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Silvicultural Guide for Northern Hardwoods in the Northeast

William B. Leak
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Abstract

This revision of the 1987 silvicultural guide (Leak et al. 1987) includes updated and expanded silvicultural information on northern hardwoods as well as additional information on wildlife habitat and the management of mixed-wood and northern hardwood-oak stands. The prescription methodology is simpler and more field-oriented. This guide also includes an appendix of familiar tables and charts useful to practicing field foresters. Northern hardwood forest types can be managed as even- or uneven-aged stands using a variety of silvicultural practices. In planning these practices, there are many factors to consider including access, species composition, desired regeneration, wildlife habitat needs and environmental concerns. The aim of this document is to provide guidelines to assist the manager in choosing the right methods to meet the landowner objectives consistent with stand conditions.

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Cover Photos

Panorama of group/patch selection harvest, White Mountain National Forest, NH. Patches vary in size and shape to efficiently remove the mature, overmature, and defective (MOD) timber and create habitat for wildlife such as (clockwise from upper left: black bear and cub; bull moose; American woodcock and chick; fisher; and a weasel and mouse). Background photo by C. Costello, U.S. Forest Service; wildlife photos © Susan C. Morse, Jericho, VT, used with permission. Cover photo collage design by Ken Dudzik, U.S. Forest Service.

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PURPOSE AND SCOPE

This is the fourth silvicultural guide for northern hardwoods (beech-birch-maple) in the Northeast. This guide is a revision of the most recent one published in 1987 (Leak et al. 1987). This new guide provides updated information compiled from decades of research and personal experience on approaches and results for a complete range of silvicultural practices for timber management as well as related implications for wildlife habitat development. Additional information on these topics, as well as additional forestry related subjects, is found in Good Forestry in the Granite State (Bennett 2010). For detailed discussions of silvicultural systems and terminology, please consult texts by Smith et al. (1997) and Nyland (2002; reissued 2007).

This guide is intended to provide ample information on the major silvicultural problems facing New England forests: (1) the need for improved value and diversity of species composition (tree and wildlife species) and stand structure for a range of objectives through better regeneration practices; and (2) the need for improved timber quality/value through better marking and harvesting practices and control of stocking. Since trees grow, forests naturally get too crowded for optimum growth. Crowding is the single most important factor affecting the health, growth, and vigor of most forest trees. Regenerating stands might have 10,000 trees per acre, and with natural development, at least 98 percent of these trees die by suppression and other natural factors by the time the stand reaches maturity. Silviculture provides methods to guide stand development by selecting the trees that make it to maturity to achieve both timber and wildlife objectives, along with creating desired stand structure. Also, when it is time to promote natural regeneration, the forester can provide conditions that are favorable to desired species without resorting to artificial regeneration.

This guide differs appreciably from the 1987 version. It contains more long-term data and less specific prescriptions (i.e., more supportive information and fewer rules). It is intended to provide a basis for well-informed, on-the-ground decisions to meet a wide array of owner objectives, financial constraints, markets, sites, wildlife habitat and ecological considerations, and regulatory limitations. Economic returns and predictions, although very important, are omitted, due to situational variability and a fluctuating economic climate. However, the general approach is to provide low-cost, low-investment, and commercially viable options.

Most of the long-term information is from the Bartlett Experimental Forest in central New Hampshire, an area with granitic soils of moderate productivity but with a wide range of site conditions. This information is tempered by decades of observations and site evaluation research throughout New England and adjacent areas, including areas with highly productive calcareous sites.

There are other silvicultural approaches being successfully taught and applied in New England (e.g., rehabilitation forestry, ecological forestry, and natural disturbance silviculture). These approaches are briefly described and cited. The guide also summarizes special options related to silvicultural practice that should be discussed as appropriate with interested landowners (e.g., reserve stands, carbon management, use of chemicals and others). In assessing silvicultural options for a property, these features should be considered along with wildlife management opportunities. The wide array of problems, objectives, and practices within this resilient forest type requires a wide range of options.

REGIONAL CONDITIONS

Northern hardwoods and associated mixed-wood types occupy at least 20 million acres in New England and New York; similar types occur further west and south, and into adjacent Canada. This area is diverse, with different problems, markets, soils, species associations, landowner goals, and options throughout the range. This diversity also creates a resiliency shown by response to past disturbances. Forest products include veneer, saw logs, boltwood, pulpwood, fuelwood, and biomass. This variety provides opportunities to grow and market a variety of species and tree qualities, therefore providing for a high level of silvicultural practice. These forests also provide habitat for more than 200 vertebrate wildlife species, excellent summer and winter recreational opportunities, watershed protection, and overall biological diversity.

Table 1.—Silvical characteristics of the important species in northern hardwood forests

Species	Shade tolerance	Early relative height growth	Relative site requirements	Natural pruning	Good seed crop interval (yrs)	Sprouting vigor
Sugar maple *Acer saccharum*	moderately tolerant	slow to moderate	high	poor to medium	3-7	moderate-small stumps
American beech *Fagus grandifolia*	very tolerant	slow	low	poor	2-5	moderate-small stumps; high-root suckers
Yellow birch *Betula alleghaniensis*	intermediate	moderate	medium to high	medium	2-3	low
Paper birch *B. papyrifera*	intolerant	fast	low	good	2-3	moderate-small stumps
White ash *Fraxinus americana*	intermediate (more tolerant as seedling)	moderate	very high	good	2-5	moderate to high
Red maple *A. rubrum*	intermediate	moderate	low	medium	1	high
Aspen *Populus* spp.	intolerant	very fast	low	good	4-5	high-root suckers
Northern red oak *Quercus rubra*	intermediate	moderate	medium	medium	3-5	high
Black cherry *Prunus serotina*	intermediate	fast	low	good	1-5	high
Red spruce *Picea rubens*	tolerant	very slow	low	poor	3-8	none
Eastern hemlock *Tsuga canadensis*	very tolerant	very slow	low	poor	2-4	none
Eastern white pine *Pinus strobus*	intermediate	moderate	low	poor	3-10	none

MANAGEMENT OBJECTIVES

Landowners in the northern hardwood region have many reasons for owning forest land. Industrial ownerships manage primarily for commercial forest products coupled with strategies to maintain wildlife habitat, visuals, and water quality. Many forest landowners are primarily interested in wildlife habitat, recreation, and esthetics, but need some level of income from forest products to meet the costs of ownership. Also, some state tax abatement programs require active timber management, which provides further incentive to manage forest land for various goals.

These objectives are often tailored to meet the requirements of easements, third party certification, and complicated family or corporate ownerships. Once objectives are clarified in terms of desired future condition, forest structure, economic objectives, and various limitations, sound application of silvicultural principles can be applied to meet a range of owner objectives.

The following silvicultural guidelines are applied on a forest stand basis. A stand is an area of fairly uniform site, type, and age/size class distribution that can be reasonably treated as a silvicultural unit; location and frequency of access may also be a consideration in defining stands. On small ownerships, a stand may be 5 to 10 acres. On larger industrial properties, a stand may be several hundred acres. Stands are defined and located prior to defining the appropriate silvicultural treatments.

SPECIES AND SITES

Major species and their characteristics are summarized in Table 1. Many other species are included as minor components of northern hardwood associations, adding incredible species diversity. Silvical characteristics are the key to understanding silviculture. Practitioners should be

Table 2.—Forest types and associated site characteristics: bedrock source and soils (Leak 1982)

Forest type	Characteristic species	Bedrock type	Soils descriptions
Sugar maple–ash	sugar maple, white ash, basswood	calcareous	well- or moderately well-drained tills
	sugar maple, white ash	granite, schist	enriched
Northern hardwood	beech, sugar maple, yellow birch	granite, schist	well- to moderately well-drained tills
Beech–red maple	beech, red maple	granite, schist	sandy, loose tills
Mixed-wood	hemlock, red spruce, white pine, yellow birch, red maple	any	shallow bedrock; moderately/poorly drained basal till or sediments; abandoned pasture/cropland
Oak with mixed pine–hardwood	northern red oak, white pine, red maple	any; often with an agricultural history	sandy tills, outwash especially

aware of shade tolerance, regeneration requirements, site preference and tolerance, resistance to decay, and insect and disease problems for each species in their range. Market preferences for species and quality will guide economic considerations. Potential for growing larger diameter and higher quality saw logs and veneer are closely related to site, by species.

Forest types (communities) and related site characteristics are in Table 2. However, past disturbances (primarily harvesting and land use) may cause significant variability. In developing silvicultural prescriptions, it is important to be aware of site characteristics and related species successional tendencies and silvical characteristics. The richest sites supporting sugar maple, ash, and some basswood[1] are found on till soils derived from calcareous bedrock. These areas usually support a rich ground flora with known indicator species. A similar forest type also occurs on enriched soils in areas dominated by granite or other bedrock sources with low to moderate nutrient levels; these soils occur at the base of slopes or terraces, with accumulations of organic matter. These rich substrates allow for a wider range of silvicultural options. However, typical northern hardwoods containing sugar maple, yellow birch, and up to perhaps 50 percent beech (sometimes more) occur on noncalcareous till soils. Beech-red maple types, often with a softwood component, are common on noncalcareous sandy tills and other lower nutrient sites. Red maple, paper birch, and aspen can be reproduced and grown on these sites, though expectations for large diameter timber, higher quality saw logs and/or rotation age may need to be reduced.

Northern red oak is of considerable interest. Red oak can develop very high quality saw logs and veneer in northern hardwood associations, contributing highly to the stand value on both agriculturally disturbed and dry or shallow-to-bedrock sites. Red oak regeneration in northern hardwood-oak stands is addressed under the section on even-age management.

Mixed-wood stands are diverse, including 25 to 65 percent softwoods, e.g., white pine, hemlock, spruce, fir, or cedar. Each of these has silvicultural and wildlife characteristics that should be considered in management goals. These often occur following harvesting disturbance on essentially softwood or variable sites: outwash, shallow bedrock, and very shallow (often wet) soils underlain with basal till or hardpan. Sometimes past agricultural use will produce a softwood component due to changes in soil characteristics from grazing, erosion or compaction; oak-pine may be a component on these disturbed sites. Often, pasture regrowth pine will be eventually replaced by hardwoods. Use the white pine silvicultural guide (Lancaster and Leak 1978) when pine is the featured species, then shift to the hardwood guide as hardwoods become more than 50 percent of the stocking. Likewise, if stands are more than 50 percent hemlock, oak, or spruce-fir, other guides are more appropriate. Mixed-woods can be managed to either favor a greater proportion of softwoods, hardwoods, or maintenance of mixed-wood condition depending on specific objectives.

[1]Scientific names of tree species are reported in Table 1.

SILVICULTURAL SYSTEMS

Silvicultural systems are planned sequences of practices to cope with biological, physical, and economic conditions for managing forest stands from establishment to maturity or harvest, and potentially continuation to manage the succeeding stand (Smith et al. 1997). Silvicultural systems are usually defined by the principal method of regeneration and the resulting structure of the stand. Of course, implementation of these systems is impacted by natural disturbances such as wind or ice storms. Systems are grouped into two general classes based on pattern and sequence of regeneration and the resulting stand structure. One system, with variations in the practice, creates and/or maintains uneven-aged, multi-aged, or all-age stands. The other system and variants thereof, creates or maintains stands with one or two primary age classes. Alternative approaches are briefly described at the end of this guide.

Uneven-age systems consist of single-tree selection and group selection (sometimes called group/patch to account for larger openings). The stands consist of, or develop, at least three age classes. A relatively high canopy is maintained over most of the stand. Harvesting occurs at somewhat regular intervals, the cutting cycle, and harvest entries are regulated so that the stand (or groups of stands) is maintained over time. It is essential that new age classes are effectively produced at nearly every entry. Generally, there are no separate cultural operations. Stand improvement with removal of defective, low-vigor, or low-value trees occurs as part of the harvesting operation, keeping in mind wildlife habitat concerns. However, there are instances where there could be cultural work within the small even-age portions created by group selection.

Even-age systems consist of regeneration harvests or pasture abandonment that creates stands with one or two primary age classes. These even-age systems include clearcutting, patch clearcuts (sometimes defined as 2 to 10 acres in size), or two age classes created by any of several shelterwood approaches. These harvests occur at the point of stand maturity, the rotation age. There are well-recognized (but optional) intermediate operations including noncommercial investments (weeding, crop tree release) as well as one or more commercial thinnings. Stand improvement takes place as part of these intermediate operations.

Various alternative or hybrid systems exist that result in essentially two age classes, or more, and do not fit traditional uneven-age, or even-age guidelines, but are useful and sustainable. As will be discussed at the end of the guide, these include rehabilitation forestry, ecological forestry, and natural disturbance silviculture. Each of these systems can be used to regenerate and grow a full range of species and products on a sustainable basis. Northern hardwood and associated mixed-wood forests are quite variable, and a wide range of approaches are effective and practical. This document presents guides for getting started. Observe the successes and failures of previous generations, test the recommendations on specific sites, and apply the concepts discussed in the text. Analyze how your stands respond on your sites, and be innovative. Northern hardwoods are resilient.

UNEVEN-AGE MANAGEMENT: SINGLE-TREE SELECTION

This method is the harvesting of single trees, or very small groups, generally separated from one another, so that a continuous crown canopy is maintained coupled with a range of diameter classes (Fig. 1). The application of this system requires specification on: 1) stand density and structure; 2) marking guidelines; and 3) cutting cycle (the time interval between harvest entries). The evaluation of single-tree selection approaches involves: 1) regeneration (species composition); 2) growth and yield; and 3) quality development. The chief advantages of single-tree selection are that it is a light touch on the landscape for those concerned about maintaining an unbroken forested appearance, and it provides maximum flexibility in choosing trees to take or leave. The system is best applied where the current stand contains an adequate stocking of quality trees with a component of quality sawtimber. It has been used to convert essentially even-aged stands to uneven-aged. Single-tree selection: 1) regenerates primarily tolerant species: beech (with some softwood) on mediocre sites, sugar maple on excellent sites with a possible concern regarding species diversity; 2) maintains a suite of wildlife species associated only

Figure 1.—Single-tree selection on granitic till showing the typical heavy beech regeneration. On richer soils (e.g., derived from calcareous bedrock), there would be a much higher proportion of sugar maple. Photo by M. Yamasaki, U.S. Forest Service.

with mature forest (Table 3 and 4); and 3) relies on main canopy trees recruited from understory stems that may have been suppressed. It is important to be watchful for bole/root damage from logging operations, a problem that can be minimized by careful choice of machinery and access.

With true single-tree selection, it is important to remove a portion of the unacceptable growing stock on each entry and to maintain a component of vigorous growing stock in both the upper and lower crown classes. Also, stocking needs to be low enough in some portions to create effective regeneration. Since overstory trees are eventually accumulated from the mid and lower canopies, previous suppression can affect the vigor and quality of these potential overstory trees.

Stand Density and Structure

Table 5 shows results from a study of stand density and structure (Leak and Gove 2008) on the Bartlett Experimental Forest (hereafter referred to as Bartlett.) This stand began as an even-age stand but developed an understory over time. Stand structure (a range in tree sizes) develops rapidly in even-age northern hardwoods, especially after a harvest. In general, the best growth results occurred with residual basal areas of 60 to 80 ft^2/acre (trees >4.5 inches diameter breast height [d.b.h.]) with at least 25 to 30 ft^2 of sawtimber (trees >10.5 inches d.b.h.). However, due to differences in species and vigor of the growing stock, growth responses were quite variable. Note in Table 5 that growth of poletimber is much greater under 60 ft^2 residual basal area as compared to 80 ft^2, i.e., lower basal areas result in a much more responsive understory. This stand was beech-red maple on a sandy till site, so the specifications on residual sawtimber basal area should be considered a minimum. On good/excellent sites such as enriched sites or calcareous tills, residual sawtimber basal areas of 50 to 60 ft^2 with 80 ft^2 total basal area are quite feasible. Within this range, it is important to leave vigorous trees with high potential quality—commonly called acceptable growing stock (AGS) as discussed under Marking Guides (page 9). It is more important to leave vigorous trees with quality potential than to follow strict guidelines on basal area.

Earlier guides (Leak et al. 1987) stressed the importance of following a reverse J-shaped stand structure (number of trees by d.b.h. class) characterized by a constant quotient between numbers of trees in successive d.b.h. classes (q-factor). For example, a quotient of 1.5 would have about 30 ft^2 of poletimber, 20 ft^2 of small sawtimber and 20 ft^2 of ≥ 16 inches trees retained after harvest.

Table 3.—Hardwoods habitat characteristics that provide structural/species diversity for various categories of vertebrate species

Wildlife species group and example species	Habitat characteristics	References
Forest wildlife diversity—broad-winged hawk (*Buteo platypterus*), barred owl (*Strix varia*), red-eyed vireo (*Vireo olivaceus*), mourning warbler (*Oporornis philadelphia*), snowshoe hare (*Lepus americanus*), moose (*Alces alces*)	forest-dominated landscapes; regulated, even-age management with a range of clearcut sizes; full-length rotations with < 10 percent of area in an unmanaged state; group/patch and some individual tree selection; maintain/improve softwoods as inclusions and stands; identify and work with the variety of within-stand habitat features	DeGraaf et al. 2005 DeGraaf et al. 2006
Cavity-dwelling wildlife—pileated woodpecker (*Dryocopus pileatus*), brown creeper (*Certhia americana*), northern log-eared bat (*Myotis septentrionalis*), fisher (*Pekania pennanti*), and weasels (*Mustela* sp.)	Live and dead trees with cavities in a range of sizes, and in larger branches; shelter sites under exfoliated bark plates; foraging sites	DeGraaf and Shigo 1985 Tubbs et al. 1987 Yamasaki and Leak 2006
Herps		
Terrestrial salamanders, e.g., red-backed salamander (*Plethodon cinereus*)	managed and unmanaged forest stands; subterranean refugia	DeGraaf and Yamasaki 2002 McKenny et al. 2006 Hocking et al. 2013
Mole salamanders (*Ambystoma* sp.) and wood frogs (*Lithobates sylvaticus*)	maintain a forest matrix (all ages/size classes) at the landscape-scale, subterranean refugia; vernal pools within both managed and unmanaged stands; variable buffer distances; maintain coarse woody material in clearcut units; maintain pool characteristics including shade over the pools	Calhoun and deMaynadier 2004 Hermann et al. 2005 Veysey et al. 2009 Freidenfelds et al. 2011
Birds		
Ruffed grouse (*Bonasa umbellus*) and American woodcock (*Scolopax minor*)	aspen/birch/mixed hardwoods; four age/size classes in 2 to 10 acre stands within 40-acre areas; mature softwood inclusions/stands for winter cover; natural appearing, permanent forest openings	Wildlife Management Institute 2012a Wildlife Management Institute 2012b Ruffed Grouse Society 2013 Gilbart, M. 2012
Early-successional breeding birds—chestnut-sided warbler (*Setophaga pensylvanica*), common yellowthroat (*Geothlypis trichas*)	clearcuts > 5 acres and some benefit from large group/patch selection; greatest use in the first 10 to 12 years post-cut; periodic cuts every 10 to 12 years to maintain this ephemeral habitat; diverse permanent forest openings	Costello et al. 2000 DeGraaf and Yamasaki 2003 Schlossberg and King 2007; 2009 King et al. 2009 King et al. 2011
Early- and later-successional post-fledging habitat—Swainson's thrush (*Catharus ustulatus*), red-eyed vireo (*Vireo olivaceus*), black-throated green warbler (*S. virens*)	patch clearcuts 5 acres and greater; dense mix of hardwood species plus fruit-producing species (e.g., pin cherry, raspberries); periodic cuts every 10 to 12 years to maintain this ephemeral habitat; permanent forest opening component	King et al. 2011 Chandler et al. 2012
Later-successional breeding birds—black-throated blue warbler (*S. caerulescens*), black-throated green warbler (*S. virens*), scarlet tanager (*Piranga olivacea*)	mature, overmature, and uneven-aged forest using both single-tree selection as well as even-age management; importance of forest structure	King and DeGraaf 2000 DeGraaf 1991 DeGraaf et al. 1998 Yamasaki 2013
Maximizing bird species numbers in a single stand	low-density shelterwoods provide both partial canopy as well as dense shrub/regeneration layer; reduce residual overstory so sunlight stimulates dense, woody regeneration and fruit-producing shrubs; residual stems serve as hunting perches, cavity trees, etc.	King and DeGraaf 2000 Yamasaki et al. in press

continued

Table 3.—continued

Wildlife species group and example species	Habitat characteristics	References
Foraging opportunities for neotropical migrants and resident birds—wood thrush (*Hylocichla mustelina*), American redstart (*S. ruticilla*), blue jay (*Cyanocitta cristata*), black-capped chickadee (*Poecile atricapillus*)	maintaining a diverse array of hardwood and softwood tree species provides suitable foraging opportunities for a wide diversity of insectivorous as well as seed-eating bird species; maintaining a range of opening sizes from tree-gap to multiple acres provides regeneration opportunities for shade-tolerant, mid-tolerant, and shade-intolerant species	Holmes and Robinson 1981 Robinson and Holmes 1982 Robinson and Holmes 1984 Holmes and Robinson 1988
Mammals		
Hard mast—particularly beech for gray squirrels (*Sciurus carolinensis*), mice (*Peromyscus* sp.), black bear (*Ursus americanus*), and white-tailed deer (*Odocoileus virginianus*)	single-tree selection to retain resistant beech in places where beech does well	Leak and Graber 1993 Leak and Sendak 2002 Leak 2006b

Table 4.—Landscape-scale wildlife habitat composition objectives: percent of acres by stand size-class and cover type (DeGraaf et al. 2005).

Habitat condition	Percent of acres
Size class:	
Regeneration	5-15
Sapling-pole	30-40
Sawtimber	40-50
Large sawtimber/old forest	<10
Cover type:	
Deciduous short rotation	5-15
Deciduous long rotation	20-35
Hard mast-oak	1-5
Conifers	35-50
Upland openings	3-5
Wetlands	1-3

Table 5.—Annual net growth (over 25 years) in basal area of poletimber (4.5 to 10.5 inches d.b.h.) and sawtimber (>10.5 inches) of a beech-red maple stand by residual basal area in poletimber and sawtimber (Leak and Gove 2008, Solomon 1977)

Basal area ft^2/acre	Percent basal area in sawtimber	Poletimber growth	Sawtimber growth	Total growth
		------------	ft^2	------------
40	30	0.82	1.42	2.24
	45	0.84	1.37	2.21
	60	1.13	1.18	2.31
60	30	0.22	1.59	1.81
	45	0.57	1.69	2.26
	60	0.46	1.52	1.98
80	30	-0.22	1.82	1.60
	45	0.08	1.47	1.55
	60	0.0	1.38	1.38
100	30	-0.13	1.80	1.67
	45	-0.17	1.49	1.32
	60	-0.24	1.44	1.20

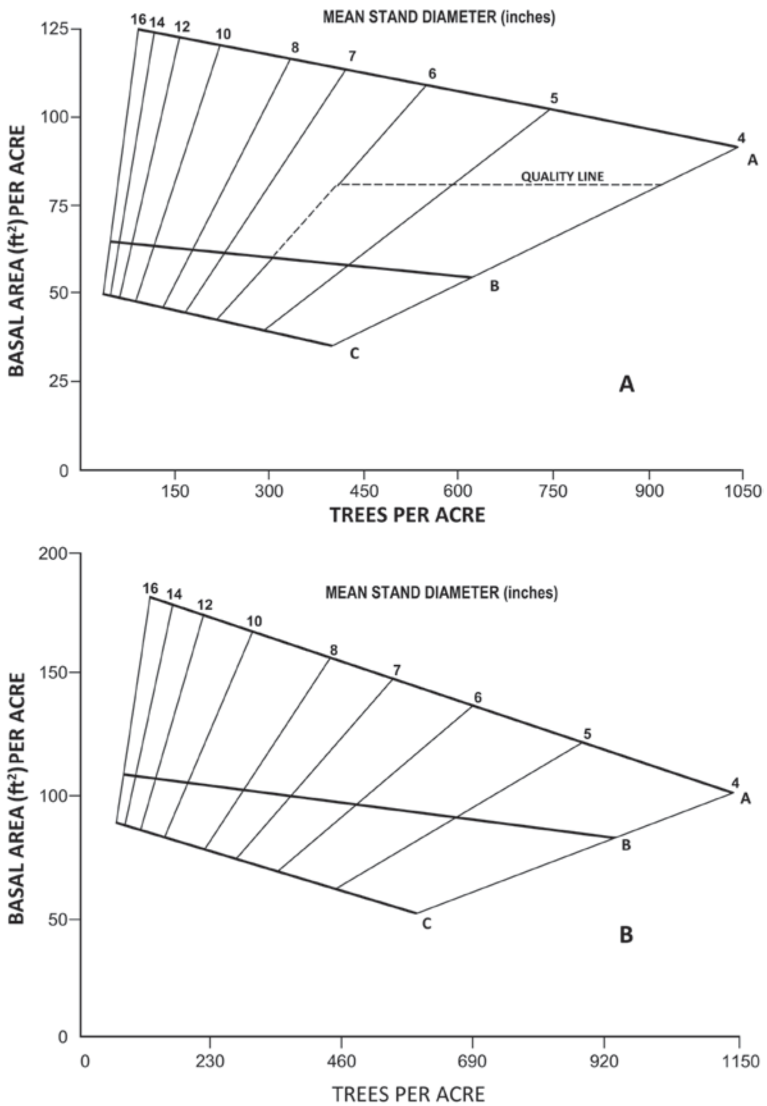


Figure 2.—Northern hardwood (A) and mixed-wood (B) stocking guides.

However, recent information and experience (Leak 2002) indicates that a more efficient structure could be somewhat sigmoid with an abundance of small sawtimber, producing high rates of value growth, and a decline in larger sawtimber due to harvesting of mature trees. In addition, within limits, stand growth is more closely related to species and vigor than to strict basal area control. And, overall quality, with some distribution in size/age classes will be more important than specific diameter distributions. For one example at Bartlett, under management since 1952 (three harvests), the stand had residual basal areas in 1993 of 17, 34, and 14 ft^2 in the poletimber (5 to 10 in), small sawtimber (11 to 17 in), and large sawtimber (≥ 18 in) respectively, a total basal area of 65 ft^2 per acre (Leak, unpublished data[2]).

[2] Data on file with author in Durham, NH

This type of sigmoid diameter distribution also could be typical of a regulated forest—even-aged or uneven-aged—that had been managed over time for maximum quality production.

Marking in poletimber sizes should be restricted to trees with low value potential; removal of small trees with quality potential to simply meet a stocking/structure objective will reduce the ingrowth into the sawtimber size class. Mixed-wood stands (stands with 25 to 65 percent softwoods) support higher basal areas than hardwoods, about 180 ft^2 maximum versus 130 ft^2 in hardwoods (Fig. 2). Residual basal area guidelines as described above should be raised by a factor of up to 50 percent in stands maintained as mixed wood; up to 100 to 120 ft^2 for example. Compare the hardwood and mixed-wood stocking guides (which represent even-aged stands) in Figure 2.

Table 6.—Approximate mature, maximum size (d.b.h.) for species-site conditions denoting the peak of possible log grade improvement (financial maturity)

Species	Site	D.b.h. objectives
		Inches
Sugar maple, yellow birch,	High	18-24
red oak, and white ash	Moderate	16-18
Red maple	Any	16-18
Beech	Any	16-18
Paper birch	Any	12-14
Red spruce	Any	12-16
Hemlock	Any	18-24

At this point, it is important to point out that wildlife habitat quality should be maintained by leaving at least 1 or 2 larger diameter wildlife trees per acre, where available. These are live trees with cavities (especially large cavities) for nesting or denning, evidence of black bear[3] feeding, raptor nests, or basket forks with potential as raptor nest sites (see Table 3). One 26 inch or two 18 inch wildlife trees per acre contribute less than 4 ft^2 per acre to the residual basal area of a stand; even five 18 inch wildlife trees per acre represent less than 10 ft^2 of residual basal area. Dead trees (snags) can be retained as foraging or sheltering habitat where available; and a large down log (hollow if possible) or two per acre where available maintains another ground cover habitat feature. Retention of softwood patches or individual trees (softwood retention) also adds to wildlife diversity, and it is important to maintain a range of wildlife habitat conditions across a property, or several adjacent properties, at the landscape level (Table 4).

Marking Guides

Previous guides have emphasized the reverse J-shaped curve and q-factors, which have proven difficult for field application. Currently, we believe that marking toward a range in residual basal area and basal area in sawtimber (possibly large versus small), based on a prior cruise or field exam, is sufficient for structural control. Generally, a range of 60 to 80 ft^2 of residual basal area with at least 25 ft^2 in sawtimber (up to 50 to 60) is a reasonable goal.

Marking should be directed toward trees that have low quality potential (defect or species) or are mature. However, as mentioned above, be sure to maintain at least 1 or 2 trees per acre with wildlife potential. From an economic point of view, mature trees are those that have reached the peak of grade improvement (including exterior and interior defect) as determined by local market conditions. Commonly, for long-lived hardwoods (and bigtooth aspen) and hemlock of acceptable growing stock, 18 to 24 in is a maximum, mature size. Spruce is economically mature at about 12 to 16 inches; balsam fir, quaking aspen, and paper birch at 12 to 14 inches (Table 6). But all these guidelines depend on site conditions, markets, visuals, and on-site logging/economic conditions—all extremely variable!

The term "acceptable growing stock" (AGS) commonly is used to describe trees that have log potential now, or in the future, and a reasonable crown. This can be expanded to include trees that meet other landowner objectives, such as wildlife trees. "Unacceptable growing stock" (UGS) denotes trees that do not meet the "acceptable definition" due to defect, noncommercial species, or unhealthy condition. AGS should comprise the bulk of the residual stocking after harvest. Stand prescriptions are clearer if mature trees are separated from AGS in evaluating potential residual stocking prior to harvest, though healthy, low risk mature trees are sometimes considered AGS in general evaluation.

[3] Scientific names of wildlife species are reported in Table 3.

Table 7.—Species composition (percent of milacres stocked by the tallest commercial species) by tolerance group and harvest method 10-15 years after cutting (Leak and Wilson 1958)

Tolerance group[a]	Clearcutting	Group/patch	Individual-tree selection
	---- percent ----		
Tolerants	43	62	92
Intermediates	19	34	7
Intolerants	38	4	1

[a] Species included in each tolerance group:
Tolerants: beech, sugar maple, hemlock, and red spruce
Intermediates: yellow birch, white ash, and red maple
Intolerants: paper birch and aspen

Cutting Cycle

The general rule on cutting cycles is to wait until there is an optimum operable harvest, prior to a significant reduction in growth due to increased stand density. Landowner concerns over logging cost, administrative cost, disturbance to the stand, and road access also play a part. Based on growth rates in Table 5, stands with basal area approaching 100 ft^2 are beginning to experience slower growth and increased mortality. Based on net annual growth rates of 1.5 to 2.0 ft^2/acre, a stand will change from 60 to 80 ft^2 to 100 ft^2 in about 10 to 25 years. A good estimate for planning purposes is about 15 years. Damage from insects/diseases and wind storms may shorten this estimate due to the need to salvage damaged trees.

Regeneration

Adequate regeneration is a primary concern with single-tree selection, specifically in terms of tree species and vigor. Standard regeneration responses to harvest methods indicate that single-tree selection produces about 92 percent tolerant species (Table 7). In typical northern hardwoods on granitic till soils, the species composition of saplings (2 to 4 in d.b.h.) in twice-harvested stands included 45 percent beech, 25 percent hemlock, 13 percent striped maple, and 10 percent sugar maple (Table 8). This species mix may be less than desirable for commercial timber management or for providing a rich array of foraging opportunities for songbirds, but quite acceptable as mature wildlife habitat for beech mast production. On calcareous soils or enriched granitic sites, sugar maple will be more prevalent or even the dominant species. This may be desirable; however there may be concerns over species diversity. Even moderate browsing on good sites will tend to move the regeneration toward higher proportions of beech, striped maple, and possibly ferns. We discuss approaches for controlling browse damage under Special Options on page 30.

Growth and Yield

Net annual growth under single-tree selection in beech-red maple with residual basal areas of 60 to 80 square feet ranges from 1.5 to 2.0 ft^2/acre (see Table 5). This is equivalent to about 40 to 50 ft^3 or about one-half cord. At 60 or 80 ft^2 residual with about 25 to 30 ft^2 of sawtimber, the net growth on sawtimber alone was 0.6 to 0.7 ft^2 /acre, equivalent to 15 to 25 ft^3, or about 100 to 125 board feet (bf) gross. Over a 15-year cutting cycle, the next cut should yield 7 to 8 cords/acre of which some portion could include 1500 to 2000 bf/acre. Lower initial or residual stocking would lead to a somewhat longer cutting cycle. Better sites would, of course, increase both yields (especially of sawtimber) and tree sizes, and reduce the cutting cycle.

Table 8.—Saplings (2-, 3-, and 4-inch classes) per acre and percentages in compartments cut twice by single-tree selection on granitic well-drained fine till (Leak 2006b)

Species	Saplings/acre	Percent
Beech	102	45
Yellow birch	8	3
Sugar maple	22	9
Red maple	1	1
Paper birch	0	0
White ash	1	1
Red spruce	8	3
Hemlock	57	25
Striped maple	30	13
Other	0	0
All	229	100

Table 9.—Changes in species composition, by volume of trees ≥ 5.0 in d.b.h. over a 50-year period after three single-tree selection harvests in 1952, 1975, and 1992 (Leak and Sendak 2002)

	Inventory year		
Species	1952	1976	2000
	percent		
Beech	53	53	49
Sugar maple	18	27	25
Yellow birch	11	7	6
Paper birch	11	0	0
Hemlock	3	9	15
Red maple	2	2	3
White ash	1	1	1
Red spruce	1	1	1

Table 10.—Changes in butt-log grade of beech and other hardwoods, by volume of trees ≥ 11.0 inches d.b.h. over a 50-year period after three selection harvests in 1952, 1975, and 1992 (Leak and Sendak 2002)

		Inventory year		
Species	Butt-log grade	1952	1976	2000
		percent		
Beech	1 and 2	21	21	30
	3	52	36	47
	5	16	41	18
	Cull	11	2	5
Other hardwoods	1 and 2	40	67	65
	3	47	25	31
	5	10	8	3
	Cull	3	0	1

Quality

Over a 50-year period and after three harvest entries, a typical northern hardwood stand (granitic fine till) on the Bartlett showed moderate changes in species composition and moderate improvements in quality (Tables 9 and 10). Despite heavy marking of the beech component coupled with a heavy infestation from the beech bark disease (*Nectria* spp.), the percentage of beech volume decreased from 53 to 49 percent. Grade 1 and 2 butt logs increased from 21 to 30 percent due to removal of the poorer quality beech. Sugar maple proportions increased from 18 to 25 percent, and hemlock from 3 to 15 percent (Table 9). Volumes in grade 1 and 2 butt logs increased from 40 to 65 percent in hardwoods other than beech (Table 10). The proportion of *Nectria*-damaged beech (cambial infection with lowered merchantability) also dropped to about 30 percent (Leak 2006a, Leak and Sendak 2002). So, the moderate volume growth and yield values would be accompanied by moderate improvements in both species composition and quality under single-tree selection.

Figure 3.—Recent, larger group/patch harvest where the existing understory was completely removed/destroyed, appropriate for stands with an undesirable understory. Photo by R. Holleran, Chester, VT, used with permission.

UNEVEN-AGE MANAGEMENT: GROUP/PATCH SELECTION

This approach to uneven-age management creates stands with distinct groups of several different age classes. It involves three alternative approaches: 1) the removal of trees in small clearcut patches ranging from less than ¼-acre to about 2 acres or sometimes larger on extensive commercial properties; 2) removal of trees in groups to release an established understory (known as group release); and 3) the initial harvest of groups in a shelterwood fashion (known as shelterwood groups).

Marking Guides

Group/patch selection is best applied in stands that are patchy, containing groups of trees that are mature, overmature, or defective (Fig. 3). In stands of this type, group/patch selection is more efficient than single-tree selection that harvests individual trees and maintains a closed canopy. A second advantage of group/patch selection is that it can be used to regenerate a range of species, not only tolerants. The method should not be applied by locating groups/patches at uniform spacing. The marker should look for areas containing at least 50 percent of the basal area in mature/overmature/defective trees and locate group/patch borders to efficiently harvest most of this material.

The first approach mentioned above, removal of trees in patches, is the more common approach and much of the following discussion deals with that method. However, there are excellent opportunities to apply the second approach, group release, during marking operations to release patches of desired seedling/sapling species such as softwoods, sugar maple, and oaks. (See the section on Regenerating Oak on page 20). The third approach, shelterwood groups, may be used to retain unusually valuable wildlife trees or to retain a small proportion of immature AGS in group harvests. However, overuse of this approach tends to defeat one main purpose of using groups: increasing the proportion of less tolerant regeneration.

During repeated harvest entries into a stand, group/patches may be placed right next to older groups without maintaining any border trees. This may enhance wildlife habitat for those species seeking larger openings than are usually provided by group/patch selection.

Marking between groups can be accomplished in one of two ways. First, improvement cutting, single-tree selection, or commercial thinning (including the crop-tree approach) can be applied throughout the stand between the groups. Remember that the next entry will be another series of group/patch harvests, so the development of additional patches of mature timber is advantageous.

Table 11.—Percent basal area by species in 50- to 60-year old groups/patches averaging about ½-acre in size by drainage class; trees ≥3.5 inches d.b.h.

Drainage class	Beech	Yellow birch	Sugar maple	Red maple	Paper birch	White ash	Hemlock	Other
	percent							
Well	26	15	11	14	26	2	5	1
Moderate	16	15	31	5	19	11	2	1

The other option is limiting treatment to some level of marking along the access trails. This approach is useful if there are concerns over excess development of a tolerant understory, excess damage to the residual trees, or a desire to maintain/increase the coarse woody material recruitment in the stand.

Experience shows that there is a natural tendency to mark trees one by one, rather than to consider whole areas as harvest or reserve groups. It takes a wider view to effectively administer group selection. Layout and sizing of groups should consider the whole range of factors: existent variation in overstory, understory, soils, and special habitats; location of groups of mature timber and/or UGS; species goals for overstory and understory; structural goals for timber regulation and wildlife habitat; access and equipment considerations; and insect and disease problems. This involves knowledge of the stand and not just the acre within sight of a forester. Marking groups larger than an acre is easier by simply delineating the perimeter if a tally of the harvest volume is not needed.

Regeneration

Numerous studies on the Bartlett (Leak 2003,2005) have shown the effectiveness of group/patch selection on reducing the tolerant component of the regeneration (increasing species diversity). Basal area tallies of 50 to 60-year-old groups, averaging about ½ acre in size (Table 11), showed that moderately-well drained sites (somewhat enriched) produced about 31 percent sugar maple, 34 percent yellow and paper birch, 11 percent ash and 16 percent beech. On calcareous sites, we believe the sugar maple proportions would be even higher, especially if the maple understory was well advanced. Also, there is some evidence that the mixed species composition, with an early successional component, following group selection will encourage an understory of sugar maple and ash, possibly because of the nutrient-rich foliage. On the very well-drained sites (known as beech ridges), the beech composition was 26 percent, birch 41 percent, and sugar maple 11 percent. Comparing these percentages with Tables 7 and 8 shows the impact of groups on regeneration as compared to single-tree selection.

The size of the group produces variable effects. The larger the group, e.g., ⅔ acre or larger, the more intolerants—aspen, pin cherry, paper birch, *Rubus* spp.—might be expected. However, the results are somewhat variable. Even very small openings, down to ⅒ acre, produce some increase in less tolerant regeneration. However, these small openings rapidly close in from the side, suppressing the regeneration, and are difficult to locate over time; though small groups may be useful on small private ownerships. In areas with an established beech understory, larger groups (1 to 2 acres) with scarification through snow-free harvesting will be effective in improving species composition. Scarification can normally be accomplished through the logging operation, especially with whole-tree harvesting.

Group selection does support a small to moderate level of early successional bird species as well as forest birds; for this reason, the larger the group/patch, the better (Table 3). Cavity trees may be left standing within groups but doing so may compromise regenerating more intolerant/midtolerant species. Some provision for cavity users over time should be considered in the surrounding stand matrix.

Where group selection does not produce adequate less-tolerant regeneration, the problem may be excessive browsing from deer or moose that removes all but the tolerant stems of beech or striped maple. Excessive browsing may also lead to an abundance of ferns and invasive plants (see Special Topics on page 30).

Regulation

Group/patch selection, using openings of ¼ acre or larger, is generally regulated by area control. For example, if the approximate rotation is 100 years, group/patch removals should approximate 1 percent of the stand area per year. (With very small openings, marking is controlled by basal area as suggested for single-tree selection). For a 15-year entry period or cutting cycle, about 15 percent of the stand area would be harvested with groups. For initial conversion of even-age or unmanaged stands, or with longer cutting cycles, larger percentages may be harvested to jump-start the new age classes. Since the regeneration in groups develops more slowly than in clearcuts, a rotation of 120 to 140 years may be more reasonable. With smaller groups especially, as overstory crowns close, the effective group acreage is reduced. For the system to be most effective, groups should be laid out in patches of mature and defective timber as stated previously; the size can vary to fit stand conditions.

On large industrial properties, the advantages of group selection can be achieved by larger-scale application of these concepts: target multi-acre patches of mature/defective trees, and reserve immature patches. This is well-suited to mechanized harvesting systems. Patch locations or boundaries can be supplied to contractors on a portable global positioning system (GPS) unit.

Growth, Yield, and Quality

There are no definitive studies comparing the effects of groups, or even-age systems, on growth and quality with single-tree selection. However, the effects on species composition are very well documented. Experience indicates that dominant and codominant trees growing in competition with one another under even-age conditions develop good quality stems.

UNEVEN-AGE MANAGEMENT: IMPROVEMENT CUTTING

Stand improvement is a part of any silvicultural partial removal. However, improvement cutting as a separate operation is a general term used to describe initial harvest operations in stands with an excess of defective or damaged timber. This condition may have resulted from ice or wind storms, poor quality pasture regrowth, insect or disease damage, or poor harvest practices in the past. It is implemented by removing a high percentage of the poor quality material with the objective of leaving sufficient growing stock to meet roughly C-level stocking. With AGS below that level, regeneration cutting may be warranted following the suggestions under even-age management or rehabilitation sections. Improvement cutting operations may be marginally commercial, and require good markets for low-grade material. In the next harvest entry following an improvement cut, follow the guidelines in the Inventory/Prescriptions section (page 26) to determine an appropriate silvicultural regime.

EVEN-AGE MANAGEMENT

Even-aged northern hardwood stands can be regenerated using the clearcut method or the shelterwood method of regeneration. Each of these methods has variations of the basic model that can be applied depending on many factors (site quality, species goals, visual, wildlife habitat, etc.). With the clearcutting method there is reliance on seed and some seedlings being in place when the harvest is made, or seed arriving from adjacent stands to establish new vegetation on the site. With the shelterwood method, the stand is partially harvested in some form to maximize seed production on the most preferred species and provide some shade on the site. Preparing a seed bed with scarification and control of undesired vegetation to maximize regeneration success may be a component of both options. The seed tree method, leaving a few trees per acre as a seed source is occasionally used and can also be called clearcut with reserves. With even-age management in hardwoods, the role of stump sprouts, stool shoots on small stumps, and root suckers can play a significant role in the regeneration. Aspen, beech, red maple, and others significantly regenerate by these means.

Following the regeneration stage, there are options on precommercial thinning or release as well as commercial thinning(s) discussed below. Rotation ages and yields under even-age management also are discussed below.

Clearcutting

As the name implies, clearcutting is the removal of mature or defective stands over areas large enough to be recognized

Table 12.—Percent composition (10 to12 years after harvest) of regeneration (based on the dominant stem per milacre of any species) in a clearcut, patch cuts (3 to 5 acres), and in a shelterwood with 40 ft^2 residual basal area retained (a portion of the clearcut harvest). Also percent composition of basal area (BA) in a 25-year-old stand (moderately well-drained) (Leak, unpublished data; Marquis 1969).

Species	Clearcut (fine till)	Two 3-acre patch cuts (sandy tills)	Two 5-acre patch cuts (sandy tills)	Shelterwood w/40 ft^2 residuals (fine till)	25-year-old clearcut
	---------------------------- percent of milacres			------------------------------	Percent BA
Beech	4	15-41	0-3	48	11
Yellow birch	9	5-24	13-45	7	10
Sugar maple	3	0	0	2	11
Red maple	1	0-5	0-3	0	5
Paper birch	23	23-25	3-24	5	24
White ash	7	0	0	2	3
Aspen	0	0-40	0-30	0	9
Red spruce	0	0	0	0	1
Hemlock	0	0-6	0	0	1
Striped maple	4	0-6	0	31	2
Pin cherry	46	0-10	24-51	2	23
Other	3	0	0-4	3	--

as a separate stand – 5 to 10 acres or larger. Clearcutting is best applied to stands where the proportion of mature and defective timber is at least 50 to 60 percent. If the understory or advance regeneration is acceptable (discussed under the section on regeneration), the harvest should be considered an overstory removal that preserves the advance growth to the extent possible by well-designed access and possibly a winter harvest. Previously thinned stands commonly have a well-developed understory. If the understory is unacceptable, the harvest should remove the smaller suppressed stems down to at least 2 inches diameter or smaller and provide for maximum ground disturbance; whole-tree harvesting is useful for this purpose. Clearcuts generally remove all merchantable trees, plus submerchantable trees down to about 2 inches d.b.h.

Often, reserve patches are retained, such as ¼ acre for every 10 acres of clearcut, that provide for cavity trees, other wildlife trees, seed sources (e.g., yellow birch), seeps, softwood inclusions, and structural diversity. Variable retention, which is a modification of the clearcutting system, retains about 10 to 30 percent of the area. These are usually no-cut patches of immature growing stock, riparian buffers, or special habitats, creating irregular stands over time. This variant will provide elements of habitat diversity beneficial to a range of species.

Two to ten-acre clearcuts are sometimes called patch clearcuts and follow the same guidelines previously mentioned for true clearcuts or overstory removals. This becomes a semantic discussion depending on what size constitutes a stand.

Table 12 provides examples of clearcut/patch-cut/shelterwood regeneration. The shelterwood with 40 ft^2 residual basal area was a portion of a true clearcut that was feathered into the uncut border, thus, it was the same site and same harvest period as the true clearcut. Note the very high percentage of beech and striped maple. Clearcuts with any component of reserve trees will begin to resemble a shelterwood. The true clearcut may have a high percentage of pin cherry, which drops out of the canopy as the stand ages but can improve the quality of desired species by natural branch shedding (Fig. 4). Note that the larger patch cuts (~5 acres) have typical early successional regeneration with high proportions of birch and pin cherry; the smaller patch cuts (~3 acres) have much less pin cherry and more beech in a dominant position (Table 12). A typical, excellent species mix of a 25-year-old stand that developed following a complete clearcut on a (good) moderately well-drained site is also included in Table 12. The regeneration will contain a mix of tolerants that were usually present prior to harvest

A

B

Figure 4.—Following patch/clearcut harvests, the vegetation after less than 10 years of age (A) will be a mixture of noncommercial/commercial vegetation, ideal for early successional wildlife; (B) at 15 to 20 years, the vegetation is mostly commercial tree species with pin cherry and only a small proportion of beech. Photos by M. Yamasaki, U.S. Forest Service.

and less tolerant species that developed anew. A more thorough clearcut with scarification usually is obtained with a whole-tree harvest rather than a standard clearcut; lower percentages of tolerant species are generally obtained with snow-off harvests.

The heavy harvests and skid trail activity associated with clearcutting require particular attention to best management practices to avoid excessive erosion and compaction, as well as stream buffers to minimize impacts on streamwater.

Clearcutting is the ideal system for encouraging early-successional bird species, as well as providing post-fledging habitat for forest songbirds (Chandler et al. 2012, King et al. 2011). And even-age management with clearcutting produces considerable vertebrate wildlife diversity; guidelines suggest that 5 to 15 percent of an ownership should be in the 0 to 10 year age class (see Table 4). In areas with heavy deer browsing, clearcuts (about 15 acres or more) help reduce the damage since deer venture less into the center of these larger openings until seedlings are out of reach. However, due partly to heavy browsing around the edges of clearcuts, invasive species and/or ferns may become established.

Aspen-birch stands, especially useful for grouse/woodcock management, are best reproduced by clearcutting where there is an aspen component (10 percent is more than sufficient) to provide root suckering capacity. Sandy, granitic tills are suitable sites, but these species can be managed on a wide range of sites including sites conducive to softwood regeneration. Aspen stands can also be managed as "coppice with reserves", which is really a two-age system. Selected overstory trees are retained in a final aspen harvest. Since aspen is particularly shade intolerant, reserve trees should be widely spaced for good aspen development. As with all prescriptions, there will be species or habitat elements both favored or unwanted; taking a larger landscape context often helps decide what course of treatment to pursue. For example, new openings can create habitat opportunities for early-successional songbirds but are less habitable for salamanders and frogs for some time after harvest (Hocking et al. 2013, Veysey et al. 2009).

Shelterwoods: Northern Hardwoods

Regeneration with the shelterwood method involves removing part of the stand, leaving a low to moderate density of canopy trees to provide seed and partial shade to aid in seedling establishment. Shelterwoods can be standard, low-density, or low-density deferred. Any of these may be "irregular" where the residual overstory density is intentionally non-uniform.

A standard shelterwood in northern hardwoods would consist of a seed cut leaving 60 to 80 ft^2 of basal area (sometimes as low as 40 to 60 ft^2) per acre in fairly mature trees in the main canopy, coupled with a removal cut 5 to 15 years later (Fig. 5). This type of harvest would regenerate a high percentage of tolerant species. However, on good sites, those with some calcareous influence or enriched sites, the regeneration should contain a substantial proportion of sugar maple and white ash. On less productive sites, the proportions of beech and striped maple would be high, especially with considerable browsing pressure. The removal cut requires careful choices on layout and equipment to avoid excessive damage to the regeneration; snow cover is an asset.

Figure 5.—Standard shelterwood with about 60 ft^2 residual basal area in dominant overstory stems. Tolerant regeneration will be common, and early overstory removal will help maintain less-tolerant regeneration. Photo by U.S. Forest Service.

Figure 6.—A stand ready for an overstory removal, leaving an understory of seedlings and saplings. Same stand as Figure 5, about 15 years later. Photo by M. Yamasaki, U.S. Forest Service.

As previously mentioned, in managed stands that have been previously thinned, or shelterwood cut, a tolerant understory may have developed already. If this is desirable, then the overstory can be removed in one or more cuts—a so-called overstory removal (Fig. 6). There is a tendency to delay the overstory removal, or to remove portions in several entries. Problems with this include suppressing the desired regeneration and damaging it with subsequent operations. If an undesirable understory has accumulated, snow-off cutting, scarification, whole-tree harvest, or herbicide treatment may be needed to shift regeneration species composition. Regeneration species composition is often visually evident, or it can be evaluated with milacre plots—making sure that primary attention is given to seedlings/saplings in a dominant position (Leak 2007a). See the section on prescriptions for suggestions on adequacy of the regeneration on page 26.

Low-density shelterwoods leave a residual of perhaps 20 to 40 ft^2 of basal area in mature trees from the main crown canopy, including individuals (e.g., yellow birch) desired for a seed source. This approach provides sufficient sunlight and ground disturbance to allow for the regeneration of a proportion of intolerant and intermediately tolerant species (e.g., yellow birch), especially if the operation is snow-off and also late fall after the seed crop is ripe. A standard low-density shelterwood would be followed by a removal cut in 5 to 20 years. Again, precautions are needed to avoid excess damage, such as operating with snow cover, although the lower amounts of residual timber help in this regard. Low-density shelterwoods leaving less than 20 ft^2 are approaching a seed-tree harvest where the residual trees primarily serve as a seed source instead of as source of light shade. Low density shelterwoods often defer removals for more than 20 years—a deferred shelterwood (Fig. 7) as described below.

The shelterwood system is usually described as being uniform in residual stocking. In practice, residual stocking is often quite variable. This is often purposely done, as desired reserve trees are irregularly located, advance regeneration may be present in patches, or to create additional diversity in stand structure or the regeneration component. We will use the term "irregular shelterwood" to define the situation where the overstory is intentionally variable in residual stocking (as seen in portions of Figure 8).

Figure 7.—A deferred, low-density shelterwood (20 to 40 ft^2 residual basal area) where the remaining trees will be mature in 20 or more years. This provides for a higher proportion of intolerant and mid-tolerant regeneration than a standard shelterwood. Photo by R. Holleran, Chester, VT, used with permission.

Figure 8.—Example of rehabilitation harvest where stand conditions required small areas of complete removal, irregular shelterwoods, and uncut reserves. Photo by M. Yamasaki, U.S. Forest Service.

Shelterwoods and the above variants provide cover for maximum numbers of breeding bird species since there is both overhead cover and a brushy understory; these conditions favor upper canopy breeding birds and foraging raptors as well as understory dwellers. Numbers of early successional birds (not necessarily numbers of species) are less in shelterwoods than in clearcuts (Table 3).

Deferred Shelterwood: Shelterwood with Reserves

Often, a mature hardwood stand contains a significant component of acceptable growing stock that has not reached maturity or maximized their grade potential. This is commonly tolerant hardwoods in intermediate crown position, 10- to 14-inch diameter, or cohorts of sapling or pole stock derived from previous harvesting. A standard shelterwood, in most cases, sacrifices many of these trees in either the establishment or final cut. Also, some landowners do not want to see the final overstory removed in one cut. Deferred shelterwood is when the overstory is retained for more than 20 percent of the rotation for additional growth. In the extreme, it becomes a two-age system where overstory trees are retained for 40 to 60 years while the understory has grown to half of its rotation age. Final removal of the overstory creates a new age class, and the understory becomes the overstory. In some cases, periodic removal of portions of the overstory will eventually transition the stand into uneven-age condition, especially if there is a patchy arrangement.

Deferred shelterwoods will usually have an irregular arrangement of stocking, as the desirable immature component will be found in groups or erratically located. It is important to reduce the stocking to well below the C-level (20 to 40 ft^2/acre) to allow for growth in the overstory, while not shading out the regeneration. Reserve trees should be selected for high quality potential, wildlife features, desirable seed source, or to meet other landowner objectives.

Smaller diameter crop trees, especially of mid-tolerant species, are prone to epicormic sprouting. Leaving groups of these trees can reduce this risk, or select trees with larger crowns. Sugar maple is long-lived and less prone to sprouting, and is often selected as a reserve species. These deferred shelterwood systems provide a tool for irregular stands that do not fit well into the normal silvicultural prescriptions. Stands that are mature or low quality, but have an immature acceptable component are particularly well suited, including previously high-graded stands. Stands that might otherwise be clearcut have another option to maintain some growing stock. Deferring the removal of the shelterwood overstory can make even-age management more attractive to small woodlot owners. It provides a more continuous forest cover than regular shelterwood, though not as much as uneven-age management. It has better regeneration success in areas of high deer browse pressure, if densities are low enough. It maintains complex stand structure, which provides both overstory and understory wildlife habitats for a longer period of time.

Table 13.—Percentage of milacres dominated by commercial and any species regeneration 10 years after a winter harvest of a low-density shelterwood on granitic, moderately well-drained soils with 40 ft^2 residual basal area/acre. Over time, the commercial species should dominate as the noncommercial species subside (Leak, unpublished data). Snow-free harvest and lower residual basal area would have improved the species mix.

Species	Commercial	Any species
	----------- percent of milacres -----------	
Beech	54	42
Yellow birch	22	17
Sugar maple	5	4
Red maple	10	4
Paper birch	2	2
White ash	5	2
Aspen	0	0
Red spruce	1	1
Hemlock	0	0
Striped maple	--	20
Pin cherry	--	5
Other	1	3

Table 13 provides an example of the moderately successful regeneration (after 10 years) under a low density, deferred shelterwood (40 ft^2/acre, granitic soils). Note that beech dominates about 50 percent of the regeneration. Residual saplings had to be removed by hand since the residual trees and the time of harvest (winter) resulted in less than optimum ground/understory disturbance. The regeneration would have been better with a snow-off, whole-tree harvest and a lower residual basal area of about 20 ft^2 basal area/acre, thus providing a higher level of ground disturbance. Better site conditions, supporting more advanced sugar maple regeneration, would have greatly improved the regeneration.

Regenerating Oak

The regeneration of oak in northern New England is especially difficult. Oak tends to be more abundant on sandy tills, outwash, and shallow bedrock soils, especially on south- to west-facing sites (Leak and Yamasaki 2013). Many of the better oak stands occur on old fields where the species regenerated under old-field pine, and then was released when the pine was harvested. This phenomenon relates to wildlife interactions where blue jays and squirrels bury acorns, sometimes at considerable distance from the parent tree (Alexander 1980, Darley-Hill and Johnson 1981, Vander Wall 2001). If the stand is more than 50 percent oak, use the appropriate oak guide. However, since oak is usually a scattered component of northern hardwood stands, the methods in this guide should be applicable. The best opportunities to regenerate oak are on fairly dry, warm sandy till soils. If there is oak regeneration present (perhaps 1 to 2 feet tall or more), it should be released by overstory removal, using groups/patches if the regeneration is patchy. If oak regeneration is absent, begin the regeneration process by a light shelterwood removal from below (perhaps a shelterwood group), leaving perhaps 80 to 100 ft^2 basal area with well-spaced oak seed trees. Harvested oak will sprout readily, contributing to the regeneration process. This first removal should be done in the fall of a good mast year with sufficient ground disturbance to bury the acorns; acorns on the surface will be almost completely lost to predation by insects, birds, and mammals. Acorn crops are sporadic but can be detected a year in advance with northern red oak. When the regeneration is approximately 1 to 2 feet tall, proceed with an overstory removal (perhaps a group release). Oak is heavily browsed by deer, so early release is advisable. Some stands with a promising overstory oak component have dense understories of beech saplings and other undesirable species. One approach to deal with this problem is a series of intensive cultural treatments, perhaps including fire and chemicals, to minimize the understory competition. Other approaches, not thoroughly tested, include a whole-tree harvest of the understory in the fall of a good acorn crop, coupled with a light overstory harvest. Another possible approach is group selection adjacent to an oak seed source since observation indicates the oak regeneration may develop under an early-successional overstory, but not under a beech canopy.

INTERMEDIATE TREATMENTS

Precommercial Thinning

Precommercial thinning is the treatment of young stands to increase diameter growth and vigor of the best trees and species by felling or killing competing trees. Four precommercial thinning (release) treatments were examined in a 25-year-old stand on the Bartlett (Marquis 1969) where an average of 385 crop trees per acre across the treatments were selected.The thinning treatments were:

1. Heavy crop-tree: removal of all trees touching the crown of selected crop trees.
2. Light crop-tree: removal of the most severe competitor around each crop tree.
3. Species removal: removal of all aspen, pin cherry, striped maple, and some red maple sprouts.
4. Control: untreated.

Residual basal areas across treatments were 56, 72, 66, and 100 ft^2 per acre, respectively, in trees > 0.5 inches d.b.h. While the number of crop trees seems high by current standards (Perkey et al. 1994), the residual basal areas following thinning are reasonable. The crop-tree approach was used to guide the thinning, not to target trees that would reach final maturity.

Results after 5 years showed a response on the crop trees of more than 50 percent growth in d.b.h. (Table 14). Over the next 30 years, the crop trees generally showed an increase of about 2 inches more than the controls; however white ash and yellow birch showed much less response. An economic analysis showed real rates of return for the light crop-tree treatment of 3.5 percent (31 years after treatment) or 2.3 percent (44 years after treatment); much less for the heavy treatment. If a harvest had been done at about age 45, and if fewer crop trees (50 to 100 per acre) had been targeted, the rates would have been better. Other research shows variable results, including great success, with precommercial thinning. Operationally, 50 to 100 crop trees released

Table 14.—Annual response (over 5 years) of a 25-year-old precommercially thinned northern hardwood stand (Marquis 1969)

Thinning level	Residual basal area (≥ 0.5 in d.b.h.)	Entire stand: basal area growth	Crop trees: basal area growth	Crop trees: d.b.h. growth
	------ ft^2/acre ------			inches
Heavy	56	4.0	3.2	0.18
Light	72	3.3	2.7	0.15
Species	66	4.9	2.7	0.15
Control	100	2.2	2.1	0.11

on three to four sides is normal. Other precommercial treatments are better described as weedings, in which selected species, such as beech, poplar, or red maple, are removed to favor trees with more value potential.

At this point, however, it is difficult to make a strong recommendation for large-scale precommercial thinning unless there are overriding circumstances such as an overtopping overstory of less desirable species resulting from a less-than-complete clearcut, sprout growth of red maple or other less favored species, or a minimal stocking of highly valuable species in a matrix of poorer quality stems. Cost-share money or landowner investment should be reserved for these situations. However, some landowners may wish to personally engage in limited precommercial crop-tree work in selected areas. Once a stand reaches pole size, there are often markets for fuelwood or pulp that make these improvement cuts at least break-even propositions.

Commercial Thinning

The definition of commercial thinning is expanding since there are growing markets for small stems as biomass or specialty products. However, we use the term herein as a commercially viable thinning for conventional products, usually in a stand containing 8- to 10-inch trees at the very least, usually 45 years old or more. Precommercial thinning is usually not warranted at this stage.

Northern hardwoods are unique in that they often contain a component of short-lived, intolerant species (aspen, paper birch) in mixture with longer-lived species of appreciable value (white ash, red maple, black cherry) plus extremely long-lived species such as sugar maple, yellow birch, and red oak (Fig. 9). The intolerants become mature at age ~50 to 70 years, the middle category at 80 to 100, while the long-lived species mature at 100 to 140 years or more. Thinning of the short-lived species, coupled with stand improvement within the long-lived species, creates the opportunity for repeated high-volume commercial thinnings. However, one important precaution: maintain a component of the most vigorous early successional tree species as a regeneration source for the next stand. This component should be well-spaced as individuals or small groups of trees.

Thinnings can be described as from above, from below, free, or crop-tree. Thinning from above removes trees from the upper crown classes and is best applied to younger stands, removing short-lived trees such as aspen, birch, or ash. Thinning from below removes mostly suppressed and intermediate crown classes. This

Figure 9.—A commercial thinning in middle-aged northern hardwoods to about 70 to 80 ft^2 of acceptable growing stock (AGS), mostly sugar maple. Photo by R. Holleran, Chester, VT, used with permission.

Table 15.—Annual (over 7 years) d.b.h. growth rates by species for thinned (to 70 ft^2 residual BA average) and unthinned northern hardwoods at 75 years of age (Leak 2007b)

Treatment	Beech	Yellow birch	Sugar maple	Red maple	White ash
	------ inches ------				
Thinned	0.17	0.13	0.20	0.19	0.17
Unthinned	0.16	0.06	0.17	0.19	0.13

Table 16.—Annual d.b.h. growth of sawtimber (25-year period) in young sawtimber/poletimber stands thinned to 60 and 100 ft^2 basal area (Leak and Gove 2008)

Residual basal area ft^2/acre	Beech	Yellow birch	Paper birch	Red maple	Hemlock
	------ inches ------				
60	0.14	0.05	0.10	0.12	0.20
100	0.11	0.04	0.06	0.10	0.19

salvages expected mortality, but does not seem to have much effect on crop tree growth unless intermediate trees compete with desired codominants. Thinning from below is recommended for late thinnings in nearly mature stands, especially in preparation for a shelterwood cut. This is sometimes called the "shelterwood preparatory cut". Many thinnings are, in fact, free thinning—removing trees from all crown classes, based on a wider range of factors. Perhaps the most useful is thinning from above—removing short-lived species and crop-trees—which concentrates the growth on to the potentially best trees.

A thinning in a 75-year old northern hardwood stand (Leak 2007b) (the precommercially thinned stand referred to previously (Marquis 1969), on an excellent site on the Bartlett produced about 19 cords/acre. The thinning removed mostly paper birch and aspen and reduced the basal area down to an average of 70 ft^2/acre, ranging from about 50 to 90 ft^2/acre, equivalent to the C-line at the low end of the range, or well above, on the northern hardwood stocking guide (Fig. 2). Diameter growth responses to the thinning were good for yellow birch and white ash (Table 15), and very slight for other species possibly due to the effects from a previous precommercial thinning. Although the northern hardwood stocking chart provides a reasonable range in stocking levels, stand growth rates were more closely related to the vigor and crown class of individual stems and species than they were to stocking level. A second study (Leak and Gove 2008) in partially harvested northern hardwoods on a moderate site showed similar (only moderate) diameter growth responses (Table 16). However, a 1936 thinning study on the Bartlett (Jensen 1940) showed that the larger trees grew at up to 0.15 inches annually in d.b.h. growth compared to about 1/10 inch in the unthinned control. This stand had not been previously managed, possibly the reason for the somewhat better diameter growth response.

Growth responses in young stands (Table 14) may be superior to those in older stands. The older-stand thinnings, however, are very worthwhile in salvaging potential mortality, and especially concentrating growth over time on high value species with high quality potential.

To produce maximum volume yields, commercial thinning in northern hardwoods is useful and almost essential in stands with a component of short-lived species. In addition, commercial thinning extends the period of increasing mean annual increment up to the end of a normal rotation (next section). But thinning does have its problems. Careful harvesting operations are more expensive and thinning products are generally lower value, so thinning may not be profitable. It is important to keep in mind the goal of increasing the growth and health of the crop trees and not to harvest the premium trees to try to make it more economical, unless they are short-lived species. If the desired thinning is deemed to be unprofitable, it may be best to wait for improved markets and additional growth. Risk of felling and skidding damage is high with repeated thinning, so the contractor needs to be compensated for the careful work required. Laying out straight access trails in initial thinning is important, regardless of crop trees, as these may be used in future entries if well located (e.g., avoiding steep slopes and seeps). This practice will reduce skidding damage, especially with repeated entries. In very uniform stands, this can almost be treated as a row-thinning. Finally, even mild thinning will provide enough light for tolerant regeneration or invasive species to accumulate. While they do not interfere with the growth of the main canopy, they may make regeneration more difficult at the end of the rotation.

Where the stand is primarily long-lived species (in contrast to stands with a short-lived component), a commercial thinning still is viable, removing lower-quality stems that have reached their maximum grade potential. A conscious effort also can be made to release the best crop trees on three or four sides (perhaps 50 per acre) – a so-called crop-tree thinning. It is best to flag selected, well-spaced premium crop trees to guide the marking, and reduce the risk of damage during harvesting. Residual stand density can be guided by the stocking guides described below; however, it is more important to mark the stand well, retaining trees with quality potential and good crowns.

The stocking chart for northern hardwoods (Fig. 2A) provides general guidance on both growth and quality; this chart is generally applicable to most hardwood stand mixtures. Stands below the B-line will appear understocked and will begin to develop a dense understory. Some species, such as yellow birch, will develop epicormic sprouts. The C-line represents our best estimate of minimal residual density. If the trees are vigorous, 10 years of growth should bring the stand to the B-line. Stands that contain acceptable growing stock below the C-line may not be worth maintaining over a full rotation. The so-called quality line suggests that fairly high densities should be maintained in young stands to ensure natural shedding of live branches. The mixed-wood stocking chart (Fig. 2B) for stands containing 25 to 65 percent softwoods range from about 50 to 60 ft^2 above the northern hardwood chart; higher stocking can be allowed with higher percentages of softwood. A white pine stocking chart is in the Appendix, Figure A-2.

Stocking charts provide very general guidance on appropriate stocking levels. Growth of hardwoods may be high at levels well below the B-line; growth of softwoods may be maximized at well above the guide recommendations. It is more important to mark stands for vigor, quality, species composition, and regeneration potential.

Growth, Yield, and Rotation

Managed and unmanaged yield tables for even-age northern hardwoods were developed through simulation procedures (Solomon and Leak 1986) and checked by available volume information (Table 17). For the unmanaged (unthinned) stands at site index 60, the maximum mean annual volume peaks at about 50 to 70 years of age (mean d.b.h. is 6 to 8 inches) at around 30 ft^3 (Table 18). For the managed stands, mean annual increment peaks at about 95 years of age at around 50 ft^3. Note that this figure is about the same as the growth estimates for uneven-age management (Table 5 and related discussion), which is consistent with expectations. Mean annual board-foot growth (gross volume) for managed stands levels at about 150 board feet/year at ages 107 to 119 years, which is a reasonable, minimum rotation age for quality sawtimber products. Rotations up to 120 to 140 years are quite within reason for long-lived species. Shorter-lived species and species with lower quality potential (paper birch, red maple, beech) might be managed on shorter rotations such as 80 to 100 years. And keep in mind that early-successional stands of aspen-birch require rotations of about 40 to 60 years.

Site conditions, as reflected by soils or substrate, have a pronounced effect on maximum tree diameters at a given age (Table 19), but much less effect on biomass productivity (Table 20). Note that the enriched site is the only category with greater annual increase in biomass, and we would expect that richer soils developed from calcareous till would also produce higher biomass productivity. As discussed previously (e.g., Tables 1 and 2), soil/site conditions have a pronounced influence on species composition.

Table 17.—Simulated yields per acre for unthinned and thinned northern hardwoods at site index 60. The cumulative thinned volumes include a summation of volumes up to a given age/mean diameter. The standing volume is the after-thinning volume. The board foot (bf) volumes are total gross volumes based on tree dimensions, trees larger than 11 in d.b.h. to an 8-inch top (Solomon and Leak 1986).

	Unthinned			Thinned				
Mean d.b.h. (overstory in inches)	Age (years)	Standing cubic foot volume (ft^3)	Standing board foot volume (bf)	Age (years)	Cumulative cubic foot volumes (ft^3)	Cumulative board foot volumes (bf)	Standing cubic foot volume (ft^3)	Standing board foot volume (bf)
4.0	30				--	--	--	--
6.0	49	1547		48	269	--	1418	--
8.0	67	1924	3560	61	1243	895	1189	2211
10.0	87	2311	6640	72	1243	895	1912	5471
12.0	114	2700	9783	83	1854	2680	2039	7375
14.0	157	3102	13048	95	2602	5633	2011	8449
16.0	--	--	--	107	2602	5633	2449	10289
18.0	--	--	--	119	3394	8960	2085	8760

Table 18.—Mean annual increment (MAI) calculations developed from Table 17 (Solomon and Leak 1986)

	Unthinned			Thinned		
Overstory mean d.b.h. (inches)	Age (years)	MAI (ft^3)	MAI (bf)	Age (years)	MAI (ft^3)	MAI (bf)
4.0	30	--	--	--	--	
6.0	49	32	--	48	35	
8.0	67	29	53	61	40	51
10.0	87	27	76	72	44	88
12.0	114	24	86	83	47	121
14.0	157	20	83	95	49	148
16.0	--	--	--	107	47	149
18.0	--	--	--	119	46	149

Table 19.—Mean d.b.h. of the largest tree per plot at stand age 100, granitic till, White Mountains of New Hampshire (Leak 1982)

Soil class	Beech	Yellow birch	Sugar maple	Red maple	Paper birch	White ash	Red spruce	Hemlock
	------------	------------	------------	------------ inches	------------	------------	------------	------------
Enriched	--	17.3	19.6	--	--	21.1	--	--
Sandy till	15.2	14.2	12.5	13.4	15.4	16.8	--	13.3
Sandy sediments	14.8		--	17.0	13.6	--	--	--
Silty sediment	12.0	12.6	--	16.9	--	--	--	22.2
Dry hardpan	12.5	12.0	9.6	14.6	13.8	--	--	--
Wet hardpan	9.8	11.2	9.4	16.8	14.3	16.0	14.8	18.6
Poorly drained	--	--	--	--	--	--	13.6	--

Table 20.—Mean annual growth in biomass and basal area per acre in 60- to 70-year-old even-aged stands by soil/site category for all trees ≥4.5 inches d.b.h. (Leak 1979)

Soil/site	Biomass (lbs)	Basal area/acre (ft^2)
Enriched	2,916	2.67
Fine till	2,162	1.77
Sandy till	2,198	2.31
Dry hardpan	2,263	2.31
Shallow/loose rock	2,129	2.54

Aspen-birch, useful for woodcock/grouse management, generally is grown on rotations of 40 to 60 years, often in small blocks of about 5 acres in size that vary in age class (Table 3) (Gilbart 2012; Wildlife Management Institute 2012a, 2012b). These stands do well on less productive sites such as sandy, granitic till, or hardpan.

MIXED-WOOD STANDS

Managing mixed-wood stands (25 to 65 percent mixtures of hemlock/spruce/fir/pine with northern hardwoods) can add challenges. Some mixed-wood stands originated from heavy harvesting of softwood stands, especially on soils that are not strong softwood sites (Table 2). Some mixed wood occurs in areas where the site conditions are variable, consisting of a mixture of softwood and hardwood sites, e.g., where fluctuating topography leads to variable depths to a restrictive soil layer. Many mixed-wood stands result from past history: essentially hardwood sites on abandoned agricultural land which can produce a mixed condition. Old-field pine is a typical example.

There is a wide range of options for dealing with mixed wood. First is the development of long-term objectives: softwood, hardwood, or maintenance of the mix. Second is the choice of an appropriate silvicultural system which could include both even-age or uneven-age approaches.

To deal with mixed wood, first try to evaluate the site capability, hardwood vs. softwood, which will help set the long-term goal. Areas with a hardwood objective can be handled through the methods described above, including the section on oak regeneration. Many mixed-wood sites support lower value hardwoods such as red maple. However, yellow birch is often readily regenerated and vigorous on mixed-wood sites, especially those with abundant moisture.

Areas to be pushed toward tolerant softwoods or hardwood/softwood mixtures are more problematic and a longer term, uneven-age approach may be useful. Advanced regeneration is important for softwood regeneration. If the stand has patches of softwood regeneration, these can be carefully released through overstory removal (i.e., group release), using equipment and harvesting layout to avoid damage.

In a well-stocked stand without any softwood regeneration, approaching the A-line on the mixed-wood stocking chart (Fig. 2), <u>light</u> thinning from below is a logical choice to begin the process of softwood regeneration. This is essentially a shelterwood preparatory cut. Scarification from snow-free logging should be helpful. Then in the future, the established softwood regeneration can be released through stand-level overstory removal or group-level release. Small group selection openings (~1/10 acre) may also be useful, although the resulting regeneration may have an overstory of early-successional hardwood with a softwood understory.

When stocking is lower and the understory is mostly unwanted hardwood or weed species (and softwood still is the objective), it may be possible to use long strips about a half-chain wide to thoroughly eliminate the understory and heavy scarification to expose the lower soil horizons. This tends to emulate the well-known phenomena of softwood in old skid trails or on cut road banks. If possible, the operation should be timed with a softwood seed crop.

Thinnings in mixed-wood stands with 25 to 65 percent softwood should follow the mixed-wood stocking chart (Fig. 2), keeping in mind that the condition of the growing stock (vigor and quality potential) are more important than strict adherence to the chart numbers.

INVENTORY AND PRESCRIPTIONS FOR UNEVEN- AND EVEN-AGE MANAGEMENT

Inventory and Prescriptions

To develop accurate stand prescriptions for uneven-age or even-age management, the following minimal procedures should be adequate. The guide below leads to a suggested range of optimum treatments, which can be adjusted to meet particular landowner objectives or operational concerns. In obviously two-aged stands, you might apply the following procedure to the overstory only and regard the understory (saplings/poles) as the regeneration layer. To help with developing prescriptions, all the silvicultural methods discussed in this guide are summarized in Table 21.

The following approaches take into account the patchiness of the stand, a feature ignored in previous guides. Prescription development is the pinnacle of forestry practice. It involves consideration of the full range of circumstances and objectives, and there is no substitute for experience. Observe the effects of previous harvests on the site and nearby areas. What worked? What did not? The key will walk you through to a range of sub-options, so this is not intended as a "recipe", but a silvicultural guide. Use your professional judgment and don't be afraid to innovate.

1. Sample at least 10 and as many as 30 plots per stand, unless the stands are very large or very small. These are simple point samples with a limited amount of data to use with this key. Experience will dictate adequate sampling for using these prescriptions. These samples can be part of a more detailed inventory or simply a low-cost walk-through set of observations. In the key below, notice that the descriptive NOTE provides a quick walk-through assessment of treatment needs.

2. The steps below apply to stands with commercial possibilities, not understocked or recently-harvested stands. If the stand is clearly saplings or noncommercial poletimber, go directly to the sections in this guide on precommercial thinning.

3. At each point, there are two steps:

A: Determine whether the surrounding area (¼ to 1 acre) should be group/patch harvested (GROUPCUT). GROUPCUT is recommended if 50 percent or more of the basal area is in mature/overmature/defective trees (MOD). Determine whether the regeneration is none (minimal)/desirable/undesirable. Desirable would imply 40 to 50 percent of milacres are dominated by desirable species. This step might meet the need for a walk-through survey.

B: Take a prism survey of:

i. Total basal area, possibly split by poletimber/sawtimber.

ii. Basal area of mature/overmature/defective trees (MOD). The remaining basal area will be immature AGS (again possibly split by poletimber/sawtimber).

4. For the stand, summarize percentage of points classed as GROUPCUT, and percentage basal area in MOD. Follow the key below; if the inventory numbers are close to the class limits, check the next closest prescription.

5. If %GROUPCUT is >50 percent of the plots: (NOTE: high overall MOD stand)

A. Regeneration mostly desirable:

Recommendation—overstory removal in one or several entries, or a low-density, irregular shelterwood harvest, possibly a deferred low-density. An irregular shelterwood would have a variable/non-uniform overstory density. See Prescription Details (page 28) for other options.

B. Regeneration mostly undesirable or absent:

Recommendation—clearcut in one or several entries, or consider the shelterwood options mentioned above (irregular low-density, or deferred low-density).

Table 21.—Summary of silvicultural methods and their application

Silvicultural method	Application	Regeneration	Residual basal areas ft^2/acre
Uneven-age:			
Single-tree and very small groups (<1/10 acre)	sawtimber stand; spatially well-distributed sizes/ages; rich sites; light visual disturbance; mature-forest wildlife; management of beech mast stands (moderate sites).	over 90 percent tolerant species	60 to 80 total; 25 to 60 sawtimber
Group/patch selection (¼-2 acres in size)	Sawtimber stand; patchy distribution; any site; moderate visual disturbance acceptable; mature and limited early-successional wildlife—larger is better.	about 2/3 tolerants in small groups; 1/3 in patches	60 to 80 between groups/ patches
Even-age:			
Clearcutting	sawtimber stand; over 50 percent mature or UGS; any site including poor-moderate; heavy visual disturbance acceptable; maximum early-successional wildlife.	about 2/3 intermediates and intolerants, especially with whole-tree harvesting	0 to 10
Overstory removal	sawtimber stand; overstory over 50 percent mature or UGS; desirable understory (seedlings, saplings, poles); complete removal or any of the shelterwood options below; must minimize understory damage (perhaps winter operation); heavy visual disturbance.	Intermediates/tolerants that are released	0 to 10
Standard shelterwood	well-distributed sawtimber stand; rich site; harvest from below leaving roughly C to B-line overstory; moderate visual disturbance acceptable; light/moderate wildlife response.	on rich sites, mostly sugar maple with component of white ash; beech a problem on poorer sites	50 to 80 in mature overstory trees
Low-density shelterwood	sawtimber stand; over 50 percent mature plus UGS; any site; harvest from below leaving 20 to 40 ft^2/acre; often undesirable understory; overstory removal in 5 to 10 years; good wildlife response with moderate early successionals.	Half tolerants, half intermediates	20 to 40 in mature overstory trees
Deferred shelterwood	mature/UGS sawtimber; component of quality small poles/sawtimber residual (20 to 40 ft^2/acre) for removal in 20 years plus; any site; heavy visual disturbance; wildlife response similar to low-density shelterwood.	half tolerants, half intermediates. Some suppression of regeneration under the reserves	20 to 40 in overstory AGS trees
Irregular shelterwood	low-density or low-density deferred shelterwoods where the residual overstory is irregular, not uniformly spaced.		20 to 40 irregular spacing
Intermediate Treatments:			
Precommercial thinning	sapling/poletimber stands; questionable economics; best applied where AGS is marginal and needs release using crop-tree approach.	none planned	use stocking chart
Commercial thinning	poletimber/small sawtimber stands; component of early-maturing species (paper birch, aspen) and UGS; follow stocking charts.	none planned but may initiate tolerant understory response	use stocking chart
Stand improvement	even/uneven/two-aged stands with high component of UGS; an initial conditioning cut prior to even- or uneven-age management.	none planned, but may initiate tolerant understory response	use stocking chart as a rough guide
Alternative Silvicultural Systems:			
Rehabilitation	heterogeneous mixture of stand conditions without recognizable uniform stands. Handled, acre by acre, as appropriate with methods listed above. Long-term goal is to increase AGS proportion, and acceptable regeneration with irregular stocking.	mixed	residual stocking will vary with microstand condition
Ecological forestry	a landscape-level approach involving a range of silvicultural practices with emphasis on maintaining diversity in species and structure.	broad range	variable depending on silvicultural treatment
Natural disturbance silviculture	emulates on-site natural regimes such as windthrow patterns and natural succession.	generally tolerant	often 100 plus

6. If %GROUPCUT is 10 to 50 percent of the plots: (NOTE: very patchy, inconsistent)

A. Regeneration mostly desirable:

Recommendation—group/patch release, retain regeneration.

B. Regeneration undesirable or absent:

Recommendation—group/patch selection, destroy/replace advance regeneration.

7. If %GROUPCUT is <10 percent of the plots. (NOTE: not patchy, but may have high MOD)

A. Average MOD basal area over 30 percent of total:

Recommendation—standard shelterwood (especially on a good site) or single-tree selection (good site). Consider commercial thinning options: from above, crop-tree, and free. (NOTE: not patchy, but high MOD)

B. Average MOD basal area 10 to 30 percent of total:

Recommendation—light single-tree selection (good site) with a few small groups, or commercial thinning are the best options, especially as MOD basal area approaches 30 percent.

C. Average MOD basal area less than 10 percent of total:

Recommendation—defer cutting unless overstocked (roughly half way between A and B lines on the stocking charts [Fig. 2]). If overstocked, consider commercial thinning, especially the crop-tree approach.

Examples

Example 1. The forester takes 30 plots. Ten plots (30 percent) occur in patches (about ¼ to 1-acre in size) where more than 50 percent of the basal area is estimated as mature, overmature, or defective (MOD). Regeneration is undesirable, mostly beech saplings. The recommendation (6B) is group/patch selection removing/destroying as much understory as possible.

Example 2. In a sample of 30 plots only two (7 percent) occur in patches (about ¼ to 1-acre in size) where more than 50 percent of the basal area is MOD. But average stand basal area is about 25 percent MOD. The recommendation (7B) is light single-tree selection with some groups/patches or commercial thinning. If the regeneration is undesirable, there will be opportunities for more drastic regeneration harvests as the stand matures.

Prescription Details

Note: the guide above may lead to a nearly borderline choice. If so, check and evaluate both options.

5A. This stand has a high proportion of mature, overmature, and defective in numerous patches with desirable regeneration such as sugar maple and ash. Overstory removal is appropriate in one or more entries using harvesting guidelines/equipment to protect the regeneration. An irregular (variable density), low-density shelterwood is another option, or a low-density deferred shelterwood retaining a basal area of 20 to 40 ft^2/acre in thrifty, small sawtimber or large poles.

5B. Same as 5A with undesirable or missing regeneration. Clearcutting with sufficient ground disturbance is the best choice, coupled with reserve patches containing seed sources and habitat features. An irregular low-density shelterwood, or deferred low-density shelterwood, with sufficient ground disturbance, is another option.

6A. This stand has numerous patches of MOD (10 to 50 percent) and is suitable for group/patch selection with group release. With desirable advance regeneration, the harvest layout/equipment/season should protect the regeneration as much as feasible. For regular returns at 10 to 20-year intervals, the area in groups/patches should be a no more than 10 to 20 percent of the stand, targeting the most defective/overmature patches. Consider commercial thinning or stand improvement between groups, or marking MOD trees along the skid trails.

6B. Same as 6A except with undesirable regeneration. Harvesting should be conducted to provide sufficient ground/understory disturbance in the group/patches. Again, consider marking between groups or along skid trails.

7A. This stand has few patches of MOD (less than 10 percent), but a high proportion of scattered MOD (over 30 percent). Consider a standard shelterwood on good sites. Single-tree selection (good sites) with a few groups/patches is another option. Over time, additional patches of MOD can develop through windthrow, insects or disease. Commercial thinning is a good option: use thinning from above if the MOD is short-lived (e.g., paper birch or aspen); if not, use a combination of crop-tree and free thinning to improve stand growth and quality.

7B. This stand has few patches of MOD (less than 10 percent), and a moderate proportion of MOD basal area (10 to 30 percent). Good options are light single-tree selection (good sites) with some group/patches. As mentioned under 7A, new patches of MOD often will develop before the next entry. Commercial thinning is another option using a combination of thinning from above (short-lived species) and crop-tree release.

7C. This stand has few patches of MOD timber (less than 10 percent), and a low proportion of MOD basal area (less than 10 percent). Defer harvesting. Or if the basal area/acre is more than half way between the A and B lines on the stocking charts (Fig. 2), consider a commercial thinning, although the operation may be marginal. Crop-tree release is a likely approach. Locate at least 50 crop trees/acre and release on at least two sides.

ALTERNATIVE SILVICULTURAL SYSTEMS

There are several alternative approaches to traditional silvicultural practice or specific methods that do not fit neatly into even- or uneven-age management. Foresters may wish to examine these systems which are described below with literature citations.

Rehabilitation Silviculture

This approach is applied to large areas with heterogeneous stand conditions (microstands) too small to be recognized as separate stands. These may be areas that experienced previous high-grading, storm damage, or insect/disease problems, and where harvesting may be commercially marginal. The overall strategy is to remove mature or unacceptable growing stock, release acceptable growing stock or regeneration, and create/release regeneration where AGS is absent, generally using the methods previously described in this guide. The difference is that each acre, or group of acres, presents a different challenge. Over time, these areas can be transitioned to individual even-aged or uneven-aged stands, as appropriate (Fig. 8) (see Kenefic et al., no date; Nyland 2011).

A microstand could consist of (1) mature or UGS overstory; (2) immature AGS overstory; (3 and 4) partial overstory with either acceptable or unacceptable understory; or (5 and 6) regeneration patches with either acceptable or noncommercial regrowth. A separate field-determined prescription is applied as a collaborative effort between the forester and logging contractor. Each microstand is treated with the goal of improving species composition, quality potential, and productivity in either overstory or understory strata as available. As a result, each 'microtype' is being treated in accordance with normal silvicultural techniques, and this solves the problem of mapping tiny stands from heterogeneous types. This differs from deferred shelterwood, in that more than two age classes normally make up the residual stand. It departs from uneven-age management in that no attempt is made at balancing age class distribution, or meeting area regulation or residual stocking goals.

This approach is generally used to prepare low-value stands for improved productivity. As such, it may have little income, or costs exceeding income. Markets for fiber or chips are essential unless this is done with herbicides or by girdling or felling cull trees. Identifying and reserving quality immature AGS (trees of acceptable species, with reasonable vigor and quality for continued growth) will be part of appropriate treatments for each 'microtype'. This will vary with ownership goals, site quality, markets, and other factors.

Rehabilitation silviculture strives to balance economic and ecological considerations, and employs a diversity of silvicultural practices, both even- and uneven-age. This may include intensive management techniques such as planting and early spacing operations, or herbicide treatment of competing vegetation. It maintains structural diversity, with variable patches of overstory retention, and a large component of seedling/sapling regeneration. As such, it is an excellent technique for dealing with high levels of deer or moose browse, and also provides benefits to wildlife requiring early-successional forest with a multistoried canopy element.

Ecological Forestry

This landscape approach follows natural processes as much as possible and generally encompasses a range of silvicultural methods. It involves long-term planning, and while implemented at the stand level, it is concerned with maintaining a balanced landscape. It is science-based and follows place-based, site-specific experience. Social concerns are as important as economic ones (Seymour and Hunter 1999). Early references (Twight and Minckler 1972) equate this approach to stand-level natural disturbance silviculture.

Natural Disturbance Silviculture

Natural disturbance silviculture consists of modeling silvicultural practices to closely follow natural disturbance regimes. In northern hardwoods, the silvicultural practices will be light – resembling individual-tree and group-selection approaches, using long, biological rotations. In softwood and mixed-wood stands, which generally experience heavier natural disturbances, the silvicultural methods may incorporate heavier harvests. The emphasis is on maintaining biodiversity in species and structural complexity (Palik et al. 2002).

SPECIAL OPTIONS

There are a number of special problems or opportunities that could be of concern. Various landowner groups will consider and weigh each of these differently. Each of these is more or less independent of silvicultural systems, and as such is treated in this separate heading. Some of these are connected to particular treatments or systems. Foresters should be aware of these concerns and be ready to provide advice or references to specialists in the field. General considerations are expressed for each of these concerns or opportunities with references where available. Advice and references on most of these subjects are in Bennett (2010).

Reserve Areas, Special Habitat Features, and Associated Buffers

No-cut decisions for special areas are a separate issue from the silvicultural approaches discussed above. It is a decision to remove portions of stands or properties from the standard silvicultural options to meet specific conservation goals. Small reserve areas can be included as part of the silvicultural system utilized. For larger areas, they should be essentially treated as separate stands or handled by careful application of natural-disturbance principles.

Wildlife Concerns

Forest management can have beneficial or negative effects on wildlife, as each species has requirements and preferences; and habitat management for some species may conflict with habitat management concerns for other species. A thorough understanding of target species requirements, along with the home range and local conditions is needed, as well as the surrounding habitat conditions. In general, diverse forest habitats (species, age classes, structure and silvicultural practices), in combination with openings and agriculture, will provide for the greatest number of species (see Tables 3 and 4). Specific considerations will include retaining nest or den trees, hard and soft mast sources, wetlands, and vernal pools (DeGraaf et al. 2006).

Rare/Endangered Species

Rare and endangered plants or animals are a special consideration for the logging process. Most states have a Natural Heritage database of known locations or rare communities that should be protected and a specific review process. These are often unusual habitats such as ledge outcrops, wetlands, ridgetops, or other areas with unique growth features that can be identified and avoided, or managed to enhance the habitat.

Deer/Moose Browsing

Ungulate damage to regeneration can be a severe problem in each silvicultural system. One strategy is to provide an abundance of regeneration to supply deer or moose and still have enough for successful regeneration, attempting to meet both wildlife and silvicultural needs. There are examples of both failure and success with this strategy. Failures are more common with smaller regeneration units in high or moderate deer/moose populations, and preferred browse species such as maples, ash, and hemlock. Herd regulation is outside the scope of this guide. Possible strategies include larger harvest areas, unlopped residual tops, brush barriers, or fencing. Fencing may not be cost effective, but has been used operationally in high-value Appalachian forests (Knopp 2007).

Invasive Plants

The presence of invasive plant species is a widespread problem in the Northeast and elsewhere. Usually found on rich soils, pasture regrowth forests, and near suburban landscapes, seeds are often moved by birds and mammals to interior forests. They are particularly problematic in shade-based regeneration systems, such as high density shelterwoods or small group/individual tree selection, although there is some evidence that invasives are less vigorous under dense shade from hemlock or beech (personal communication, T. Lee, University of New Hampshire). Prevention and early awareness are the best strategies, as the first invaders are easiest to control. Chemical control is often warranted for advanced populations, using a licensed, experienced applicator.

Invasive Insects and Disease

Exotic introduced pests have plagued northern hardwood forests for more than a century, and will continue to do so. Great efforts are currently underway to control the spread of Asian long-horned beetle (*Anoplophora glabripennis*), emerald ash borer (*Agrilus planipennis*), and hemlock wooly adelgid (*Adelges tsugae*). New pests are undoubtedly on their way. Silvicultural strategies to reduce the impacts of these will require understanding pest dynamics, along with silvics and silviculture to manipulate stand structure and species composition toward less susceptible conditions.

Chemical Application

For control of certain undesirable species such as understory beech, ferns, invasive plants or pests, chemical applications may be the best strategy. Some ownerships or certain certifications may preclude use of non-organic chemicals. This discussion is beyond the scope of this guide. Licensed applicators are required for most pesticides. Check state and federal requirements (Nelson and Wagner 2011, Nyland et al. 2006).

Insects/Diseases

Native insects and diseases are a natural part of the forest ecosystem, and most are in some sort of balance. Periodic outbreaks can sometimes be predicted. The forester can prepare for these by maintaining species and structural diversity, and harvesting high-risk trees during active operations. After an outbreak, salvage of mortality or dieback may be appropriate. This may alter the best laid forest plans.

Best Management Practices

Every state has its laws and rules regarding water quality and Best Management Practices (BMPs). Field foresters and logging professionals should be intimately acquainted with them in each state they work. Most of these boil down to common sense, keep the mud out of the flowing water. Logging in and around wetlands, vernal pools, and in buffer strips along water courses, steep slopes, and even seeps all have risk of impacting clean water, and are treated differently in each state.

Stream crossings are probably the greatest risk. Most state forestry departments have service foresters available to provide technical assistance in applying BMPs.

Quality Beech

Some stands contain a nucleus of clean-barked beech that are genetically resistant to the beech bark disease. These groves should be maintained and encouraged to regenerate through vegetative means (Houston 2001). Research on the Bartlett shows that proportions of resistant beech can be greatly increased over time by removal of the susceptible beech and reservation/ regeneration of the resistant individuals (Leak 2006a).

Carbon Management

Due to climatic uncertainty, some landowners may wish to engage in carbon management. There is some uncertainty about the best approach, but some guidelines are available (Nunery and Keeton 2011). Emerging markets for 'Carbon Credits' to offset carbon sources may influence future management decisions. It is the opinion of the authors that "good forest management is good carbon management" (Birdsey et al. 2006).

Cultural Features

The protection of historical cultural resources should be considered during access and harvesting, such as cellar holes/foundations, old roads, stone walls, boundary markers, etc. Various landowners will place different emphasis on these. Many formerly agricultural lands contain many of these features, and some disturbance may be unavoidable.

Planting

Occasionally, planting may be undertaken to add a less common or exotic species to a stand. Commonly, these might include oaks, butternut (*Juglans cinerea*), black walnut (*J. nigra*), chestnut (*Castanea dentata*), or softwoods. Especially for hardwoods, protection from deer, moose, and hare is usually required using fencing or tree protectors.

LITERATURE CITED

Alexander, L. 1980. **The influence of gray squirrels and red oaks in establishing eastern white pine.** Durham, NH: University of New Hampshire. 90 p. M.S. thesis.

Bennett, K.P., ed. 2010. **Good forestry in the Granite State: recommended voluntary forest management practices for New Hampshire. 2nd edition.** Durham, NH: University of New Hampshire Cooperative Extension. 224 p.

Birdsey, R.; Pregitzer, K.; Lucier, A. 2006. **Forest carbon management in the United States.** Journal of Environmental Quality. 35: 1461-1469.

Calhoun, A.J.K.; deMaynadier, P. 2004. **Forestry habitat management guidelines for vernal pool wildlife.** MCA Tech. Pap. 6. Bronx, NY: Metropolitan Conservation Alliance, Wildlife Conservation Society. 32 p.

Chandler, C.C.; King, D.I.; Chandler, R.B. 2012. **Do mature forest birds prefer early-successional habitat during the post-fledging period?** Forest Ecology and Management. 264: 1-9.

Costello, C.A.; Yamasaki, M.; Pekins, P.J.; Leak, W.B.; Neefus, C.D. 2000. **Songbird response to group selection harvests and clearcuts in a New Hampshire northern hardwood forest.** Forest Ecology and Management. 127: 41-54.

Cunningham, F.E.; Filip, S.M.; Ferree, M.J. 1947. **Relation of tree-stump diameter to diameter breast height.** Station Note 1. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 3 p.

Darley-Hill, S.; Johnson, W.C. 1981. **Acorn dispersal by the blue jay (*Cyanocitta cristata*).** Oecologia. 50: 231-232.

DeGraaf, R.M. 1991. **Breeding bird assemblages in managed northern hardwood forests in New**

England. In: Rodiek, J.E.; Bolen, E.G., eds. Wildlife and habitats in managed landscapes. Washington, DC: Island Press: 154-171.

DeGraaf, R.M.; Hestbeck, J.B.; Yamasaki, M. 1998. **Associations between breeding bird abundance and stand structure in the White Mountains, New Hampshire and Maine, USA.** Forest Ecology and Management. 103: 217-233.

DeGraaf, R.M.; Shigo, A.L. 1985. **Managing cavity trees for wildlife in the Northeast.** Gen. Tech. Rep. NE-101. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 21 p.

DeGraaf, R.M.; Yamasaki, M. 2002. **Effects of edge contrast on redback salamander distribution in even-aged northern hardwoods.** Forest Science. 48: 351-364.

DeGraaf, R.M.; Yamasaki, M. 2003. **Options for managing early-successional forest and shrubland bird habitats in the northeastern United States.** Forest Ecology and Management. 185: 179-191.

DeGraaf, R.M.; Yamasaki, M.; Leak, W.B.; Lester, A.M. 2005. **Landowner's guide to wildlife habitat: forest management for the New England region.** Lebanon, NH: University Press of New England. 128 p.

DeGraaf, R.M.; Yamasaki, M.; Leak, W.B.; Lester, A.M. 2006. **Technical guide to forest wildlife habitat management in New England.** Burlington, VT: University of Vermont Press. 305 p.

Freidenfelds, N.A.; Purrenhage, J.L.; Babbitt, K.J. 2011. **The effects of clearcuts and forest buffer size on post-breeding emigration of adult wood frogs (*Lithobates sylvaticus*).** Forest Ecology and Management. 261: 2115-2122.

Gevorkiantz, S.R. 1951. **Distribution of volume in Lake States trees.** Tech. Notes 347. St. Paul, MN: U.S. Department of Agriculture, Lake States Forest Experiment Station. 1 p.

Gevorkiantz, S.R.; Olsen, L.P. 1955. **Composite volume tables for timber and their application in the Lake States.** Tech. Bull. 1104. Washington, DC: U.S. Department of Agriculture. 51 p.

Gilbart, M. 2012. **Under cover: wildlife of shrublands and young forest.** Cabot, VT: Wildlife Management Institute. 87 p. Available at http://www.youngforest.org/sites/default/files/Under_Cover-010412_FINAL.pdf (Accessed September 26, 2013).

Hermann, H.L.; Babbitt, K.J.; Baber, M.J.; Congalton, R.G. 2005. **Effects of landscape characteristics on amphibian distribution in a forest-dominated landscape.** Biological Conservation. 123: 139-149.

Hocking, D.J.; Babbitt, K.J.; Yamasaki, M. 2013. **Comparison of silvicultural and natural disturbance effects on terrestrial salamanders in northern hardwood forests.** Biological Conservation. 167: 194-202.

Holmes, R.T.; Robinson, S.K. 1981. **Tree species preferences of foraging insectivorous birds in a northern hardwoods forest.** Oecologia. 48: 31-35.

Holmes, R.T.; Robinson, S.K. 1988. **Spatial patterns, foraging tactics, and diets of ground-foraging birds in a northern hardwoods forest.** Wilson Bulletin. 100: 377-394.

Houston, D.R. 2001. **Effect of harvesting regime on beech root sprouts and seedlings in a north-central Maine forest long affected by beech bark disease.** Res. Pap. NE-717. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Research Station. 20 p.

Jensen, V.S. 1940. **Results of thinning and its effect on residual yellow birch and associated hardwoods species.** Tech. Note 35. New Haven, CT: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 4 p.

Kenefic, L.; Wilson, J.; Brissette, J.; Nyland, R.; Lilieholm, R. (n.d.). **Silvicultural rehabilitation of**

cutover mixedwood stands. Available at http://www.umoncton.ca/umce-foresterie/files/umce-foresterie/wf/wf/pdf/EKENEFIC.pdf (Accessed September 26, 2013).

King, D.I.; Chandler, R.B.; Schlossberg, S.; Chandler, C.C. 2009. **Habitat use and nest success of scrub-shrub birds in wildlife and silvicultural openings in western Massachusetts, USA.** Forest Ecology and Management. 257: 421-426.

King, D.I.; DeGraaf, R.M. 2000. **Bird species diversity and nesting success in mature, clearcut and shelterwood forest in northern New Hampshire, USA.** Forest Ecology and Management. 129:227-235.

King, D.I.; Yamasaki, M.; DeGraaf, R.M.; Costello, C.A. 2011. **Three decades of avian research on the Bartlett Experimental Forest, New Hampshire, USA.** In: Long-term avian research. Forest Ecology and Management (special issue). 262: 3-11.

Knopp, G. 2007. **Reducing deer browse damage.** Forestry Tech. Note 44 (OR 72). 15 p. St. Paul, MN: U.S. Department of Agriculture, National Resources Conservation Service. Available at http://efotg.sc.egov.usda.gov/references/public/NE/Nebraska_Forestry_Tech_Note_72(Reducing_Deer_Browse_Damage).pdf (Accessed September 26, 2013).

Lancaster, K.F.; Leak, W.B. 1978. **A silvicultural guide for white pine in the Northeast.** Gen. Tech. Rep. NE-41, Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 13 p.

Leak, W.B. 1979. **Effects of habitat on stand productivity in the White Mountains of New Hampshire.** Res. Pap. NE-452. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 8 p.

Leak, W.B. 1982. **Habitat mapping and interpretation in New England.** Res. Pap. NE-496. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 28 p.

Leak, W.B. 2002. **Origin of sigmoid diameter distributions.** Res. Pap. NE-718. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 10 p.

Leak, W.B. 2003. **Regeneration of patch harvests in even-aged northern hardwoods in New England.** Northern Journal of Applied Forestry. 20: 188-189.

Leak, W.B. 2005. **Effects of small patch cutting on sugar maple regeneration in New Hampshire northern hardwoods.** Northern Journal of Applied Forestry. 22: 68-70.

Leak, W.B. 2006a. **Fifty-year impacts of the beech bark disease in the Bartlett Experimental Forest, New Hampshire.** Northern Journal of Applied Forestry. 23: 141-143.

Leak, W.B. 2006b. **Sixty years of change in the sapling understories of northern hardwood selection stands in New Hampshire.** Northern Journal of Applied Forestry. 23: 301-303.

Leak, W.B. 2007a. **Accuracy of regeneration surveys in New England northern hardwoods.** Northern Journal of Applied Forestry. 24: 227-229.

Leak, W.B. 2007b. **Thinning northern hardwoods in New England by dominant-tree removal-early results.** Northern Journal of Applied Forestry. 24: 312-313.

Leak, W.B.; Gove, J.H. 2008. **Growth of northern hardwoods in New England: a 25-year update.** Northern Journal of Applied Forestry. 25: 103-105.

Leak, W.B.; Graber, R.E. 1993. **Six-year beechnut production in New Hampshire.** Res. Pap. NE-677. Radnor, PA: U.S. Department of Agriculture, Northeastern Forest Experiment Station. 6 p.

Leak, W.B.; Lamson, N.I. 1999. **Revised white pine stocking guide for managed stands.** NA-TP-01-99. [Radnor, PA:] U.S. Department of Agriculture, Northeastern Area State and Private Forestry. 2 p.

Leak, W.B.; Sendak, P.E. 2002. **Changes in species, grade, and structure over 48 years in a managed New England northern hardwood stand.** Northern Journal of Applied Forestry. 19: 25-27.

Leak, W.B.; Solomon, D.S.; DeBald, P.S. 1987. **Silvicultural guide for northern hardwood types in the Northeast (revised).** Res. Pap. NE-603. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 36 p.

Leak, W.B.; Wilson, R.W. 1958. **Regeneration after cutting of old-growth northern hardwoods in New Hampshire.** Station Pap. 103. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 8 p.

Leak, W.B.; Yamasaki, M. 2013. **Regeneration of upper-elevation red oak in the White Mountains of New Hampshire.** Research Note NRS-161. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 5 p.

Marquis, D.A. 1969.**Thinning in young northern hardwoods: 5-year results.** Res. Pap. NE-139. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 22p.

McKenny, H.C.; Keeton, W.S.; Donovan, T.M. 2006. **Effects of structural complexity enhancement on eastern red-backed salamander (*Plethodon cinereus*) populations in northern hardwood forests.** Forest Ecology and Management. 230: 186-196.

Nelson, A.S.; Wagner, R.G. 2011. **Improving the composition of beech-dominated northern hardwood understories in northern Maine.** Northern Journal of Applied Forestry. 28: 186-193.

Nunery, J.S.; Keeton, W.S. 2010. **Forest carbon storage in the northeastern United States: net effects of harvesting frequency, post-harvest retention, and wood products.** Forest Ecology and Management. 259: 1363-1375.

Nyland, R.D. 1996, 2002 (reissued 2007). **Silviculture concepts and applications. 2nd edition.** Long Grove, IL: Waveland Press. 682 p.

Nyland, R.D. 2011. **Characteristics of cutover stands, a challenge for rehabilitation [Presentation].** In: New England Society of American Foresters 91st winter meeting; 2011 March 30-April 1; Fairlee, VT.[Publisher unknown].

Nyland, R.D.; Bashant, A.L.; Bohn, K.K.; Verostek, J.M. 2006. **Interference to hardwood regeneration in Northeastern North America: controlling effects of American beech, striped maple, and hobblebush.** Northern Journal of Applied Forestry. 23: 122-132.

Palik, B.J.; Mitchell, R.J.; Hiers, J.K. 2002. **Modeling silviculture after natural disturbance to sustain biodiversity in the longleaf pine (*Pinus palustris*) ecosystem: balancing complexity and implementation.** Forest Ecology and Management. 155: 347-356.

Perkey, A.W.; Wilkins, B.L.; Smith, H.C. 1994. **Crop tree management in eastern hardwoods.** NA-TP-19-93. Morgantown, WV: U.S. Department of Agriculture, Forest Service, Northeastern Area State and Private Forestry, Forest Resources Management. 58 p. + appendices.

Robinson, S.K.; Holmes, R.T. 1982. **Foraging behavior of forest birds: the relationships among search tactics, diet, and habitat structure.** Ecology. 63: 1918-1931.

Robinson, S.K.; Holmes, R.T. 1984. **Effects of plant species and foliage structure on the foraging behavior of forest birds.** The Auk. 101: 672-684.

Ruffed Grouse Society. 2013. **Grouse facts.** Coraopolis, PA: Ruffed Grouse Society. Available at http://www.ruffedgrousesociety.org/grouse-facts (Accessed September 26, 2013).

Schlossberg, S.; King, D.I. 2007. **Ecology and management of scrub-shrub birds in New England: a comprehensive review.** Washington, DC: U.S.

Department of Agriculture, Natural Resources Conservation Service, Resource Inventory and Assessment Division. 120 p. Available at ftp://ftp-fc.sc.egov.usda.gov/NHQ/nri/ceap/schlossbergkingreport.pdf (Accessed September 26, 2013).

Schlossberg, S.; King, D.I. 2009. **Postlogging succession and habitat usage of shrubland birds.** Journal of Wildlife Management. 73: 226-231.

Seymour, R.S.; Hunter, M.L., Jr. 1999. **Principles of ecological forestry.** In: Hunter, M.L., Jr., ed. Managing biodiversity in forest ecosystems. New York, NY: Cambridge University Press: 22-61.

Solomon, D.S. 1977. **The influence of stand density and structure on growth of northern hardwoods in New England.** Res. Pap. NE-362. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 13 p.

Solomon, D.S.; Leak, W.B. 1986. **Simulated yields for managed northern hardwood stands.** Res. Pap. NE-578. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 24 p.

Smith, D.M.; Larson, B.C.; Kelty, M.J.; Ashton, P.M.S. 1997. **The practice of silviculture. 9th ed.** New York, NY: John Wiley and Sons. 560 p.

Tubbs, C.H.; DeGraaf, R.M.; Yamasaki, M.; Healy, W.M. 1987. **Guide to wildlife tree management in New England northern hardwoods.** Gen. Tech. Rep. NE-118. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 30 p.

Twight, P.A.; Minckler, L.S. 1972. **Ecological forestry for the northern hardwood forest.** Washington, DC: National Parks and Conservation Association. 12 p.

U.S. Forest Service. 2008. **Timber management field book.** NA-MR-02-08. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area, State and Private Forestry. [not paged].

Vander Wall, S.B. 2001. **The evolutionary ecology of nut dispersal.** The Botanical Review. 67: 74-117.

Veysey, J.S.; Babbitt, K.J.; Cooper, A. 2009. **An experimental assessment of buffer width: Implications for salamander migrator behavior.** Biological Conservation. 142: 2227-2239.

Wenger, K.F., ed. 1984. **Forestry handbook. 2nd edition.** Society of American Foresters Publ. No. 84-01. New York, NY: John Wiley and Sons, Inc. 1335 p.

Wildlife Management Institute. 2012a. **The woodcock management plan.** [Place of publication unknown]: Wildlife Management Institute. Available at http://www.timberdoodle.org/northernForestInitiative (Accessed September 26, 2013).

Wildlife Management Institute. 2012b. **The young forest project—growing wildlife habitat together.** [Place of publication unknown]: Wildlife Management Institute. Available at http://www.youngforest.org/content/think-5-5-5 (Accessed September 26, 2013).

Yamasaki, M. 2013. **Uneven-aged management and wildlife habitats—what do we know?** In: Bennett, K.P., tech. coord. Implementing uneven-aged management in New England. Is it practical? 2006 workshop proceedings. Durham, NH: University of New Hampshire Cooperative Extension Natural Resource Network: 10-13.

Yamasaki, M.; Costello, C.A.; Leak, W.B. In press. **Clearcutting, patch cutting, and low-density shelterwoods in northern hardwoods, New Hampshire: effects on breeding birds and regeneration.** Research Paper. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station.

Yamasaki, M.; Leak, W.B. 2006. **Snag longevity in managed northern hardwoods.** Northern Journal of Applied Forestry. 23: 215-217.

APPENDIX

Familiar tables and charts useful in field applications

Table A-1.—Plot radius factors (PRF): Multiply the PRF and tree d.b.h. to determine the maximum horizontal distance from prism-plot center to tree center (U.S. Forest Service 2008).

Table A-2.—Basal area by d.b.h. class, and number of stems/acre for each tree counted by several basal area factors (U.S. Forest Service 2008).

Table A-3.—Volume in board feet (International ¼-inch rule) by d.b.h. and number of 16-foot logs to an 8.0-inch top diameter inside bark (d.i.b.) (Gevorkiantz and Olsen 1955, Wenger 1984).

Table A-4.Percent of board-foot volume (International ¼-inch rule) in 8-foot bolts by tree log height. Bolts are numbered from bottom (#1) to top (#10) (Gevorkiantz 1951, Wenger 1984).

Table A-5.—Cubic-foot volume inside bark to a variable top diameter (> 4 in. d.i.b.) by d.b.h. and number of 8-foot bolts (U.S. Forest Service 2008).

Table A-6.—Saw log scale deduction for sweep in percent of gross scale for 16-foot logs and 8-foot logs (U.S. Forest Service 2008). Note C = cull.

Table A-7.—Relation of stump d.i.b. to d.b.h.: stump height 0.5 ft (stumps 5 to 10 inches diameter) and 1.0 ft (stumps > 11 inches diameter) (Cunningham et al. 1947, Wenger 1984).

Table A-8.—Weights for various species (U.S. Forest Service 2008).

Figure A-1.—Site index curves for species occurring in northern hardwoods: American beech, yellow birch, red maple, white ash, black cherry, red spruce, sugar maple, and white pine (U.S. Forest Service 2008).

Figure A-2.—Revised white pine stocking guide for managed stands (Leak and Lamson 1999).

Figure A-3.—Textural classification of soils (U.S. Forest Service 2008, Wenger 1984).

Table A-1.—Plot radius factors (PRF): Multiply the PRF and tree d.b.h. to determine the maximum horizontal distance from prism-plot center to tree center (U.S. Forest Service 2008)

Basal area factor	Plot radius factor
5	3.8891
10	2.750
20	1.9445
40	1.3750
80	0.972

Table A-2.—Basal area by d.b.h. class, and number of stems/acre for each tree counted by several basal area factors (U.S. Forest Service 2008)

D.b.h.	Basal area	Basal area factor				
Inches	ft^2	5	10	20	40	80
		stems/acre				
2	0.022	229.4	458.7	917.4	1834.9	3669.7
3	0.049	101.9	203.7	407.4	814.9	1629.7
4	0.087	57.3	114.6	229.2	458.4	916.7
5	0.136	36.7	73.3	146.7	293.4	586.7
6	0.196	25.5	50.9	101.9	203.7	407.4
7	0.267	18.7	37.4	74.8	149.7	299.3
8	0.349	14.3	28.6	57.3	114.6	229.2
9	0.442	11.3	22.6	45.3	90.5	181.1
10	0.545	9.2	18.3	36.7	73.3	146.7
11	0.660	7.6	15.2	30.3	60.6	121.2
12	0.785	6.4	12.7	25.5	50.9	101.9
13	0.922	5.4	10.8	21.7	43.4	86.8
14	1.069	4.7	9.4	18.7	37.4	74.8
16	1.396	3.6	7.2	14.3	28.6	57.3
18	1.767	2.8	5.7	11.3	22.6	45.3
20	2.181	2.3	4.6	9.2	18.3	36.7
22	2.640	1.9	3.8	7.6	15.2	30.3
24	3.142	1.6	3.2	6.4	12.7	25.5
26	3.690	1.4	2.7	5.4	10.8	21.7
28	4.280	1.2	2.3	4.7	9.4	18.7
30	4.910	1.0	2.0	4.1	8.1	16.3
32	5.590	0.9	1.8	3.6	7.2	14.3
34	6.300	0.8	1.6	3.2	6.3	12.7
36	7.070	0.7	1.4	2.8	5.7	11.3

Table A-3.—Volume in board feet (International ¼-inch rule) by d.b.h. and number of 16-foot logs to an 8.0-inch top diameter inside bark (d.i.b.) (Gevorkiantz and Olsen 1955, Wenger 1984)

D.b.h.	Number of 16-foot logs							
Inches	1/2	1	1 1/2	2	2 1/2	3	3 1/2	4
	board feet							
12	30	57	80	100				
13	36	68	96	118	134			
14	42	79	110	140	163	184		
15	50	92	128	160	188	214	232	
16	59	105	147	180	213	247	274	295
17	66	118	166	208	245	281	314	340
18	74	135	188	235	278	320	360	400
19	83	152	212	265	314	360	405	450
20	92	170	236	295	350	400	450	500
21	102	189	262	328	390	450	505	550
22	112	209	290	362	430	495	555	610
23	122	228	316	396	470	540	610	680
24	133	252	346	430	510	595	670	740
25	145	275	376	470	555	645	730	810
26	158	300	410	510	605	700	790	880
27	172	325	440	550	650	760	850	950
28	187	348	480	595	700	810	920	1020
29	203	378	515	640	760	870	990	1100
30	220	410	550	685	810	930	1060	1180
31	237	440	595	740	870	1000	1140	1260
32	254	470	635	790	930	1070	1210	1350
33	270	500	680	840	990	1140	1290	1440
34	291	530	725	900	1060	1210	1380	1530
35	311	565	770	950	1120	1290	1460	1630
36	333	600	820	1010	1190	1370	1550	1725

Table A-4.—Percent of board-foot volume (International ¼-inch rule) in 8-foot bolts by tree log height. Bolts are numbered from bottom (#1) to top (#10) (Gevorkiantz 1951, Wenger 1984)

	Tree log height (16-ft logs)						
Bolt no.	1	1 1/2	2	2 1/2	3	4	5
1	56	41	33	27	24	20	18
2	44	32	26	23	20	17	15
3		27	22	19	18	16	13
4			19	17	15	13	12
5				14	13	12	11
6					10	9	9
7						8	8
8						5	6
9							5
10							3

Table A-5.—Cubic-foot volume inside bark to a variable top diameter (> 4 in d.i.b.) by d.b.h. and number of 8-foot bolts (U.S. Forest Service 2008)

D.b.h.	No. of 8-ft bolts							
Inches	1	2	3	4	5	6	7	8
	ft^3							
6	1.3	2.2	3.2	--	--	--	--	--
8	2.4	3.9	5.4	6.9	8.4	--	--	--
10	3.9	6.5	8.8	10.5	12.6	14.9	--	--
12	5.5	9.6	13.0	15.6	17.8	20.5	23.7	--
14	7.5	13.2	18.0	21.6	24.6	27.9	31.6	37.1
16	9.6	17.4	23.7	29.0	33.2	37.1	41.9	46.6
18	12.2	22.3	30.2	37.1	43.4	47.4	51.3	57.7
20	15.3	27.9	37.9	46.6	53.7	60.0	64.0	70.3
22	19.0	34.8	47.4	57.7	66.4	73.5	79.0	84.5
24	22.8	41.1	56.9	69.5	79.0	88.5	95.6	101.1
26	26.9	49.0	66.4	82.2	94.0	105.1	113.8	119.3
28	30.7	56.9	76.6	94.8	109.0	122.4	131.9	139.0
30	34.0	63.2	86.9	108.2	125.6	134.3	152.5	161.2

Table A-6.—Saw log scale deduction for sweep in percent of gross scale for 16-foot logs and 8-foot logs (U.S. Forest Service 2008). Note C = cull.

Scaling diameter	Absolute sweep (in) for 16-foot logs							
Inches	3	4	5	6	7	8	9	10
	percent							
8	12	25	38	50	C	C	C	C
9	11	22	33	44	56	C	C	C
10	10	20	30	40	50	60	C	C
11	9	18	27	36	45	54	64	C
12	8	17	25	33	42	50	58	C
13	8	15	23	31	38	46	54	62
14	7	14	21	29	36	43	50	57
15	7	13	20	27	33	40	47	53
16	6	12	19	25	31	38	44	50
17	6	12	18	24	29	35	41	47
18	6	11	17	22	28	33	39	44
19	5	11	16	21	26	32	37	42
20	5	10	15	20	25	30	35	40
22	5	9	14	18	23	27	32	36

Scaling diameter	Absolute sweep (in) for 8-foot logs						
Inches	2	3	4	5	6	7	8
	percent						
8	12	25	38	50	C	C	C
9	11	22	33	44	56	C	C
10	10	20	30	40	50	60	C
11	9	18	27	36	45	54	64
12	8	17	25	33	42	50	58
13	8	15	23	31	38	46	54
14	7	14	21	29	36	43	50
15	7	13	20	27	33	40	47
16	6	12	19	25	31	38	44
17	6	12	18	24	29	35	41
18	6	11	17	22	28	33	39
19	5	11	16	21	26	32	37
20	5	10	15	20	25	30	35
22	5	9	14	18	23	27	32

Table A-7.—Relation of stump d.i.b. to d.b.h.: stump height 0.5 ft (stumps 5 to 10 in diameter) and 1.0 ft (stumps > 11 in diameter) (Cunningham et al. 1947; Wenger 1984)

Stump d.i.b. Inches	Beech	Red/sugar maple	Yellow/black birch	Aspen	Red oak	White ash	White pine
	d.b.h. (inches)						
5	4	4	4	5	4	4	4
6	5	5	5	6	5	5	5
7	6	6	5	7	6	6	6
8	6	7	6	8	6	7	7
9	7	8	7	9	7	8	8
10	8	8	8	10	8	9	9
11	10	10	9	11	10	10	10
12	11	11	10	12	10	11	11
13	11	12	11	13	11	12	12
14	12	13	12	14	12	13	12
15	13	14	13	15	13	14	13
16	14	14	13	16	14	15	14
17	15	15	14	--	14	16	15
18	15	16	15		15	17	16
19	16	17	16		16	17	17
20	17	18	17		17	18	18
21	18	19	17		18	19	--
22	19	20	18		18	20	
23	19	20	19		19	21	
24	20	21	20		20	22	
25	21	22	21		21	22	
26	21	23	--		21	23	
21	22	24			22	24	
28	23	--			23	--	
29	24	--			24		

Table A-8.—Weights for various species (U.S. Forest Service 2008)

Species	Green weight per cord	Green weight per mbf of lumber	Green weight per ft^3	Air dry weight per ft^3
	pounds			
Ash, white	4300	4000	48	41
Aspen	3900	3600	42	27
Basswood	3800	3500	41	26
Beech	4900	4500	55	44
Birch, yellow	5100	4800	58	43
Birch, white	4500	4200	50	39
Cherry, black	4000	3800	46	35
Elm	5000	4600	56	37
Hemlock	4500	4200	49	28
Hickory	5700	5300	64	51
Locust, black	5200	4800	58	49
Maple, hard	5300	4600	56	44
Maple, soft	4300	3900	50	38
Oak, red	5700	5200	63	44
Oak, white	5600	5200	62	48
Pine, red	3800	3500	42	33
Pine, white	3200	3000	36	25
Spruce	3000	2800	34	28

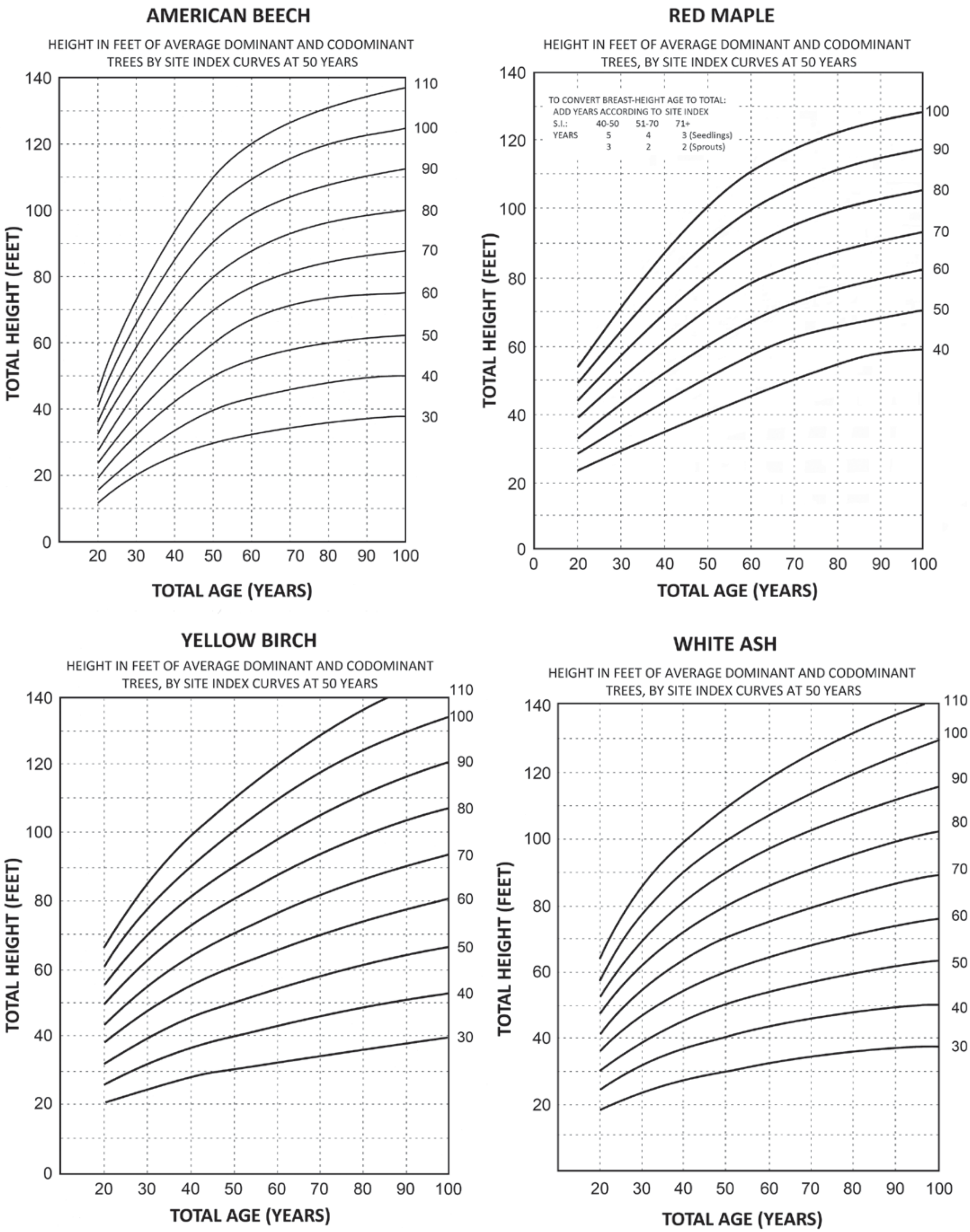
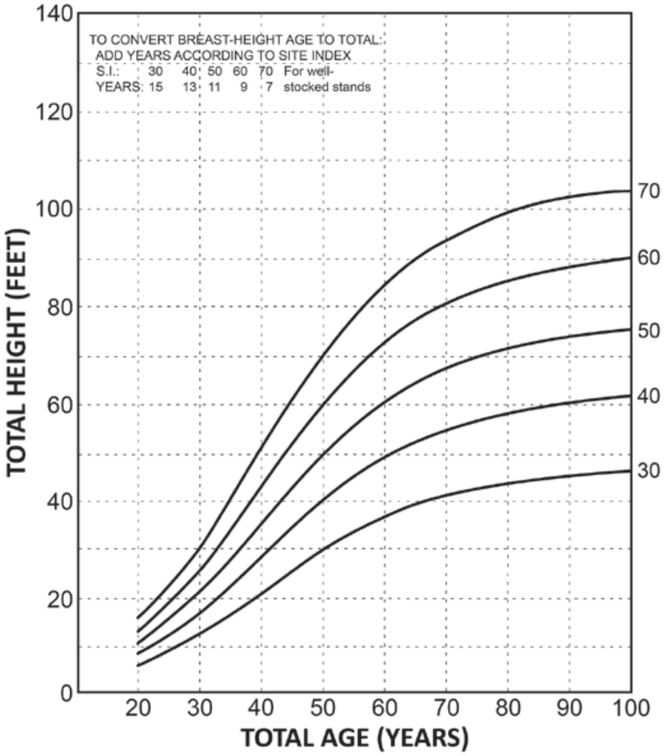


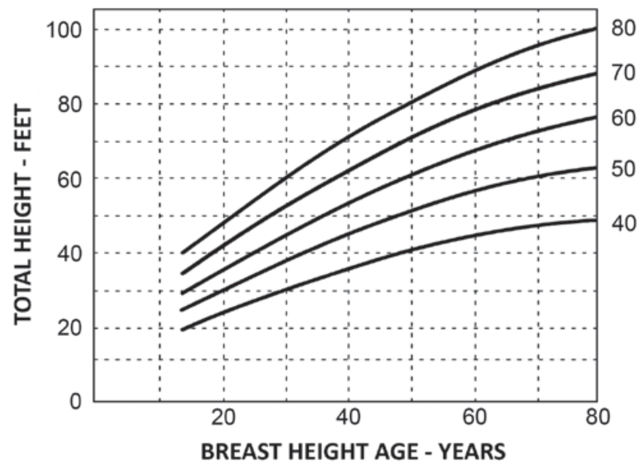
Figure A-1.—Site index curves for species occurring in northern hardwoods: American beech, yellow birch, red maple, white ash, black cherry, red spruce, sugar maple, and white pine (U.S. Forest Service 2008).

RED SPRUCE

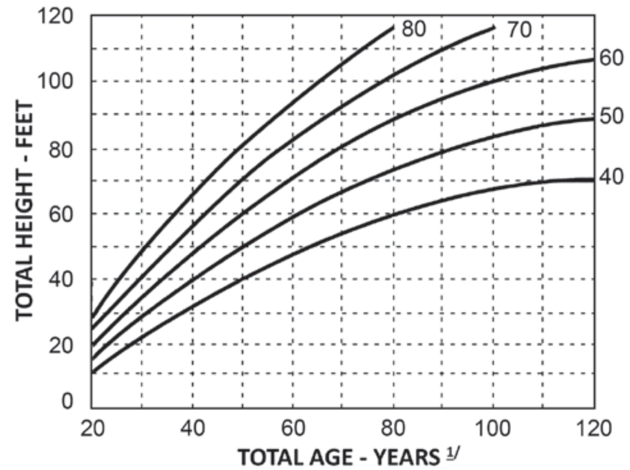
HEIGHT IN FEET OF AVERAGE DOMINANT AND CODOMINANT TREES IN EVEN-AGED STANDS BY SITE INDEX CURVES AT 50 YEARS IN NATURAL RANGE



SUGAR MAPLE



WHITE PINE



1/ Total age = breast height age + 10 years

BLACK CHERRY

HEIGHT IN FEET OF AVERAGE DOMINANT TREES, BY SITE INDEX CURVES AT 50 YEARS

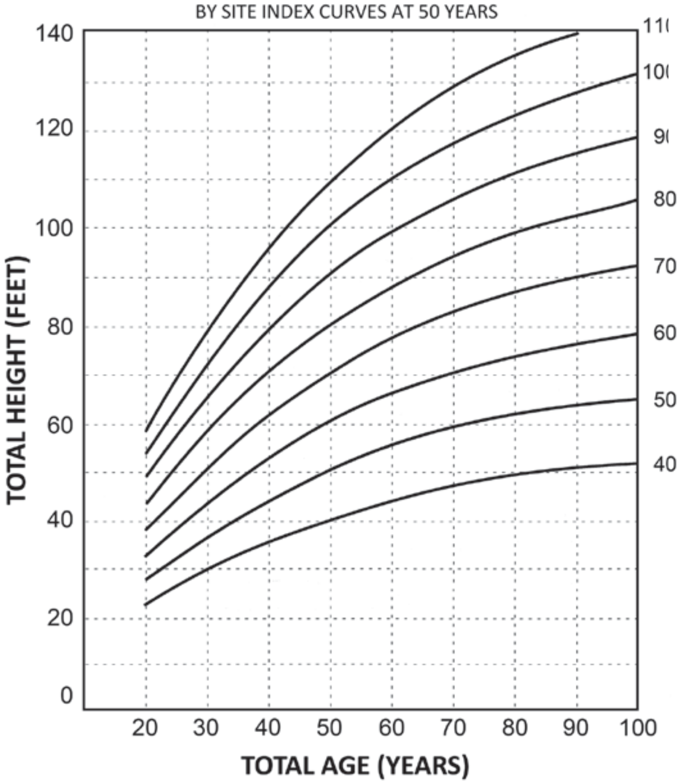


Figure A-1.—continued.

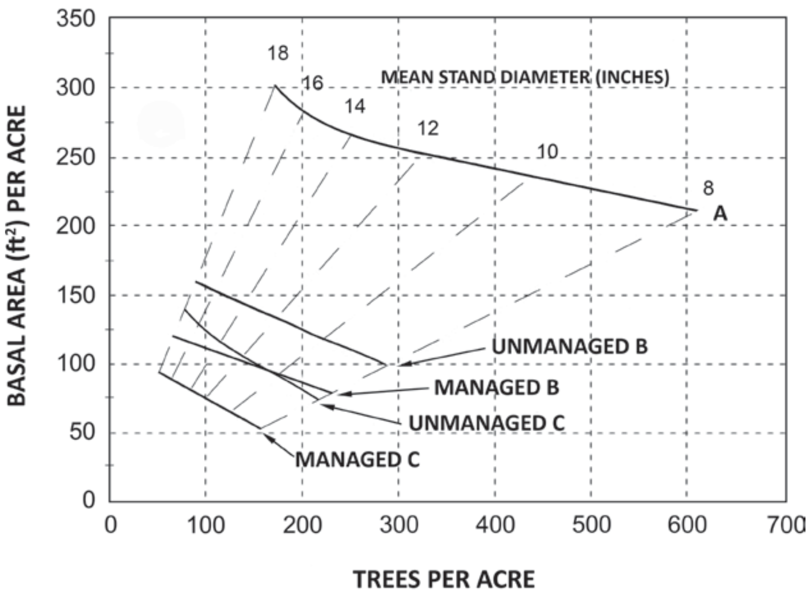


Figure A-2.—Revised white pine stocking guide for managed stands (Leak and Lamson 1999).

Textural Classification of Soils

Soil texture refers to the relative proportions of sand, silt, and clay particles that make up the soil mass. Fig. A-3 shows the percentage of these soil fractions in the basic textural grades. Use the arrows provided to facilitate reading the axes properly.

Three classifications—sandy loam, loam, and silt loam—are common surface soils; they also may occur as subsoils. The rest of the classifications are subsoils.

For example, a soil consisting of 10 percent clay, 20 percent silt, and 70 percent sand is sandy loam.

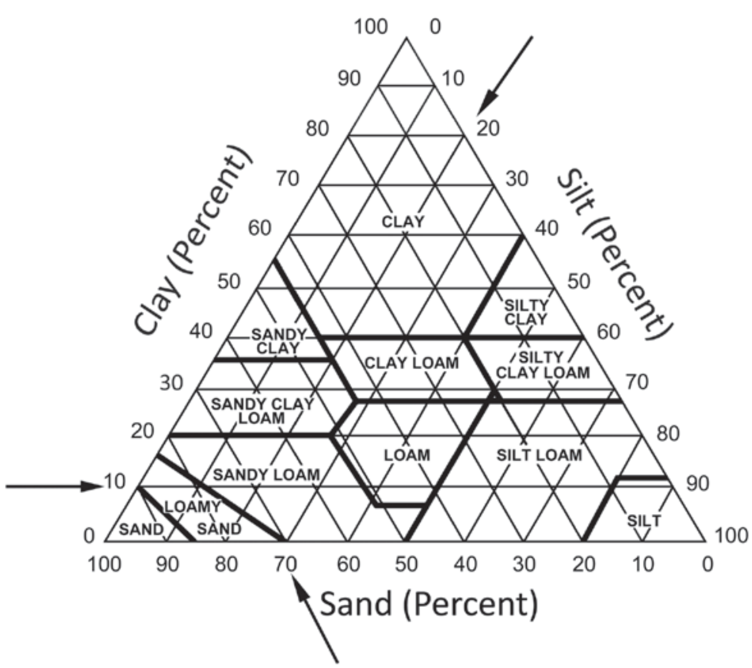


Figure A-3.—Textural classification of soils (U.S. Forest Service 2008, Wenger 1984).

Leak, William B.; Yamasaki, Mariko; Holleran, Robbo. 2014. **Silvicultural guide for northern hardwoods in the northeast.** Gen. Tech. Rep. NRS-132. Newtown Square, PA: U.S. Department of Agriculture, Forest Service, Northern Research Station. 46 p.

This revision of the 1987 silvicultural guide includes updated and expanded silvicultural information on northern hardwoods as well as additional information on wildlife habitat and the management of mixed-wood and northern hardwood-oak stands. The prescription methodology is simpler and more field-oriented. This guide also includes an appendix of familiar tables and charts useful to practicing field foresters. Northern hardwood forest types can be managed as even- or uneven-aged stands using a variety of silvicultural practices. In planning these practices, there are many factors to consider including access, species composition, desired regeneration, wildlife habitat needs and environmental concerns. The aim of this document is to provide guidelines to assist the manager in choosing the right methods to meet the landowner objectives consistent with stand conditions.

KEY WORDS: northern hardwoods, silviculture/wildlife prescriptions, even-age management, uneven-age management, forest management, beech-birch-maple

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