH. The more the better, and the bigger the better, from a wildlife habitat perspective (10). Data were averaged across two stands (replicates) of each treatment.

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