2

The Northeastern Region

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LOCATION

Forests of the six New England states and New York include the eastern extensions of the Northern Hardwood (beech–birch–maple) and Northern Coniferous (mainly spruce–fir–hemlock) forests. The oak-dominated Central Hardwood Forest also extends eastward throughout the southern part of the region, and much of the economically important eastern white pine resource also occurs here. Abundant, uniformly distributed precipitation and a glaciated landscape of generally fertile soils are highly favorable to forest growth. The unique combination of ecosystems, cultural history, ownership, and socioeconomic factors creates an extraordinary diversity of forest conditions that demand an equal variety of silvicultural systems (Fig. 2-1).

FOREST STATISTICS

Area

Forests dominate the northeastern landscape, covering nearly 51 million acres (72 percent of the total land area). Maine is the most heavily wooded state, with nearly 90 percent of its land in forest, followed by New Hampshire (87 percent), Vermont (77 percent), New York (61 percent), and the three southern New England states (60 percent). Recent forest surveys (Considine and Frieswyk, 1982; Powell and Dickson, 1984; Frieswyk and Malley, 1985a,b; Brooks et al., 1993) indicate that

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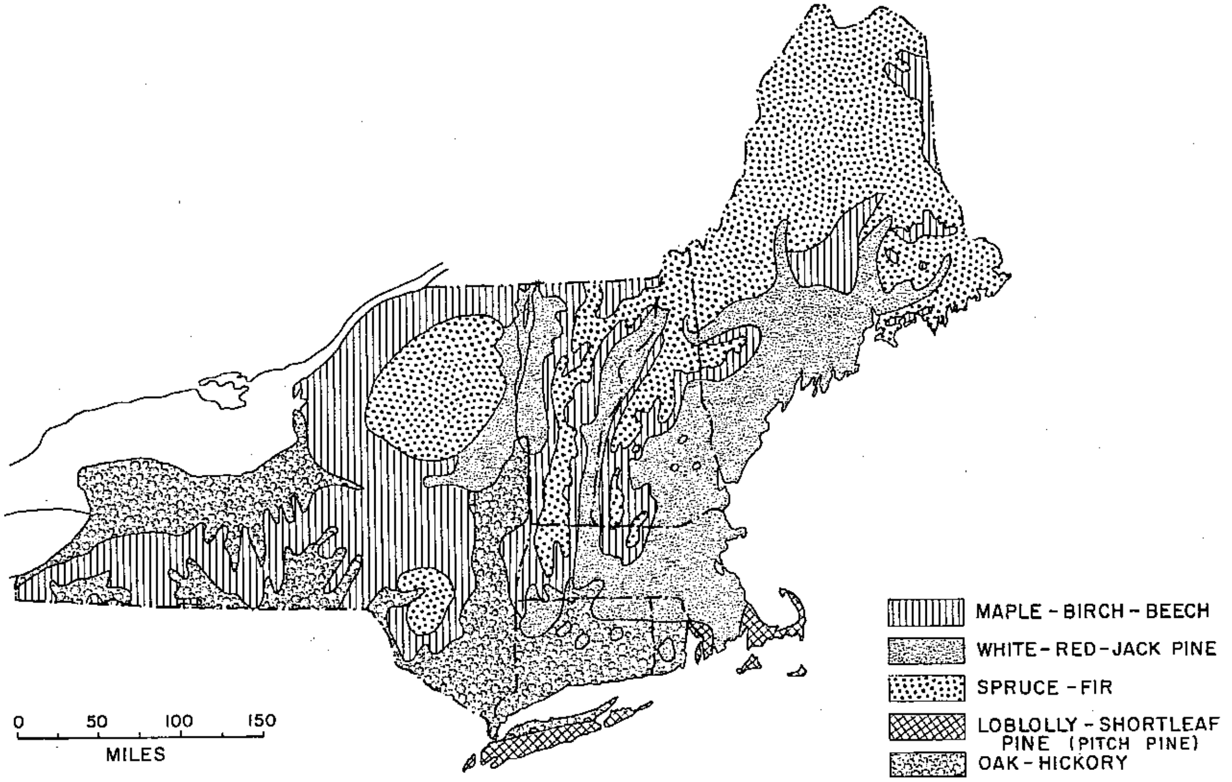

Figure 2-1. *A classification of forest type groups in the Northeast. (By permission from Deciduous Forests of Eastern North America, by E. Lucy Braun, copyright 1950, The Blakiston Co., Philadelphia.)*

the region gained 1.5 million acres of forest land (2 percent of all land) during the past decade, suggesting that cessation of agriculture has slightly outpaced losses to development.

Virtually all northeastern forests are classified as commercial timberland. Only limited areas of some wetland and high-elevation forests are considered commercially unproductive. About 8 percent of the forest—mainly a few large public parks in the Adirondacks and in Maine—is productive reserved land where silvicultural activities are legally restricted.

Character of Forestland Ownership

Northeastern forests are owned almost exclusively (93 percent) by private entities, ranging from the large industrial holdings of over a million acres in northern New England to small woodlots of a few acres associated with suburban residences. Industrial ownerships (mainly large pulp and paper companies with integrated sawmilling operations) are substantial, comprising 22 percent of the private timberland in the region. Maine, a relatively small state by national standards, has far more industrial timberland (over 8 million acres) than any other state, mostly situated in one large contiguous block in the sparsely inhabited northern counties. Most the remaining timberland is owned by individuals who do not depend on their properties for income. Farm ownerships, once a dominant feature of the landscape, continue to decline and now comprise less than 10 percent of the private timberland.

Tract size of nonindustrial ownerships is small and continues to decrease as properties are subdivided. For example, the average size in southern New England declined from 21.5 acres in 1972 to 10.3 acres in 1985. Timberland area in ownerships under 10 acres increased 62 percent during this period. Subdivision of ownerships has prompted a long-standing concern over timber availability, as larger tracts tend to be harvested more often (Alig et al., 1990). However, from 66 percent (southern New England and New York) to 91 percent (Maine) of the area occurs in parcels of over 50 acres, despite the fact that tracts under 50 acres account for about 80 percent of all private forest owners.

Recent landowner surveys indicate that 68 percent of forest landowners in New York and New England who own over 85 percent (New York and southern New England) to 97 percent (Maine and Vermont) of the area, are open to silvicultural activity (Brooks et al., 1993; Birch, 1983; Birch, 1986; Widmann and Birch, 1988). This is a reversal of historical attitudes; in the early 1970s, 70 percent of the owners (43 percent of the area) in southern New England (Kingsley, 1976) and 55 percent of the owners (12 percent of the area) in Vermont (Kingsley and Birch, 1977) never intended to harvest. Furthermore, only a small minority of nonharvesting owners are philosophically opposed to harvesting. More commonly, inadequate markets, low timber values, lack of technical assistance, or threats to visual quality or wildlife habitat are cited. Clearly, silvicultural opportunities are open to the vast majority of the privately owned forests of the Northeast.

Only 7 percent of the region's timberlands is publicly owned, mainly in two national forests and numerous state properties. Although small in total area, these public forests have been under multiple-use management for many decades and provide excellent examples of continuous, long-term silvicultural systems that are rare on many private ownerships. The limited area of public forests, along with fears of breakup of several large industrial ownerships, has focused national attention on long-term forest land stewardship and prompted a major federal study of over 25 million acres of the northern forest (Harper et al., 1990).

Forest Inventory

The growing stock inventory of the Northeast consists of about equal volumes of softwood and hardwood species. Red spruce and balsam fir, mostly in Maine and New Hampshire, dominate the softwood inventory, and substantial volumes of eastern white pine and eastern hemlock grow throughout the region (Table 2-1). Northern hardwoods, especially the maples, comprise the vast majority of hardwood volumes, although oaks are the most prominent hardwood in southern New England and in parts of New York and New Hampshire. Inventories rose substantially during the 1970s; overall, the growing stock increased by nearly 10 billion cubic feet. In general, the region's forests appear to be underutilized, with net periodic increments well above harvest levels. Maine is a distinct exception, however; the spruce–fir inventory was essentially stable during the 1970s, and is

TABLE 2-1. Net Volume of Growing Stock on Timberland in the Northeastern Region

Species	Growing Stock Volume, (million cubic feet)[a] ca. 1982	Percent Increase Since ca. 1970
	Softwoods	
Spruces and fir	12,786.2	–5
Pine	6,782.4	15
Hemlock	4,368.2	19
Others	2,297.2	24
Total softwoods	26,234.0	7
	Hardwoods	
Sugar maple	6,224.5	19
Yellow birch	2,504.8	21
Beech	2,505.7	18
Red maple	7,434.4	26
Oaks	5,302.0	17
Paper birch	2,420.1	30
Ashes	2,091.5	33
Aspens	2,516.4	43
Others	3,491.1	20
Total hardwoods	34,490.5	24
Total all species	60,724.5	16

[a] Trees 5.0 inches d.b.h. and larger.

predicted to decline dramatically as a result of mortality from the 1972–1984 spruce budworm outbreak and intense utilization of the spruce–fir resource (Seymour and Lemin, 1989).

The regional increase in timber volumes is largely a consequence of widespread maturation of forests throughout the region, not the result of silvicultural activity (Seymour et al., 1986; Seymour, 1988). Many stands that have reached sawtimber size in the past few decades originated because of a fortuitous coincidence, which occurred during an approximately 50-year period surrounding the turn of the century, of heavy cuttings, cessation of farming and fuelwood coppicing, insect and disease outbreaks, and the virtual extirpation of white-tailed deer.

PHYSICAL ENVIRONMENT

Physiography

The major portion of the region consists of upland plateaus ranging between 500 and 1500 feet in elevation. This peneplain matrix is frequently interrupted by mountain peaks and valley lowlands. The leveled, rolling surface is a northern extension of the Appalachian Highlands. The mountains are usually monadnocks, remnants of summit peneplains resulting from earlier cycles of uplift and erosion or the remains of volcanic intrusions. Most prominent of the mountain schemes are the Adirondacks of northern New York, the Green Mountains of Vermont and the Berkshires of western Massachusetts, and the White Mountains of New Hampshire. The White Mountains, containing the Presidential Range with Mount Washington, which is about 6290 feet above sea level, and four other peaks above 5300 feet, are the highest in the Northeast. Mount Katahdin in Maine reaches above 5300 feet. The timberline occurs at about 4000 feet throughout the region.

The lowlands include a number of areas below 500 feet in elevation. These include all or parts of the Seaboard Lowlands of New England, the Connecticut River Valley, the valleys of the Mohawk, Hudson, and St. Lawrence Rivers, and the Erie-Ontario Plains in New York. Settlement and industry throughout the Northeast have tended to locate in lowland areas because of greater accessibility and opportunities for farming where woodland ownership is highly fragmented.

Rivers of the Northeast offered the first means of moving logs from the forest to the mill, and certain of the more important rivers once were declared public waterways. One reason floatable softwoods were preferred by the early forest industries was the ease of water transportation. A multitude of lakes large and small embellish the northeastern countryside and contribute to the recreational attractiveness of the region.

Geology and Soils

Geologically this is a very old region. Some of the most ancient metamorphic rock formations in the world are found in New England and the Adirondacks. Throughout the ages, sediments have been buried, metamorphosed, and subsequently intruded with magmas before being thrust upward by convolutions in the earth's crust. Present-day elevation differences are mainly due to the resistance of bedrock to erosion.

The mountain sections and upland plateaus are formed principally of granitic igneous and metamorphic bedrock. This material, containing a high percentage of quartz, resists erosion and reduces to coarse-textured or moderately coarse-textured acid soils of relatively low fertility. In contrast, valley soils mainly derived from finer-textured, sometimes-calcareous parent material are moderately textured with greater fertility. In some places throughout the region limestone outcrops or shale and slate parent material results in finer-textured productive forest soils.

If soil genesis were in place, it would be easy to generalize about forest soils in the Northeast. Mountain and high-plateau soils would be relatively low in fertility, grading into more productive lowlands and valleys. This simple pattern has been modified greatly by glaciation. During the Pleistocene epoch, ice masses covered practically all of the region. Ice sheets several thousand feet thick probably covered even the tallest peaks. The typical results of glacial action, namely, U-shaped valleys, smooth-sided mountains, scooped-out and kettle lakes, peat bogs, and a heterogeneous mantle of glacial deposits, are evident.

The manner in which transported glacial drift was deposited has in large measure determined present site quality. Unsorted drift or till, composed of heterogeneous materials ranging in size from large glacial erratics to clay, generally produce the best sites. They are usually found on mid-slopes of hills and higher mountains and on tops of lower mountains. At the other end of the scale, the coarser water-transported, sorted, and often stratified drift found in kames, eskers, outwash plains, and glacial lakeshores and bottoms are usually the poorest sites.

A compact stratum or fragipan located from a few inches to several feet below the surface is characteristic of many till soils in this region. Where the hardpan is close to the surface site, productivity decreases. Disrupted drainage patterns, scouring-out of glacial basins, kettles, and the blocking of waterways with glacial material have created numerous ponds and lakes. Swamps and bogs have frequently developed in the shallow depressions.

Soils of this region are classified as podzols, or brown or gray-brown podzolic, of the orders Spodosols and Alfisols, respectively. The true acid podzols are usually found in the higher elevations associated with coarse textures, abundant precipitation, cool climate, and conifer cover. Where these conditions occur, mor may accumulate to a depth of several inches and the leached E horizon is well defined. Even under hardwood cover, if the other conditions hold, there is a tendency for an appreciable E horizon to develop. The brown or gray-brown podzolic soils are generally related to the features of fine-textured soils, warmer temperatures, and hardwood cover found at lower elevations and in the southern part of the region. Mull humus can be expected with these conditions, although mor may occur on the drier sites. In mountainous country, mull will rarely be found except in the most favorable spots.

Climate and Weather

The Northeast is a cool humid region. The prevailing west-to-east air-mass movement results in a typically continental climate. Differences in climate within the region are occasioned by the north-to-south span and wide ranges in elevation. Precipitation is abundant and evenly distributed over the year. Average annual precipitation ranges from about 32 to over 52 inches, with most of the area having 40 inches or more. Soil moisture deficiencies seldom occur. Mean annual snowfall for southern New England is about 32 inches, whereas the northern mountains can have four times this amount (Lull, 1968).

The number of frost-free days varies from as few as 90 on the mountains to twice that number in the southern part of the region. Also, the severity of winter increases dramatically from south to north. Northern stations have recorded more than 60 days of subzero readings, while such temperatures occur only rarely in localities near the southern coast (USDA, 1941).

The fire season occurs in two rather brief periods. In the spring, high fire danger is usually experienced just before the flush of foliage. Forest fuels are in a cured condition, there are brief periods without rain, daytime temperatures rise into the 80s or 90s, relative humidity is low, and winds are frequently brisk. Greening of the vegetation brings an end to this period. The fall season generally follows killing frosts.

MAJOR FOREST TYPE GROUPS

About 40 different cover types (Eyre, 1980) occur in the Northeast. For silvicultural purposes, this array can be grouped into four type groups that cover 89 percent of the region: spruce–fir, northern hardwood, white pine–hemlock–hardwood, and oak. These type groups occur in predictable geographic and attitudinal patterns related primarily to the glacial history reviewed above, along with latitudinal gradients in climate and growing season. Stand composition is far from homogeneous within any geographic area, however. Braun's classic map (Fig. 2-1) serves only as a very broad regional reference. Virtually all of the northeastern forest originated naturally; plantations (mainly Norway spruce, red pine, and exotic larches) are scattered throughout the Northeast but do not comprise a significant resource.

Northern Hardwoods Type Group

Northern hardwood forests composed of sugar maple, American beech, and yellow birch are the most extensive type, covering 43 percent of the region (Seymour, 1988). Northern hardwoods dominate New York and Vermont and form an important association in Maine, New Hampshire, and western Massachusetts. Leak et al. (1987) distinguished three silviculturally important variants of the northern hardwood type from a more detailed system of 11 habitat types in central New Hampshire (Leak, 1982). First is the *beech–birch–maple* subtype, which contains at least 20 percent sugar maple as the characteristic species. This type occupies well drained, fine-textured tills, the most productive soils in the region. On fertile soils derived from limestone or enriched by downslope movement of organic matter, sugar maple often forms nearly pure stands. As fertility declines, beech becomes important, often comprising 50 percent or more of the basal area. Yellow or paper birch is also present, but red maple and conifers are uncommon or absent from this subtype. Basswood, a very common associate of the northern hardwood type in the Lake States, is only a minor constituent in the Northeast (Seymour, 1988).

On sites that are somewhat shallower and wetter or drier than the beech–birch–maple subtype, sugar maple is less competitive and is replaced by the *beech–red maple* subtype. On wet, compact tills and sediments, red maple is most abundant, whereas beech tends to dominate drier, coarse tills. The birches are also important components and are the most valuable species here. A third subtype consists of *mixed-wood* stands, where conifers (red spruce, hemlock, or balsam fir) occur in mixture with hardwoods of any species. Mixed-wood stands occur on similar soils to the beech–red maple subtype, and in some cases appear to be more a result of disturbance than site conditions. Their origins include repeated heavy partial cutting of spruce–fir or hemlock stands, allowing significant invasion of hardwoods; an early seral stage on some abandoned fields where conifers did not fully occupy the growing space; or spatially diverse sites where good and poor soils form a fine-scale mosaic. Mixed-wood stands dominated by conifers should be considered as variants of the spruce–fir type discussed in the following section.

There are two other silviculturally important variants of the northern hardwoods type, both the result of heavy disturbances. The *cherry–maple* type, which dominates the Allegheny Plateau in Pennsylvania, also extends northward into southern New York. This unique and very valuable forest originated after repeated logging of the old-growth beech–maple stands, first for sawlogs, then for small-diameter hardwoods used in wood distillation plants. This history of treatment occurred when the white-tailed deer had been virtually extirpated, which fortuitously created ideal conditions for the regeneration of extensive black cherry forests (Marquis, 1975). Natural succession normally returns this type to a high proportion of tolerant hardwoods and hemlock, except where heavy deer browsing eliminates advance growth.

The early successional *aspen–paper birch* type, the most common forest in the Lakes States, also occurs throughout the Northeast wherever intense disturbances such wildfire or repeated heavy cutting have eliminated late-successional species. This type can occur over a wide variety of sites, from former spruce flats to rich tills formerly occupied by beech–maple stands. Paper birch can be a very valuable species where local industries have developed specialty markets for small wood products made from its white, even-textured wood. Aspen is not as valuable as paper birch but is widely used for pulpwood and waferboard and is also quite important to such wildlife species as ruffed grouse.

Spruce–Fir Type Group

The spruce–fir type covers 21 percent of the Northeast; it dominates the highest elevations and those northern interior portions of the region that are characterized by cold temperatures and relatively coarse, somewhat poorly drained, acid soils. Although spruce–fir forests were once regarded as having been stable features of the northeastern landscape since deglaciation (Westveld, 1953a), recent analysis of pollen records suggests that today's red spruce–fir forest emerged only about 1000 years ago, corresponding to a decline in hemlock and beech abundance (Jacobson et al., 1987).

Red spruce, the characteristic species of this type, is ubiquitous on soils developed from glacial till, although stand composition varies greatly with soil drainage and topography (Fig. 2-2). Westveld (1953a) distinguished several variants of the spruce–fir forest based on relationships of vegetation with soils and landforms along with observed successional patterns. *Dominant softwood sites* are those where a combination of poor soil drainage, low nutrient availability, and topographic position tends to exclude the more demanding northern hardwood species such as sugar maple. These can be further subdivided into four subtypes. *Spruce swamps* support nearly pure stands of black spruce in mixture with tamarack and northern white-cedar on organic or very poorly drained mineral soils. *Spruce flats* occur on shallow glacial tills with impeded drainage at low elevations; red spruce and balsam fir, in various mixtures, dominate these sites with minor components of paper birch and red maple. *Spruce slopes* occur on mountainsides above an elevation of about 2500 feet on shallow, very rocky soils. Balsam fir and paper birch represented a minor component of the spruce slope type prior to human disturbance. A fourth subtype dominated by red spruce occurs along the Maine coast as a result of maritime influences (Davis, 1966).

Secondary softwood sites occur on mid-slopes supporting well-drained soils. Deeper rooting zones and improved nutrient status allow various hardwood species to form an important stand component. Yellow birch, red maple, beech, and sugar maple are the principal associates of red spruce and fir in mixed-wood stands. Pure spruce stands of old-field origin fall naturally into this type, since these agricultural soils originally had a strong hardwood component and revert to hardwoods after disturbance. Throughout the southern part of the red spruce forest, northern white-cedar, eastern hemlock, and eastern white pine often form important stand components. The boreal white and black spruces are uncommon associates of red spruce–dominated stands in Maine. White spruce often forms a minor component of spruce–fir stands, especially those dominated by fir. Black spruce is limited to poorly drained swamps, and is rarely found on upland sites. Red and black spruce hybridize extensively (Manley, 1972); spruce hybrids are most prevalent on poorly drained sites with a frequent history of disturbance (Osawa, 1989).

White Pine–Hemlock–Hardwoods Type Group

The white pine type group covers 14 percent of the region. It is most prominent in the Seaboard Lowlands, the Connecticut River Valley, and the eastern slopes of the

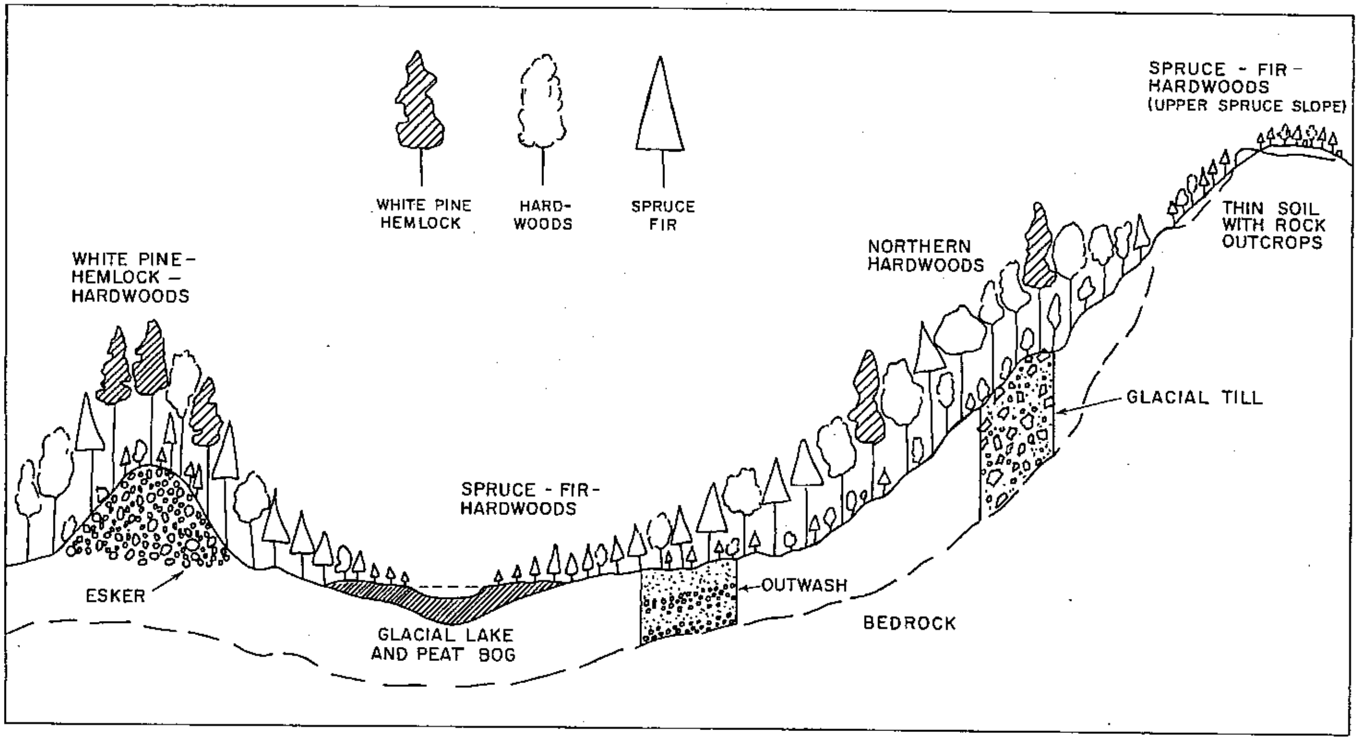

Figure 2-2. *A typical topographic transect in northern New England, with associated forest type groups.*

Adirondacks. Pine naturally maintains pure stands on coarse-textured, excessively drained outwash soils or eskers where hardwoods are not competitive. These droughty sites may be the only ones in the region where fire was an important natural disturbance. Many pitch pine forests of Cape Cod and other scattered localities in central New England evidently were originally white pine forests prior to logging and repeated burning (Patterson and Backman, 1988). Highly productive pure pine stands also develop on old fields wherever a seed source is present. These white pine stands are an early successional stage that is succeeded naturally by oak or northern hardwoods without silvicultural treatment.

Oak Type Group

The oak type group, covering 10 percent of the Northeast, is predominant in the Hudson Valley and southern New York, in Connecticut, Rhode Island, and eastern Massachusetts and also extends into southern New Hampshire and Vermont. Northern red oak is the most prominent species in this type, although black, white, scarlet, and chestnut oaks also occur widely.

Oak forests in the Northeast have two main origins. Decades of coppice cutting for fuelwood favored oak and chestnut, both prolific sprouters. When coppicing ceased and chestnut was extirpated by the chestnut blight, sprout-origin forests of nearly pure oak developed. Despite this origin, however, these oak stands are now often well stocked with high-quality trees. Oak forests also developed from advance regeneration when large areas of old-field pine were clearcut during the early 1900s. In these stands, red oak tends to be mixed with red maple, black birch, and hickories; hemlock and white pine are sometimes important associates. Although their ultimate successional patterns are unclear, oak stands can be replaced by hemlock or northern hardwoods in the absence of disturbance or silvicultural intervention.

HISTORY OF FOREST USE

Prior to 1800, much of the original forest in the southern part of the region was cleared extensively for agriculture. After agriculture ceased, vacant fields often succeeded to conifers, usually white pine in southern New England and spruce in northern regions. Old-field succession by mixed northern hardwoods is also common on productive sites lacking a conifer seed source.

After these old-field conifer stands were harvested during the early 1900s, forest composition usually returned to various hardwood associations that are more competitive on these productive soils. Patterns of abandonment and revegetation were highly site-dependent, creating profound and long-lasting changes from the presettlement forest (Foster, 1992). Hardwood forests near metropolitan areas, which had been coppiced repeatedly for fuelwood, were allowed to grow after fossil fuels replaced wood as the primary source of domestic heating. At the same time, an introduced, lethal fungus *(Endothia parasitica)* killed virtually all American chestnut trees, which had formerly been a prominent component throughout the eastern hardwood forest. The extensive red oak forests of southern New England are a direct result of these combined influences. Farther north and in mountainous areas where land was never cleared, old-growth forests were heavily and repeatedly logged, first for white pine, then for spruce, and finally for northern hardwoods. During 1913–1919, a severe spruce budworm outbreak swept over northern Maine, killing much of the balsam fir and some red spruce that survived logging (Seymour, 1992a). Wildfires were also widespread as a result of heavy slash accumulations, extension of railroads, and a lack of organized control activities.

Except for some industrial ownerships and some public forests, these stand-creating disturbances have not been replaced by deliberate regeneration cutting. The area containing young stands continues to decline, resulting in an increasingly unbalanced age structure regionwide. Although the overall forest area is essentially stable, over 2.5 million acres (over 50 percent of the total) of young (seedling-sapling) stands grew to pole-timber size during the 1970s (Fig. 2-3). Seedling-sapling stands occupied less than 9 percent of New England's forests around 1980. Less than 6 percent of the white pine type is now in this size class, dropping 72 percent in a single decade.

These profound trends set the context for silvicultural practice in the region. The rising growing stock volumes and values, coupled with improved markets for low-value forest products such as fuelwood, pulpwood and biomass, present exten-

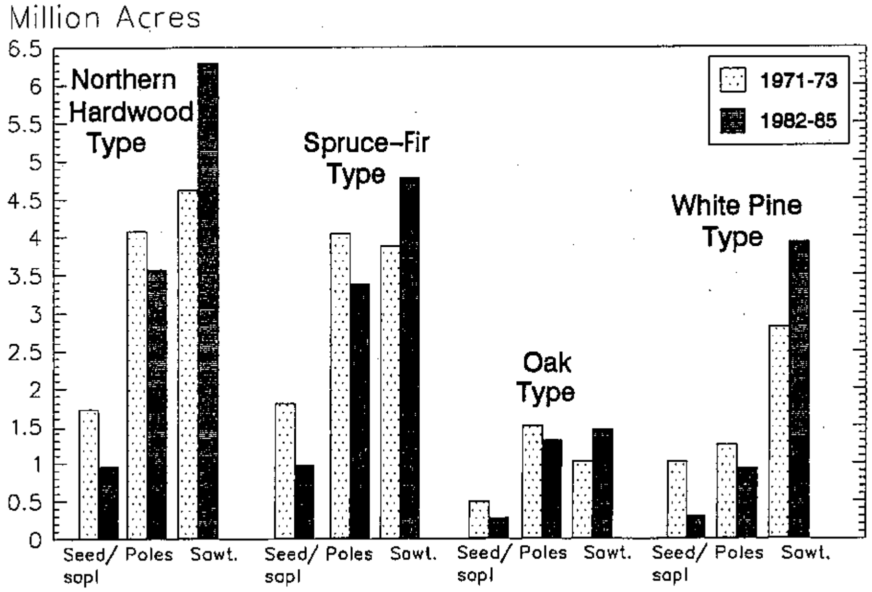

Figure 2-3. Change in size structure of New England's forests during the 1970s and early 1980s, by forest type. Note the dramatic loss of seedlings and sapling stands and the increase in sawtimber stands.

sive opportunities for commercially viable silvicultural operations in many stands that formerly could not be treated. This increasingly favorable economic environment could lead to complacency if it were not recognized that the maturing forests also present many difficult silvicultural challenges. The same economic conditions that facilitate silvicultural treatment also create an ideal environment for high-grading immature stands (Nyland, 1992). For silviculturists, the most important issue is to manage harvesting activities in ways that both enhance future growing stock values and create appropriate conditions for regeneration (Seymour et al., 1986).

Clearly, the circumstances that created today's forests nearly a century ago are not being repeated. The historical reliance on old-field abandonment for creating young stands has ended. The Northeast has become "resaturated" with forest land. Landowner surveys cited earlier in the chapter repeatedly demonstrate that the most pervasive harvesting methods are partial cuttings focused mainly on extracting value (Seymour, 1988). With appropriate professional guidance, partial cuttings can be used to manage the shade-tolerant forest types such as northern hardwoods and spruce–fir under multiaged silvicultural systems. If this became commonplace, then the decline in seedling-sapling stands would not be a cause for concern. However, similar practices usually lead to the valuable white pine, paper birch, and oak types being replaced by later-successional forests, often dominated by the ubiquitous red maple, which has increased 26 percent during the 1970s (Table 2-1).

SILVICULTURE OF THE MAJOR TYPE GROUPS

Northeastern forests lend themselves well to managing for biodiversity as well as high-value forest products. With appropriate modifications, silvicultural systems traditionally used for wood production can enhance diversity more often than they conflict. The attributes of forests that influence wildlife, aesthetics, and landscape diversity—stand size or area, stage of development, species composition, amount of vertical structure, presence of dead and down trees, and the spatial arrangement of stands on the landscape (Hunter, 1990; DeGraaf et al., 1992)—are all key silvicultural considerations.

Even on small- to medium-sized tracts, site variability, diverse community structure, and existing populations usually present a myriad of options for silvicultural treatment to enhance diversity. To illustrate, the manual of Degraaf et al. (1992) provides a comprehensive procedure for inventorying forest properties, setting realistic objectives, and narrowing the choices based on species' requirements. Occurrence and utilization information for 338 species of amphibians, reptiles, birds, and mammals is compiled in detailed tables with ratings for each species. Data are grouped by four important habitat features, all of which are strongly influenced by silvicultural practices: species composition, habitat-breadth and size-class categories; structural features including forest-floor and subterranean habitats; and area requirements.

In addition to conventional systems, specific silvicultural practices described by

DeGraaf et al. (1992) include *wildlife clearcuts* that leave scattered residual trees (both living and dead) for high exposed perches and cavity users. *Low-density wildlife thinnings* and *open wildlife shelterwoods,* designed to promote development of understory vegetation, mesh nicely with systems required to regenerate species of intermediate shade tolerance (such as white pine, yellow birch, and white ash) as well as heavy crown thinnings used under crop-tree systems. Irregular shelterwoods or selection systems provide permanent vertical structure if some low-quality trees are retained. Areas disturbed during logging (such as skid trails, landings, and roadsides) can be maintained semipermanently in early successional grass or forb communities. Herbicide release of young spruce–fir stands may temporarily reduce hardwood stocking, but in many cases can actually prolong browse availability by extending the early successional stage (Newton et al., 1989).

Northern Hardwoods Type Group

Stand Development Patterns and Natural Disturbances Sugar maple and American beech, the principal species of this type, are long-lived and shade-tolerant. Early-height growth rates in full sunlight are slow relative to their common associates. Unlike the more valuable sugar maple, beech regenerates prolifically from root suckers that often dominate frequently disturbed stands (Hornbeck and Leak, 1992).

Red maple, yellow birch, and white ash all rank intermediate in shade tolerance and grow somewhat more rapidly than sugar maple when young. They shed branches more quickly and develop into quality trees with little effort when grown in open or lightly shaded conditions. Red maple is a prolific seeder, can persist as advance regeneration, and sprouts vigorously from cut stumps at old ages, giving it a strong advantage over species with more limited regeneration mechanisms. Yellow birch also seeds dependably and benefits from moderate forest-floor disturbance and removal of low shade. White ash seeds less often, but unlike the species above, retains significant viability after 1 year, and delayed germination is common. Yellow birch and ash will become established as advance growth, but will not persist and develop unless overstory density is reduced.

Paper birch and aspen are relatively short-lived, shade-intolerant species that grow well only at high light levels. Under these conditions, stem quality is usually quite good. Paper birch, which is a prolific and frequent seeder, regenerates best on a moderately scarified seedbed. Aspen regenerates primarily from root suckers, which are a dependable regeneration mechanism until the tree reaches about 50 years. Pin cherry, a very aggressive but short-lived pioneer species, also thrives in many stands after heavy disturbance. Pin cherry seeds remain viable for over a century in the forest floor and can dominate stand composition during early development even when living individuals were not present in the previous stand. Striped maple, a small, shade-tolerant tree, is also a common component of many northern hardwood understories.

The Northern Hardwood Forest is a very stable climax community. The most common natural disturbances are severe windstorms that blow down scattered overmature trees weakened by decay. Younger, thrifty trees are usually quite windfirm; however, intense hurricanes occasionally cause widespread mortality in all forest types in central and southern New England (Foster, 1988). Natural stand-replacing disturbances such as wildfire are very rare. The natural dynamics favor small canopy gaps that are reoccupied by formerly suppressed shade-tolerant species in the understory (Runkle, 1982). The beech–birch–maple subtype is quite stable and maintains a climax association unless heavily disturbed by logging. Beech–red maple stands may eventually succeed to shade-tolerant conifers; such stands may have resulted from earlier high-grading operations that removed only the softwood component of originally mixed-wood stands. Others appear to develop a strong preponderance of beech due to its greater longevity than red maple and the birches. In mixed-wood stands succession tends to increase the stocking of the shade-tolerant conifers (red spruce or hemlock), which outlive the hardwoods.

Because natural disturbances caused only sporadic, partial mortality, old-growth northern hardwood forest typically developed multiaged structures, with both young saplings and trees up to 30 inches in diameter at breast height (d.b.h.) and over 200 years old (Leak, 1974; Tubbs, 1977). However, most remaining remnants of old-growth stands are protected in reserves and are not under management. Most of the northern hardwood forest is dominated by middle-aged stands of irregular structures and mixed species composition. Truly even-aged stands appear to be much less common, although data are inconclusive. Unpublished data analyzed by Seymour (1988) show that, in 1980, about 65 percent of Maine's northern hardwood type was classified as either two-storied or uneven-aged. Partial harvesting and old-field succession are the main processes affecting today's forest. The typical logging treatment involves heavy partial cuttings repeated at fairly long (20- to 40-year) intervals. Such cuttings often leave significant residual stands of old, poor-quality trees yet still regenerate a new cohort (Seymour, 1988). This type of disturbance leads to irregular, two-storied stands in which neither residual tree quality nor future stand composition is controlled. Carefully managed two-aged silvicultural systems offer much promise if careful attention is given to regeneration and to the choice of reserve trees (Nyland, 1991; Marquis, 1992; Seymour, 1992a).

Silvicultural Systems Silvicultural guides are available for all important northern hardwood types (Leak et al., 1987; Safford, 1983; Marquis et al., 1992), but these excellent handbooks cannot cover all possible situations. The extensive disturbance history, in combination with the extraordinary diversity of species and sites, has produced a bewildering array of stand conditions that resists standard silvicultural classifications and simple prescriptive approaches. Strict even-aged silviculture was in vogue during the 1960s and 1970s on national forests, but concerns about visual quality, nutrient cycling, and premature harvesting of immature growing stock has led to adoption of silvicultural systems that maintain stands with more vertical structure (Seymour et al., 1986; Hornbeck and Leak, 1992). Currently, the main applications of even-aged systems are maintaining the early-successional aspen–paper birch type in New England and in the cherry–maple stands of the Allegheny Plateau. However, small-patch clearcutting (for paper birch) and uniform shelterwood (for cherry–maple) have replaced large-block clearcutting as the dominant even-aged paradigm. Selection silviculture is once again the prevailing doctrine for northern hardwood silviculture, but long-term examples where stands have been managed repeatedly according to a balanced residual structure are limited mainly to a few public forests and research plots.

The main focus of northern hardwood silviculture has been on growing quality trees for high-value sawlogs. Regardless of the specific system, the key principle is identifying the potential for future value growth of a relatively few trees and favoring them with appropriate treatments. As society has come to value amenities in addition to wood products, foresters are challenged to formulate silvicultural systems that, in addition to creating high economic values, also maintain diverse stand structures to enhance wildlife habitat and the high visual quality of the northeastern landscape. Concern over biodiversity also dictates that species composition of all forest vegetation and fauna, not just valuable crop trees, be considered in any treatment. Almost any silvicultural practice designed to favor crop trees also produces regeneration if trees have reached seed-bearing age, owing to the shade tolerance and longevity of many northern hardwood species. Thus it is difficult to separate treatments focused on manipulating overstory growing stock from regeneration measures; in practice, most cuttings do both. Other critical skills for controlling species composition are knowledge of the specific site requirements and potential productivity of each species, along with the ability to recognize often-subtle differences in the field (Leak, 1983). For example, it is futile to attempt growing large sugar maple on shallow soils of low fertility, where mixtures of birch, beech, and conifers are best adapted.

Regeneration Because all northern hardwoods except the birches depend strongly on either advance growth, stump sprouts, or root suckers, the status and fate of this "stored" regeneration is the most important single consideration in controlling initial species composition. Other important factors are density of the overstory and how long it is retained over the developing reproduction. At one extreme is paper birch, which is favored by complete clearcutting and widespread disturbance that both creates ideal seedbeds and eliminates competing advance growth (Safford, 1983). Sugar maple represents the other extreme; this species must be several feet tall before overstory removal in order to compete successfully with birches and shade-intolerant competitors that germinate after harvest (Leak et al., 1987; Godman and Tubbs, 1973). Shorter maples may survive but will lapse into the lower stratum. This important distinction in regeneration methods between birches and other northern hardwood species is vividly demonstrated by an experiment in which all advance growth and vegetative reproduction except beech root suckers were intentionally eliminated in 80-foot-wide strip clearcuttings (Smith and Ashton, 1993). After 18 years, strips were completely dominated by birches despite the fact that they were a very minor component of the original stand.

Virtually all species germinate better under partial shade, including many shade-intolerants (Marquis, 1973). This consideration has led to widespread adoption of the shelterwood method, where structural objectives do not require uneven-aged stands (Hannah, 1988). Wide latitude in controlling species composition can be achieved by varying the overwood density and timing of removal cuttings; conversion tables between basal area and crown coverage (Leak and Tubbs, 1983) expedite this task. For intolerant black cherry, an establishment cutting removing about one-third of the overstory followed by overstory removal within 5 years results in very high densities of pure cherry that will survive intense deer browsing (Marquis, 1979). For yellow birch and white ash, Leak et al. (1987) recommend an overwood of 30 to 40 percent cover, although Hannah (1991) found good regeneration beneath higher overwood densities under which low shade was eliminated by cutting all trees below the main canopy. Removal cuttings can be made when seedlings reach a height of two feet. Longer retention of even 40 square feet of basal area will eliminate all shade-intolerants (Hornbeck and Leak, 1992), although intermediates may persist for several decades.

Heavier overwood densities (80 percent) and longer retention periods, or application of light selection cutting, will strongly favor shade-tolerant maples unless deer populations are high. Under any shelterwood regime, some birches and early successional vegetation will develop in disturbed openings created by the removal cutting if seed sources are present. Unless the tolerant advance growth is very tall, the intolerants will compete successfully, ensuring a diverse species mix. Small-patch clearcuttings can ensure some representation of intolerant and intermediate species, ranging from about one-third of the stocking in 0.5-acre patches to over half in patches up to 2 acres (Leak et al., 1987). Where adequate advance regeneration exists naturally, the overstory can simply be removed in a single, or *one-cut,* shelterwood cutting (Seymour et al., 1986), using care in the logging to control disturbance and minimize damage (Seymour, 1986). This practice is an effective way to convert high-graded, poor-quality stands of tolerant species to productive mixtures of all species (Walters and Nyland, 1989).

Competing vegetation usually is not a problem in northern hardwood regeneration. Pin cherry is a very aggressive competitor, but it casts light shade and drops out at a young age due to deer drowsing and very short life span. Leak (1988) found that pin cherry did not reduce stocking of commercial species under a variety of partial-cutting treatments ranging from 38 to 95 square feet of basal area. After complete clearcutting, very dense stocking of pin cherry can reduce stocking and height growth of yellow and paper birches, however (Safford and Filip, 1974). *Rubus* species often are prominent shortly after cutting, but they usually die out by age 10 after being overtaken and shaded out by taller vegetation (Walters and Nyland, 1989; Smith and Ashton, 1993).

The most difficult problems in regenerating northern hardwoods exist in stands where the understory is dominated by small beech and other tolerant competitors such as striped maple and hobblebush. Many such stands result from high-grade harvests of the more valuable maple and birch, leaving the less valuable beech to regenerate prolifically from root suckers. This problem can be exacerbated by deer browsing, because deer prefer other species to beech (Tierson et al., 1966). If a paper birch seed source is present, such stands can be converted by clearcutting. If the goal is to rebuild the maple and yellow birch components, shelterwood or selection cuttings must be coupled with herbicide treatment of the beech understory prior to the establishment cuttings (Kelty and Nyland, 1981; Horsley and Bjorkbom, 1983; Ostrofsky and McCormack, 1986). In the Allegheny hardwood forests, ferns, grasses, and sedges can also cause serious interference with hardwood regeneration and must be controlled (Marquis et al., 1992). Understory treatments are typically done using skidder-mounted mist blowers if the target vegetation is under 20 feet tall; larger stems must be treated individually using basal sprays, girdling, or injection (Sage, 1987).

Control of Density and Structure—Even-aged Stands Application of early precommercial treatments to young northern hardwood stands depends strongly on the shade tolerance and relative height development patterns of the species mix. Fast-growing shade-intolerants such as paper birch and black cherry will grow more rapidly than the slower-growing tolerants such as maple and beech, which persist in the shaded lower stratum. Such stands will develop naturally into stratified mixtures (Leak, 1961; Gilbert, 1965; Smith, 1988) unless all species are shade-tolerant (Guldin and Lorimer, 1985). Young hardwoods often do not respond to early release and can lose bole quality if forking or poor branch shedding results from low stand density (Voorhis, 1990; Heitzman and Nyland, 1991). Thus, early cleanings are generally unnecessary or even counterproductive in young northern hardwoods. Stands should be allowed to develop naturally at high density and can be treated with later commercial entries (Smith and Lamson, 1983; Seymour et al., 1986; Marquis et al., 1992). Exceptions include stands where low-value intolerants such as aspen or pin cherry overtop paper birch. Here, birch yields can be increased dramatically by early release of crop trees (Marquis, 1969; LaBonte and Nash, 1978). Selective treatment of red maple stump sprouts is also helpful where they threaten to suppress white ash and yellow birch (Leak et al., 1987).

Improvement cutting is perhaps the most widely applicable practice in stands of old-field origin or with a history of mistreatment. Trees targeted for removal—those of high risk, poor bole quality, or undesirable species—are usually quite obvious, making improvement cuttings the simplest of all treatments to prescribe. The need for maintaining suitable habitat for cavity nesters and other wildlife, as well as future replenishment of large-diameter woody debris on the forest floor, dictates that a few large cull trees be left. Residual stocking is controlled by reducing density to the B line on the widely used stocking guide (Fig. 2-4) or by cutting to a particular d.b.h. distribution if eventual conversion to a selection structure is planned. If the stand does not contain enough suitable trees to reach at least the C line, then a regeneration cutting (usually shelterwood) should be considered (Leak et al., 1987). In this case it may be necessary to leave poor-quality trees of desirable species as part of the overwood in order to maintain the appropriate crown coverage.

In immature well-stocked stands, early crown thinnings concentrate future growth on selected high-quality stems. The first entry should coincide with the time when a straight, branch-free bole of 20 feet or more has formed (Fig. 2-5). Before this time, stand density should be maintained above the quality line on the stocking guide (Fig. 2-4) until crop trees reach about 6 inches d.b.h., especially in stands

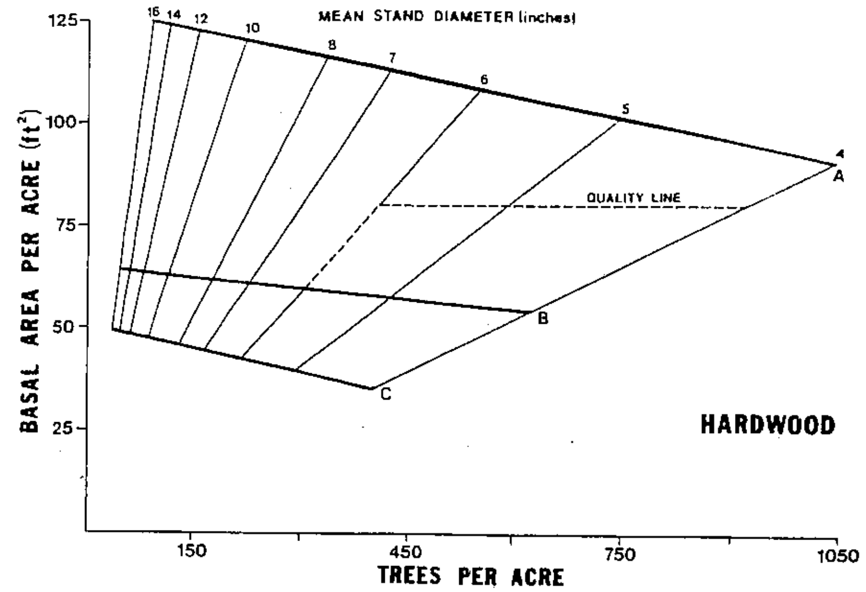

Figure 2-4. *Northern-hardwood stocking guide. (From Leak et al., 1987.)*

dominated by shade-tolerant species with poor branch-shedding ability (Leak et al., 1987). Relationships between crown area and d.b.h. for northern hardwoods (Leak, 1983) show that only 35 to 50 trees will fully occupy the site at a d.b.h. of 20 inches when trees begin to reach financial maturity. Therefore, it is most important in early thinnings to select about 100 uniformly distributed crop trees from the upper crown classes and release them quite heavily by removing all competitors whose crowns

Figure 2-5. *Early crown thinning of a 20-year-old northern hardwood stand. High-value paper birch, white ash, and northern red oak crop trees form the overstory, with white pine advance regeneration in the lower stratum.*

are touching. In highly stratified stands, only competitors from the upper stratum need be removed. Shade-tolerant trees in the lower stratum will also respond to thinning but will remain below the crop trees and provide a desirable training effect. Preoccupation with achieving a particular residual basal area can result in residual stands that are much too dense for maximum crop-tree response. At this stage in development, most upper-canopy trees continue to grow vigorously and their quality does not degrade from epicormic branching.

Subsequent commercial thinnings are often needed to maintain rapid crop-tree growth and can increase total yields substantially. If the stand had a previous crop-tree release, treatments should focus on again releasing the best 30 to 50 stems per acre. At this stage, the goal should be to prevent any further retreat of their live crowns. This requires that some former crop trees and some nearby trees from the lower stratum be removed. Ideally this thinning should be made when the competing trees reach 10 to 12 inches d.b.h. and can therefore be sold as small sawlogs. If the stand has reached this stage without prior treatment, residual stand density should not be reduced below the B line. Crowns of potential crop trees will be smaller and will respond less vigorously, if at all, to heavy release. Degrade from epicormic branches or sunscald is also more likely, especially on yellow birch, which is sensitive to abrupt exposure.

Control of Density and Structure—Uneven-aged Stands The shade tolerance, longevity, and high value of northern hardwoods make this forest type well suited to uneven-aged silviculture under the selection system. An important advantage of this system is the permanent presence of large trees throughout the landscape. This enhances visual quality and provides a high degree of vertical diversity for many wildlife species (Hunter, 1990; DeGraaf et al., 1992). Selection systems also can provide for long-term sustained yields if a balanced age structure is achieved and maintained within the stand. Strictly speaking, the sustained-yield goal is not a requirement of selection silviculture. On large forests where yields can be more easily regulated over the entire property, unbalanced stand structures with three or more age classes may provide a simpler means of maintaining visual quality and vertical diversity than the more elaborate practice of cutting to a balanced residual diameter distribution discussed later (Smith, 1986).

In order to be considered balanced, stand structures must possess two attributes: Each age class must occupy approximately equal ground area, and each age class must be separated in time by a period equal to the cutting cycle (Nyland, 1987). Each stand entry must therefore accomplish three things: harvest mature trees from the oldest age classes; tend immature age classes; and perhaps most importantly, regenerate a new age class to replace the one harvested. In practice it is impossible to record precisely how much area is occupied by each age class, especially since reproduction often develops beneath the older trees. Thus, the common procedure is to convert theoretical area requirements to conventional stand density measures (trees per acre and basal area) under two assumptions (Nyland, 1987): That crown areas are highly correlated with d.b.h. or basal area, and that d.b.h. is highly correlated with age. While the former is always true, the latter is often questionable.

In highly stratified mixed-species stands, small shade-tolerant beech and maple of the lower strata can be just as old as the dominant birch and ash (Wilson, 1953; Smith, 1988). Because understory sugar maple responds well to release, such trees are an important source of regeneration regardless of their age if the goal is perpetuation of maple–beech stands using single-tree selection cutting (Tubbs, 1988). If some intermediates or intolerants are desired, however, group-selection cuttings or shelterwood systems with reserve trees must be substituted.

Target residual d.b.h. distributions are specified by three parameters: the total basal area or equivalent number of trees in the stand; the maximum d.b.h. to be grown; and the distribution of trees by diameter classes (often defined by *q*, a constant ratio between the numbers of trees in adjacent 2-inch d.b.h. classes). Basal area is based on the same growing-space requirements as those in even-aged stands, with the added constraint that some growing space be freed for developing saplings. For pure hardwood stands, Leak et al. (1987) recommend 65 to 75 square feet in trees 6 inches d.b.h. and larger, a value slightly above the B line on the northern hardwood stocking guide (Fig. 2-4). Even higher values may be feasible on very productive sites or in mixed-wood stands with a hemlock or red spruce component. Basal area is also influenced by the length of the cutting cycle; longer intervals between entries generally require lower basal areas to prevent the stand from becoming overstocked. Maximum d.b.h. depends on product objectives or wildlife requirements for large cavities (Tubbs et al., 1986); site quality is also important. Typical values range from 16 inches for beech and spruce on poor sites to over 24 inches for sugar maple on excellent sites.

The choice of d.b.h. distribution form is more difficult. Using a single value of *q* facilitates structural calculations and provides a simple way to describe the relative allocation of growing space between large and small trees in a selection stand. However, this concept has little biological basis other than empirical observations of a few old-growth stands and often does not adequately describe structures of managed selection stands. The important test of any selection stand is not its conformance to a particular mathematical model, but whether the interaction of basal area, maximum d.b.h., and d.b.h. distribution result in a stable structure and sustainable growth over time. Segmented structures based on several different values of *q* have been proposed (Leak, 1978a), in which the submerchantable d.b.h. classes have a higher q value than the poles and sawtimber. In general, it is desirable to maintain as low a *q* value as possible in order to maximize growth on sawtimber-sized trees. For example, reducing *q* from 1.7 to 1.3 (the usual range recommended) increases the stocking of sawtimber trees from 45 to 70 percent of the basal area, assuming a total basal area of 70 square feet per acre and a maximum d.b.h. of 20 inches (Leak et al., 1987).

Stand structures proposed for northern hardwood stands are compared in Figure 2-6. The structures from Leak et al. (1987) all assume a constant basal area of 70 and maximum d.b.h. of 20 inches, varying only the value of *q*. It is noteworthy that all structures in Figure 2-6 have only 30 to 40 trees in the sawtimber class (12 inches d.b.h. and larger), where virtually all the stand value is concentrated. This point highlights the fact that success depends critically on the early tending and subse-

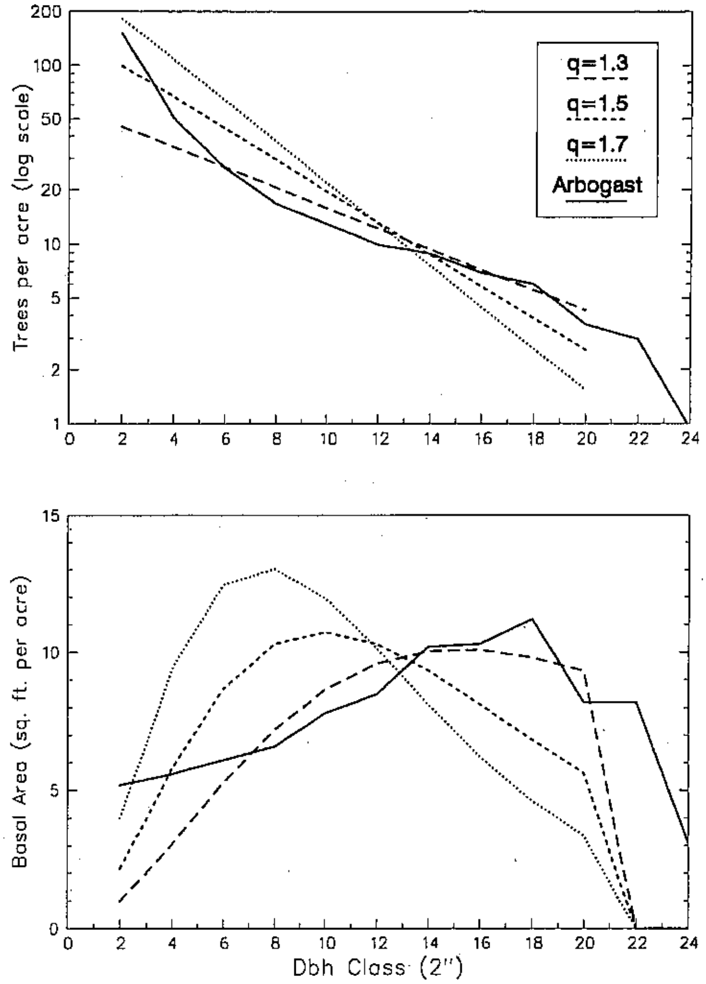

Figure 2-6. *Comparison of recommended stand structures for northern hardwood selection management. (From Leak et al., 1987; Nyland, 1987.)*

quent culture of a relatively small number of trees, just as in even-aged systems.

Between 6 and 20 inches d.b.h., the structure defined by $q = 1.3$ closely resembles the *Arbogast structure* (Nyland, 1987), derived empirically by Eyre and Zilgitt (1953) for old-growth sugar maple on good sites in the Lake States. The Arbogast structure is more heavily stocked in the sapling class, with a q value of well over 2.0 below 6 inches d.b.h. This structure also contains about four more trees and about 10 square feet more basal area in the 22- to 24-inch classes; as a result, a total basal area of over 6 inches d.b.h. is about 80 square feet. An extensive simulation study (Hansen and Nyland, 1987) found a structure similar to Arbogast's to be sustainable, confirming Leak's (1978a) suggestion that segmented distributions based on several different q values can provide more realistic results. In contrast, all structures based on a single q value developed deficiencies in the small-diameter classes within 30 years. Hansen and Nyland also found that volume and value production of large sawtimber are optimum with a maximum d.b.h. of about 20 inches. Retaining larger trees offered no advantage and reduced the total volume production and rate of return.

To facilitate field application and marking of selection cutting, it is customary to convert structures specified originally by numbers of trees to basal areas in 4- to 6-inch classes. Marking guidelines are commonly expressed as removal ratios within these groupings. It is unnecessary and often futile to achieve rigid conformity in a single cutting, especially in stands with no prior treatment. The spatial pattern of the cutting must also take into account the need for continued regeneration and recruitment, releasing understory saplings and creating small openings where possible to maintain the desired species composition.

Potential Pitfalls Considering the growing popularity of selection cutting for northern hardwood management on public forests, it is well to reconsider the pitfalls inherent in this system and why it was abandoned in the 1960s. One problem was a failure to pay adequate attention to overall structure especially in the smaller-diameter classes (Marquis, 1978). Lack of markets for anything but large sawtimber encouraged cutting only in the larger-diameter classes; subsequent entries were made possible only by a gradual relaxation of merchantability standards. Even though these early cuttings often left significant residual stands, they eventually produced a more even-aged, bell-shaped d.b.h. distribution, as excessive numbers of pole-timber trees released by these cuttings dominated the stand and excluded regeneration (Roach, 1974). Diameter-limit cuttings that leave a minimum basal area, which are sometimes proposed as a form of selection cutting, will produce the same undesirable stand development (Nyland et al., 1993). The practice of cutting only large trees has even more negative consequences in even-aged mixed-species stands, which often have the reverse-J-shaped d.b.h. distribution of a balanced selection stand if species patterns are ignored. Such cuttings remove the fastest-growing and most valuable trees from the upper stratum, releasing lower-value and slower-growing shade-tolerant trees of the same age. Repeated application reduces both yields and species diversity and does not lead to a balanced uneven-aged structure. Smith (1988) discusses many even-aged silvicultural approaches to treating mixed stands appropriately, as well as some uneven-aged systems that employ group selection cuttings to maintain the full range of species diversity.

Commercial thinnings or selection cuttings in high-value northern hardwoods should always favor the largest and best-growing trees until they reach financial maturity, typically 16 to 24 inches d.b.h. Because this is well beyond the stage when trees become merchantable, stands are highly vulnerable to mistreatment if "logger's choice" or other expedient measures such as diameter-limit cutting are used to control the harvest. Future earning potential of high-quality trees should be the dominant consideration, and cuttings also must consider the immediate or future effects on regeneration. Control of logging damage in any partial cutting operation is also very important.

Rotations and Yields Simulations predict that mean annual increments (MAI) for unmanaged even-aged northern hardwood stands range from 46 board feet per acre per year on site index 50, to 148 on site index 70. Without management, yields culminate on rotations of 120 to 100 years, at average d.b.h.s of 10 to 14 inches, on site indexes 50 to 70, respectively. Under an intensive thinning regime that begins at an average d.b.h. of 6 inches and repeatedly lowers stand density to the B line, yields are increased by a factor of 1.5 (site index 70, MAI = 227) to 2.1 (site index 50, MAI = 97) times those without thinning (Solomon and Leak, 1986). Optimum rotations are similar to those without thinning, but the average d.b.h. at culmination is about 4 inches larger on all sites. Net present values (NPV) at 4 percent interest of various thinning schedules are maximized under similar rotations and are strongly dependent on the product and species mix. On site index 60, for example, a low-intensity thinning that produces a product mix of only 5 percent of the volume in veneer and high-quality logs yields an NPV of only one-seventh that of a quality-line thinning with 20 percent in high-value material (Leak et al., 1987). Without thinning, most NPV values were negative, illustrating the importance of intermediate income from the thinnings. These results reinforce the conventional silvicultural wisdom of focusing attention on high-quality trees of valuable species growing on productive sites.

If site index cannot be measured directly, the matrix developed by Leak (1978b) can be used. The site index of birches, which grow in most habitats, ranges from below 50 to nearly 80. Red maple and beech appear to be less responsive, ranging from 52 to 65. Sugar maple and white ash grow well only on the best habitats, where their site index varies from 60 to 80. Curves are available to estimate the site index of one species if that of another is known (Curtis and Post, 1962; reproduced in Leak et al., 1987).

The relationship of growth to residual stocking level has been a continuing source of uncertainty for northern hardwoods. Leak (1981) found little variation in basal area accretion between residual stands of 40 to 100 square feet, and later proposed that basal area could be as low as 30 square feet without growth reductions (Leak, 1983). Leak (1983) also suggested that optimum basal area bears little relationship to average diameter or age, contrary to stocking guides based on crown area–d.b.h. relationships that give higher basal areas with increasing d.b.h. These findings led to a substantial downward revision of the B line to about 60 square feet in the most recent publication of the northern hardwood stocking guide (Fig. 2-4), which formerly had been at about 75 square feet for comparable stands. The lack of any clear relationship between stocking and growth reinforces the earlier point that treatments should focus on heavy crown release of a small number of crop trees without regard for leaving a specific residual basal area, especially if begun early in stand development.

In mixed stands where species have very different growth rates and product values, fixed rotation lengths for the entire stand have little meaning. For example, in cherry–maple mixtures, rotations can vary from 80 to over 150 years, when the average d.b.h. reaches 18 inches and many trees qualify as veneer or grade 1 sawlogs. Here, the recommended procedure is to calculate financial maturity for each stand individually based on its unique structure and then to harvest accordingly (Marquis et al., 1992). Stands with under 35 percent stocking in acceptable growing stock have passed financial maturity regardless of their size or age and should be regenerated if wood production is the primary goal. Yields of mixed-species stands can also be enhanced by favoring the valuable shade-intolerants such as cherry and ash, which are taller and produce more wood per unit of growing space than maple or beech. Heavy removals from above reduce yields dramatically (Marquis and Ernst, 1991). However, thinnings must also consider the need to retain some well-formed maples as future seed sources and potential reserve trees in two-aged stands after the intolerants are regenerated. This system helps to avoid the creation of pure-cherry monocultures, which do not develop as well as mixtures with maple (Marquis, 1992).

Virtually no data are available on long-term yields of uneven-aged northern hardwood stands managed according to a balanced structure. The highest periodic annual growth rates observed by Eyre and Zillgitt (1953) were slightly over 200 board feet per acre over a 20-year period in formerly unmanaged old-growth stands in northern Michigan. Simulations of Hansen and Nyland (1987) showed maximum growth of large sawtimber to be about 250 board feet per acre per year using a low q value of 1.2, although this structure proved to be unsustainable. These yields are comparable to those predicted by Solomon and Leak (1986) for intensively managed even-aged stands, suggesting that they might be sustainable, but proof must await much longer observations.

Traditional yield tables and empirical growth studies tend to lack generality for the enormous variety of stand compositions and structures in the Northern Hardwood Forest. Several recently available simulation models, developed the USDA Forest Service, will predict stand development and yield under a wide variety of silvicultural treatments. The most flexible is NE-TWIGS, an individual-tree model derived from the STEMS and TWIGS models developed originally in the Lake States. FIBER, a stand-table projection model developed from a large data base in New England (Solomon et al., 1987), is also valuable for short-term forecasts. SILVAH (Marquis and Ernst, 1992) provides a comprehensive approach to silvicultural prescriptions for the Allegheny hardwood forests, including a growth simulator that predicts stand development. All of these growth simulators (as well as others) have been incorporated in the Northeast Decision Model (NED), an expert system for silvicultural decision making that is currently in the prototype stage (Twery, 1992). NED processes stand data and helps the user formulate prescriptions that can include many nontimber objectives.

Susceptibility to Damage Major insects and diseases that threaten northern hardwoods have been thoroughly reviewed by Allen (1987) and Houston (1986). The most serious mortality agent, and arguably the only disease that cannot be managed using routine silvicultural practices (Ostrofsky, 1988), is the introduced beech bark disease. Widespread mortality caused by the interaction of the beech scale insect and several *Nectria* spp. (Houston and Wainhouse, 1982) began in the 1940s when the killing front passed through New England; it continues to produce serious defects in second-generation beech in the aftermath zone. Another formerly serious problem was the birch dieback, in which paper and yellow birch during the late 1940s were killed or deformed over large areas throughout northern New England. Subtle climatic warming causing rootlet mortality, along with attack of the bronze birch borer, were implicated, but the cause of birch dieback was never definitively established. Several declines of sugar maple have been observed; most appear to affect trees stressed by repeated insect-caused defoliation followed by invasion of root pathogens such as *Armillaria* spp. (Ostrofsky, 1988). A recent decline of white ash, known as *ash yellows,* has been attributed to a mycoplasma-like organism. Pure middle-aged ash stands and fragmented woodlots surrounded by agricultural land appear to be most at risk; older trees in mixed stands growing in large blocks of contiguous forest are not usually affected (Smallidge et al., 1991).

Because northern hardwood silviculture emphasizes growing high-quality trees for finish lumber, internal discolorations and decays are the most serious economic problem. Microorganisms causing discolored and decayed wood invade primarily during the natural process of branch shedding, although logging wounds can also be important sources of infection. Because discoloration and decay affect only the wood produced prior to infection, future degrade is usually prevented by the natural barrier zone that prevents outward spread (Shortle, 1987). In addition to ensuring good stem form, high stand density during the sapling stage promotes rapid branch shedding, thereby minimizing this center column of discolored wood. However, crop trees must be grown to fairly large diameters in order to ensure that the lower logs have a high percentage of unstained wood (Ostrofsky, 1988). Stem cankers can cause serious degrade but rarely affect a high percentage of trees in a stand. The most important are *Nectria galligena* on birches and *Eutypella parasitica* on maples. Because cankers are generally apparent early in stand development, removing infected trees in improvement cuttings is usually an effective way to upgrade stand quality.

Various defoliators occasionally reach local outbreak status and can cause serious growth reduction and mortality. Chief among these are the saddled prominent, the forest tent caterpillar, the pear thrips *(Taeniothrips inconsequens),* and cankerworms (Hornbeck and Leak, 1992). Some evidence suggests that mixed stands are less susceptible to attack, so avoidance of monocultures may be an effective silvicultural control measure.

Spruce–Fir Type Group

Stand Development Patterns and Natural Disturbances Both red spruce and balsam fir, the dominant components of this type in the Northeast, are very shade-tolerant and typically develop as advance growth in shaded understories. Fir seeds earlier in life and more frequently than red spruce; good seed crops normally occur every other year. Fir seeds are also somewhat larger, and the fir's root system develops more quickly. Neither species maintains significant viability beyond 1 year. These factors explain why fir advance seedlings tend to outnumber spruces, even under overstories dominated by spruce. Shaded, undisturbed coniferous leaf litter can also be a good seedbed except in unusually dry years when the normally abundant, well-distributed summer precipitation is lacking. Large rotten logs on the forest floor can also be an excellent seedbed, especially for red spruce. Lightly scarified mineral soil is an excellent seedbed for both species, but circumstances that produce such conditions (usually harvesting) tend to favor more aggressive competitors such as paper birch, *Rubus* spp., and pin cherry.

Early height growth responds to improved light conditions up to about 50 percent of full sunlight. Fir and spruce both retain long, narrow crowns and shed branches slowly. Little knot-free wood forms unless spruces are grown on long rotations or are pruned. However, high stand densities early in development produce small branches, which are not important defects since most trees are used for pulpwood or structural lumber. Fir is much shorter-lived than red spruce owing to its high susceptibility to heart rots, which weaken the stem and result in wind breakage. Red spruce resists decay and is very long-lived; trees over 300 years old were not uncommon in virgin forests (Seymour, 1992a). Both species are shallow-rooted, and older trees are generally not windfirm as individuals.

On sites with good internal drainage, all the northern hardwoods are common associates of spruce and fir. In these mixed-wood stands, hardwood leaf litter is a poor seedbed for spruce and fir, resulting in much lower densities of advance growth (Westveld, 1931). Northern white-cedar or eastern hemlock are also important stand components on certain sites. Both of these species are even longer-lived and slower-growing than spruce. Eastern white pine also competes successfully with spruce and fir where moderate to severe disturbances allow enough light for the pine seedlings to become established and outgrow the more tolerant associates.

Spruce–fir forests are a late successional community, and in many respects follow similar developmental patterns as the tolerant northern hardwoods. Although natural disturbances affecting spruce—fir stands are more extensive and frequent than in northern hardwoods, their effects on stand structure are largely the same. In general, the natural pattern has been extensive partial disturbances that kill mainly large, old trees, releasing growing space to the lower strata. However, red spruce is even more shade-tolerant and long-lived than sugar maple and possesses an extraordinary ability to respond to release at advanced ages after enduring over a century of suppression. Historical evidence reviewed by Seymour (1992a), Lorimer's (1977) analysis of surveyors records, and descriptive studies of the few remaining old-growth stands (Oosting and Billings, 1951; Leak, 1974) all suggest that this disturbance regime maintained a presettlement landscape dominated by multiaged stands.

Over 150 years of utilization of the industrially owned spruce–fir resource have led to important changes in stand structure and composition. The combination of many decades of preferential logging, beginning in the mid-1800s and repeatedly removing the largest spruces and pines, followed by the 1913–1919 budworm outbreak and chronic blowdown of postharvest stands, created second-growth forests with much less age diversity. Species composition has probably been altered in favor of the more competitive fir, and selective logging may have eliminated or greatly reduced the spruce component of former mixedwood stands that are now pure northern hardwoods (Weiss and Millers, 1988). Although truly even-aged stands have greatly expanded in area, irregular stand structures were still more common in the early 1980s because various types of partial cutting remained in widespread use (Seymour, 1992a). Many mixed-conifer stands with a history of repeated light cuttings can have complex age structures that are not evident from casual inspection. Several spruce–hemlock–white pine stands in eastern Maine included some trees in every 10-year age class up to age 200, with many older individuals (Fajvan and Seymour, 1993).

The maturation of the large early-1900s age class, coupled with substantial industrial expansions during the 1970s, made it extremely difficult to manage the 1972–1984 budworm outbreak without large losses. The resulting unbalanced age structure and a legacy of salvage clearcutting continue to plague foresters attempting to regulate the industrial spruce–fir forest for sustained wood production (Seymour, 1985).

Silvicultural Systems These trends in stand structure and forest development have led to widespread adoption of even-aged silvicultural practices for spruce–fir wood production. Handbooks on spruce–fir silviculture (Frank and Bjorkbom, 1973; Blum et al., 1983) emphasize conventional treatment of uniform, even-aged stands. However, more common are heavy partial cuttings that create stands with an irregular, two-aged structure. Such practices regenerate much of the stand but also leave significant numbers of residual trees that respond to release and influence the reproduction.

Because the objective of much spruce–fir silviculture is to get high yields of commodity products, silvicultural systems place more emphasis on full stocking and use shorter rotations than those used to grow northern hardwood sawtimber. High-yield production silviculture for spruce–fir stands generally follows the same principles as in other conifer forests, although practices such as herbicide release and early stocking control did not become operational until the late 1970s (Newton et al., 1987; Seymour, 1992b). Natural regeneration is by far the dominant method of stand establishment; planting remains uncommon. Shelterwood systems for sawlog production have also become increasingly sophisticated, including irregular shelterwoods that use extended regeneration periods and retain reserve trees after the final removal cutting in order to enhance vertical structure (Seymour, 1992a; Seymour and Hunter, 1992).

Regeneration Avoiding natural regeneration failures requires that full stocking of advance seedlings be achieved prior to the final removal cutting of the overstory. This important principle was clearly demonstrated by Westveld (1931) and has been stressed most recently at a regionwide symposium (Simpson, 1991). The current practice of year-round mechanized logging of dense, even-aged stands with sparse advance growth requires close attention to the regeneration process.

The importance of advance regeneration, along with the uniform even- or two-aged structure of most second-growth stands, leads naturally to some form of the shelterwood method. Included here is the one-cut variant, where naturally established advance seedlings are simply released by a final, complete removal cutting (Seymour, 1992a). Clearcutting, where new seedlings germinate in exposed microsites after a complete harvest, is very risky and undependable. If there is no seed crop in the year of cutting, or if a "catch" is not obtained within 2 years or less, clearcut sites invariably are taken over by hardwoods, *Rubus*, or other competing vegetation.

Mature second-growth stands typically have adequate stocking of small (under 12 inches tall) advance growth. These trees can withstand abrupt exposure resulting from a complete removal cutting if they are rooted in mineral soil (Frank and Bjorkbom, 1973). Protection by dead shade of logging residues also helps survival. Excessive site disturbance during logging destroys advance growth and aggravates problems from competing vegetation. Winter cutting on frozen ground with snow cover, using controlled-layout tree-length or short-wood systems with in-stand delimbing, is vastly preferable to haphazard whole-tree skidding during the growing season (Seymour, 1986).

If advance growth is not well established, then the options are either to allow the stand to develop naturally to the understory reinitiation stage (Seymour, 1992a) or to carry out an establishment cutting. Establishment cuttings should ideally be from below, favoring the largest spruces as growing stock and seed bearers (Fig. 2-7). Here, windfirmness of the residual stand is the dominant consideration, especially on shallow, poorly drained soils. Removals should be as light as the economics of harvesting allow. Residual overwood density should be at least 80 to 100 square feet of basal area (corresponding to the B line on the spruce–fir stocking guide at 6 to 8 inches d.b.h.; in no case should removals exceed about 40 percent of the preharvest stand (Frank and Bjorkbom, 1973). High overwood densities also minimize problems with shade-intolerant competing vegetation.

The usual goal of favoring red spruce can be difficult to reach using shelterwood cutting alone, because fir and tolerant hardwoods (red maple and beech) also thrive under the same shaded conditions. Ideally, these species should be removed in earlier entries, but this is difficult unless the spruce stocking is exceptionally high

Figure 2-7. *Mature red spruce stand immediately after a shelterwood establishment cutting that removed about 40 percent of the basal area.*

and uniform. Harvesting all fir in the establishment cutting, coupled with moderate forest-floor disturbance that destroys fir advance growth and creates receptive seedbeds for spruce germination, can be very effective if the cutting is timed with a good spruce seed year. Selective herbicide treatment of hardwood stumps to reduce sprouting or suckering, or subsequent understory mist-blower applications, may also be warranted on better mixed-wood sites to prevent hardwoods from taking over the understory.

Delaying removal cuttings until the advance growth reaches sapling size (at least 10 years) has many advantages. Most shade-intolerants will not persist this long except in large openings, allowing the very tolerant spruce and fir to become well established. Extending the regeneration period until advance growth reaches 3 to 6 feet in height also gives the reproduction a competitive advantage over pioneer vegetation that invariably develops after the final removal cutting. Delayed or incomplete final removals also impart more irregularity in height to the sapling regeneration than if the overstory were removed when seedlings are small. Such irregularity promotes natural expression of dominance, reducing or eliminating the need for precommercial thinning to encourage differentiation. The main drawback of delaying the final removal is the greater risk of logging damage as the height of saplings increases. This problem can be minimized by careful overstory removal using appropriate harvesting systems that operate only on widely spaced trails (Seymour, 1986).

A small amount of the area regenerated annually is planted, mainly to convert productive soils dominated by previously high-graded, low-quality hardwood stands to monocultures of black, white, or Norway spruce, red pine, or exotic larches. Neither balsam fir nor red spruce are planted for timber production. Site conversion planting has benefited from expansion of wood energy markets and biomass harvesting technology. This permits effective site preparation to be done at a break-even cost. Some supplementary planting of voids is done to remedy understocking of natural regeneration, but the high costs relative to the yield increases make this practice difficult to justify economically (Needham and Clements, 1991).

Plantations and small advance growth released by complete removal cuttings usually must be treated by herbicide release to ensure survival and eventual dominance of the crop trees (Newton et al., 1992). Taller advance growth that can outgrow most competitors except sprouting aspen and red maple, or stands on poorly drained soils where competing species do not grow vigorously, usually do not require release. Timing of release treatments should await the germination of all buried-seed competitors such as pin cherry and *Rubus* but should not be delayed until overtopping and height-growth suppression is apparent (McCormack, 1985). The ideal application window varies between 2 years after harvest on the best sites (usually plantations on former hardwood sites) to up to 7 years on less productive soils. Treatments are typically carried out by helicopter late in the growing season. Glyphosate, the most commonly used herbicide, is very effective except on maples, where triclopyr is sometimes substituted. Herbicide release yields substantial benefits at modest costs, and has become the dominant silvicultural investment in systems for spruce–fir wood production.

Control of Density and Structure—Even-aged Stands Advance growth developing after overstory removal is sometimes so abundant that severe overstocking can result. Precommercial thinnings that leave uniformly spaced crop trees have received increasing interest during the last two decades. The only long-term study (Ker, 1987) has shown significant growth responses (Fig. 2-8). The optimum spacing to maximize pulpwood production of 6-inch-d.b.h. trees is about 6 feet (1200 stems per acre). Precommercial thinnings are carried out motormanually by contract workers using brush saws. Ideal timing is just after crown closure, when the trees can be cut off below the lowest living whorl. Crop trees are usually 5 to 10 feet tall at this stage in dense stands.

The high cost of motormanual spacing with brush saws (Seymour and Gadzik, 1985) makes this practice of questionable economic value, even when future benefits include lower logging costs due to larger tree size along with yield increases (Seymour, 1993). Early attempts to favor subordinate spruces over dominant firs have evolved into crop-tree selection rules that leave standing the most dominant conifer regardless of species (except white-cedar). On poorly drained

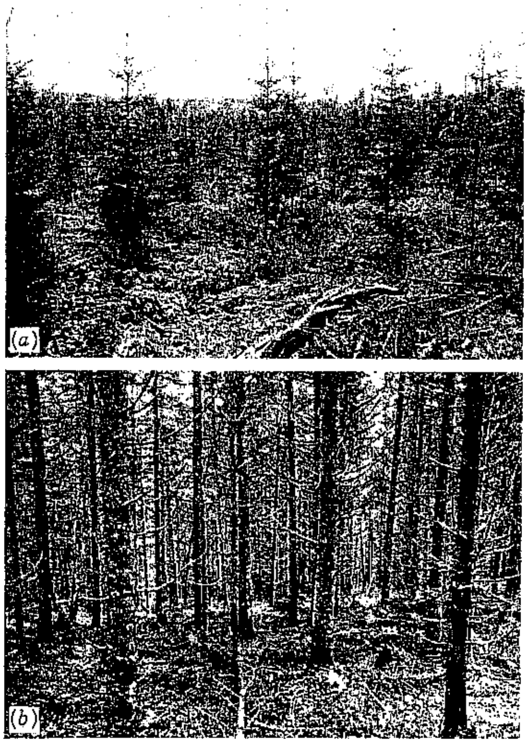

Figure 2-8. *Precommercial thinning in spruce–fir spaced to a density of about 700 trees per acre. (a) 15-year-old spruce–fir stand in northern Maine after spacing. (b) Pure balsam fir stand in northwestern New Brunswick 30 years after spacing.*

soils where spruce and fir grow at nearly equal rates early in development, this practice produces mixed spruce–fir stands. However, on well-drained soils where spruce lapses somewhat behind fir, this procedure may eradicate spruce from the stand and must be modified to maintain a spruce component (Meng and Seymour, 1992). Attempts to mechanize precommercial thinning, in order to reduce the cost and improve worker productivity, have been unsuccessful. A combined mechanical-motormanual system, involving large swath cutters followed by brush-saw spacing of residual strips, was operational in the early 1980s (Seymour et al., 1984) but was later abandoned. Strip thinnings using broad-spectrum herbicides to kill narrow swaths of conifers, carried out early in the growing season by helicopters equipped with special booms and precise guidance systems, have also been tested experimentally (McCormack and Lautenschlager, 1989).

Commercial treatment of merchantable spruce–fir stands has long focused on improving the conifer component of mixed-wood stands, and on increasing the proportion of spruce on account of spruce's greater longevity, resistance to budworm and decay, and higher value. Poor windfirmness has been the major constraint to applying any thinning or partial cutting system to dense, middle-aged or older stands, and many attempts have found that blowdown offsets accretion of residual trees. Most partial cuttings have been carried out by modified diameter limits and removed too many of the most windfirm and best-growing trees. If logging systems and markets had been available to thin from below, then results might have been better. However, spruce and fir, unlike most hardwoods, pine, and hemlock, are not windfirm as individual trees. This makes low-density thinning schedules infeasible, except perhaps when they are begun early in development. As with shelterwood cutting, the challenge in commercial thinning is to make partial entries as light and uniform as possible, taking care to leave fully stocked residual stands that resist blowdown.

Refined density management programs do not exist for eastern spruce—fir stands. Thinning schedules involving commercial entries in uniform, even-aged stands, have been applied only experimentally. No consensus has been reached about issues such as timing, thinning method, removal rates, residual stocking levels, or whether commercial thinning is even desirable. Virtually none of the large age class of second-growth even-aged stands has ever been treated this way, even though stocking guides and suggested thinning schedules (Frank and Bjorkbom, 1973) have existed for 20 years. Commercial thinnings removing trees 4 to 8 inches d.b.h. are contemplated as the large age class regenerated since 1970 begins to reach merchantable size around the year 2000.

Control of Density and Structure—Uneven-aged Stands Early silvicultural recommendations for spruce–fir forests emphasized harvesting of spruces over 14 inches d.b.h. At that time, spruces this size were all very old remnants of the presettlement forest that had escaped earlier cutting. Although this system evidently was thought to be a form of selection cutting, no attention was given to age structure. These cuttings, in combination with the 1913–1919 budworm mortality, actually created more uniform stands and reduced age diversity (Seymour, 1992a).

Westveld (1953a) and Hart (1963) recommended a slightly more refined partial cutting system, in which most merchantable fir is removed at frequent intervals but spruce is left to larger sizes, in the belief that spruce stocking would gradually increase and a balanced age structure would eventually develop. From the 1940s through the early 1970s some industrial landowners applied this system using different diameter limits for each species, sometimes coupled with marking based on risk and vigor classes. However, quantitative residual-stand densities were not specified, and there was no attempt to control overall stand structure in the smaller-diameter classes. These practices were largely abandoned by the 1970s. The spruce budworm outbreak threatened to kill the small-diameter fir, and increasing awareness of the even-aged structures of second-growth stands challenged the validity of uneven-aged silviculture.

There is little interest in balanced selection cutting by most spruce–fir landowners except in special protection zones where even-aged practices are prohibited. The only long-term documented example is located on the Penobscot Experimental Forest in east-central Maine, where replicated 25-acre compartments have been treated by three levels of intensity since the early 1950s. All use a very high *q* value of 1.96 (1.4 for 1-inch d.b.h. classes) and a maximum d.b.h. of 20 inches; target basal areas vary from 115 on a 5-year cutting cycle to 80 on a 20-year cycle (Frank and Blum, 1978). Stand quality has improved dramatically during the 40 years of treatment, and the goal of reducing stocking of merchantable-sized fir and hardwood has been largely met. In the 5-year cutting-cycle treatment, harvests have averaged 306 cubic feet per acre, but during the past 15 years they have been maintained only by gradually reducing the residual basal area to nearly 20 feet below the goal. A deficit of pole timber has developed due to inadequate recruitment from the 1- to 4-inch class and heavier-than-planned presalvage cuttings during the budworm outbreak of the early 1980s. Meeting the overall basal-area goal has forced a strong shift to a structure overstocked with sawtimber-sized trees. Hemlock increasingly dominates the composition of the merchantable-sized classes, although all conifers are well represented in the reproduction. The increasing divergence from the goal suggests that this particular structure may not be sustainable, or that many decades will pass before stability is achieved.

Two-aged Silviculture—Irregular Shelterwood The nominal selection cutting practices of the 1950s failed to develop balanced uneven-aged stands but did provide an alternative, two-aged model of stand development. Two features characterize this silvicultural system: Advance growth is held for extended periods beneath a partial overstory, and some trees from the older age class are retained at least until the younger cohort reaches merchantable size. The closest silvicultural analogue is the irregular shelterwood method, or *shelterwood with reserves.* Marquis (1992) provides an excellent description of stand development patterns under this system (which he terms *even-aged with residuals*) for the cherry–maple type. Davis (1989) has also documented a two-aged developmental pattern in spruce–fir forests originating after similar heavy cuttings.

Intensive application of two-aged silviculture in spruce–fir forests is quite recent, and no consensus has emerged. One issue is the choice of the *two-rotation* reserve trees that are retained after the final, incomplete removal cutting. For example, many even-aged spruce–fir stands contain a few white pines that develop high-quality, knot-free boles as a result of competing with densely stocked spruce–fir stands (Fajvan and Seymour, 1993). At the end of a 60-year fir pulpwood rotation, such pines reach 8 to 12 inches d.b.h. as codominants but, unlike similar spruces, have the ability to remain windfirm and grow as emergents until they are 24 to 30 inches d.b.h. or larger. Leaving such pines as reserve trees sacrifices little in harvest value (since often they are only pulpwood- or small-sawlog-sized) and does not interfere with the developing spruce–fir reproduction for several decades.

Another justification for irregular shelterwood cutting involves retention of spruces, hemlocks, or cedars from the lower crown classes in order to ensure these species remain competitive with the more aggressive fir and tolerant hardwoods after overstory removal. Even though these trees may be as old as the dominants and have small crowns, they do not blow down. Because they are much shorter, they generally respond well by expanding their crowns upward after release. Thinning schedules must consider future reserve trees beginning early in development using moderate crown thinnings. In addition to the usual objective of favoring development of large-crowned dominant and codominant spruces or firs, crown thinnings also can release spruces that have lapsed into lower strata. Such treatments may be especially appropriate in stands on good sites where the upper stratum is pure fir and paper birch but where the lower stratum contains some intermediate or overtopped spruces. Heavy low thinnings, on the other hand, are undesirable, as they can eliminate spruce.

Two-aged structures offer a flexible way to overcome many drawbacks of strict even-aged spruce–fir silviculture without adding the complexity of balanced selection management. Removing the overstory in several stages, along with retention of widely spaced reserve trees, can obviate precommercial thinning by imparting an irregular height structure to the sapling regeneration. Windfirm reserve trees develop into valuable large-diameter stems, some or all of which can be removed along with smaller stems in the first commercial thinning or left as large-cavity producers. The naturally pruned, branch-free residuals provide a low-cost way to grow high-value sawlogs. Carefully chosen reserve trees also can greatly improve the appearance of harvested sites and provide permanent vertical structure absent from even-aged systems. Two-aged stands also can help to maintain species diversity in cases where shade-tolerant conifers with slow juvenile growth patterns are at a competitive disadvantage after overstory removal.

Rotations and Yields Yields of spruce–fir stands under management have long been a source of great uncertainty. Estimates have ranged from as low as 10 cubic feet per acre per year in cutover post-budworm stands (Westveld, 1953b) to over 10 times this value on rotations of about 70 years in fully stocked even-aged stands on good sites (Meyer, 1929). Empirical growth studies established in the 1950s found periodic annual increments of 38 to 53 cubic feet per acre in fully stocked softwood stands (Safford, 1968). However, it is now recognized that these growth rates were somewhat inflated by above-normal ingrowth as the second-growth age class reached merchantable size (Seymour, 1985). Mean annual increments have proven to be less at about 30 cubic feet per acre per year (Seymour and Lemin, 1991). These values are discouragingly low relative to the potential under management, and may represent a legacy of inadequate stocking control as well as widespread partial cutting that removed the best-growing trees well before maturity.

Yields of spruce–fir stands under silvicultural production systems can be impressive if density and spacing are controlled early in development. At least 1200 stems per acre will reach pulpwood size (5 inches d.b.h.), so current practice in precommercial thinning is to leave closely spaced stands. The best spruce plantations on old-field sites have yielded 80 to 120 cubic feet per acre per year (Seymour, 1992b). Precommercially thinned natural stands commonly grow on poorer sites than plantations, and are often not as fully stocked. Thus, their yields may be somewhat lower (50 to 80 cubic feet per acre per year), although no such stands have yet reached maturity. Optimum financial rotations culminate at ages 40 to 50 for high-site plantations, to over 60 years for natural stands on site 50 (Seymour, 1993). The FIBER and NE-TWIGS models discussed earlier can also be used to predict stand development and yields for mixed stands for which no yield tables or empirical data are available.

Net growth of mixed spruce–hemlock–fir stands under various partial cutting treatments ranged between 50 and 60 cubic feet per acre per year, with little relationship to residual-stand basal areas of 40 and 120 square feet per acre (Solomon and Frank, 1983). Shorter cutting cycles did not reduce mortality, which averaged slightly above 10 cubic feet per year for all treatments. Sawtimber growth was best under high stocking levels, mainly because all the low-density treatments removed most sawtimber growing stock.

Widespread growth declines beginning around 1960 in red spruce and balsam fir have been reported by many investigators. Air pollution or other anthropogenic factors have been implicated in causing growth declines in mature red spruce in high-elevation stands. In low-elevation stands where most of the commercial forest is located, growth declines can be explained by normal maturation of the second-growth forest and recent budworm defoliation (Smith et al., 1990).

Suceptibility to Damage By far the most serious pest of spruce–fir forests is the eastern spruce budworm, a native insect that has reached outbreak status three times during the 20th century (Irland et al., 1988). During uncontrolled outbreaks, most mature fir is killed after several years of complete defoliation, while immature stands suffer partial mortality. Some red spruce may also be killed in severe outbreaks, but rarely is spruce mortality high. Extensive insecticide protection during the recent 1972–1984 outbreak prevented the tremendous losses experienced during the 1913–1919 outbreak, but substantial volumes of fir were killed in stands that went unprotected and were not salvaged (Irland et al., 1988; Seymour, 1992a). Budworm outbreaks historically return at about 40-year intervals. In fir-dominated stands, this cycle perpetuates a two-aged forest structure of even-aged stands by periodically thinning the 40-year age class and killing 80-year old stands (Baskerville, 1975a). Where substantial stocking of the resistant, longer-lived red spruces or hardwoods survive, budworm-caused mortality may favor development of uneven-aged stands that resist future outbreaks (Seymour, 1992a).

Experience from the recent outbreak largely confirmed the unfortunate dilemma noted by Baskerville (1975b). Virtually any stand structure that produces high volumes of spruce and fir also risks large losses from an uncontrolled outbreak. The traditional recommendation has been the frequent removal of fir along with efforts to favor red spruce and nonhost species (Blum and MacLean, 1985). However, even pure red spruce stands, while demonstrably less vulnerable than fir, suffer growth reduction and some mortality without insecticidal protection (MacLean, 1985). Thus, the lower vulnerability of spruce is of no value unless the landowner can suffer substantial fir mortality. Multistoried stands recommended by some authors (Westveld, 1946) may suffer nearly complete loss of the regenerating strata caused by downward dispersal of large budworm larvae. Current precommercial thinning practices that favor dominant firs are creating stands that undoubtedly will be at great risk in the next outbreak; protection will be essential. Black spruce plantations may offer the best hope for maintaining spruce–fir production under the certainty of episodic budworm outbreaks, but relatively few are being established.

During the nineteenth century, the most serious pest of old-growth red spruce was the spruce bark beetle (Hopkins, 1901). This insect caused serious damage primarily to old, large-diameter trees that are now so uncommon that outbreaks are rare. This insect may well have been the principal natural mortality agent in virgin spruce–fir forests, but evidence is inconclusive. The introduced balsam woolly adelgid also is a serious pest of fir in coastal regions but appears to be climatically limited and does not cause serious damage inland.

Wind is an important disturbance agent, owing to the shallow-rooted habit of spruce and susceptibility of fir to heart rots. Unlike insect epidemics, however, wind damage is usually a chronic phenomenon. Fire was rare in presettlement forests. Estimates of the natural recurrence interval in northeastern Maine vary from a minimum of 800 to over 1900 years (Lorimer, 1977), but it is virtually impossible to separate a few, very large and probably human-caused fires from purely natural events. Extensive spruce logging, especially of pure stands on upper slopes and near railroads, appears to have increased both fire frequency and severity during the late 1800s in comparison to the presettlement era (Weiss and Millers, 1988).

Decay fungi play an important role in limiting the pathological rotation of fir to 50 to 70 years. The most important is *red heart,* caused by the trunk-rotting fungus *Haematostereum sanguinolentum*. Numerous butt rots also are important. These pathogens all enter the tree through naturally occurring wounds, so the only silvicultural control measure is harvesting the fir on short rotations. The high susceptibility of fir to decay makes this species a valuable cavity producer, although such trees are often so weakened that their longevity is limited by wind breakage.

Lethal disturbances affecting hardwood species, primarily the beech bark disease and birch dieback (discussed earlier), also have influenced stand development of mixed spruce-hardwood stands. Lethal disturbances affecting other conifer species that potentially have affected spruce–fir stand development include the larch sawfly outbreak of the late 1800s, which virtually eliminated tamarack from poorly drained sites throughout the spruce–fir region, and the pine leaf adelgid, which can kill eastern white pine without damaging the alternative host red spruce.

White Pine Type Group

The white pine type group is given major emphasis in Chapter 3. This discussion will focus on treatment of nearly pure stands, usually of old-field origin, common in the Northeast.

Growing eastern white pine for production of high-quality lumber can be very lucrative, but it "should be done well or not at all" (Smith and Seymour, 1986). Because this species has little value for pulpwood but commands high prices for high-quality sawlogs, success depends critically on developing a few high-quality crop trees early in stand development. Intensive measures are essential to overcome two serious problems: deformation of the terminal shoots by the white pine weevil, and the persistence of large, dead branches that prevent formation of knot-free wood.

The best method for developing high-quality trees is to establish dense pine regeneration beneath a light pine overwood and to grow it there for several decades until 100 to 200 future crop trees per acre achieve a straight stem of 17 to 25 feet. Weevils will avoid the partially shaded understory pines. Dense stocking also limits branch size and causes rapid shedding, which greatly facilitates later pruning treatments. Overwood density must be kept to below about 40 percent crown cover to prevent shade-tolerant species such as red maple, hemlock, or balsam fir from shading out the pine seedlings (Lancaster and Leak, 1978). This may require several partial removal cuttings to maintain an overwood composed of a few high-value trees that grow rapidly as large-crowned, isolated individuals.

After the overwood is removed and the crop trees reach about 6 inches d.b.h. with their live crown base at about 20 feet, no more than 100 crop trees per acre should be released in a heavy crown thinning and pruned to a height of 17 to 25 feet. Future density management should maintain the live crown base at this point in order to maintain rapid growth of the crop trees and prevent formation of dead branches. This requires an unconventional low-density thinning schedule, where stands are kept well below the B line throughout the remainder of the rotation (Seymour and Smith, 1987; Fig 2-9A). Fortunately, this coincides with the need to maintain a partial overstory for shelterwood regeneration, which should begin perhaps 30 years before the crop trees reach financial maturity at 20 to 24 inches d.b.h. (Page and Smith, 1994). Conventional high-density thinning schedules will produce more total board-foot volume (Leak, 1986), but most of the yield will be in small, poor-quality sawlogs unless very long rotations are used (Fig. 2-9B).

In pure stands of old-field or plantation origin, crop-tree quality may be very poor from weevil attacks and low establishment density. However, if only 50 to 100 reasonably straight pines can be found, stand quality can be upgraded dramatically over time by pruning and careful tending of these trees, on which most of the future value will form. Another problem in old-field pine silviculture is the successional

Figure 2-9. Contrasting approaches to crown thinning in a 40-year-old eastern white pine plantation. (a) Low-density thinning to 120 trees per acre. (b) Conventional thinning to the B line on the pine stocking guide.

tendency to revert to oak or northern hardwoods. Timing the establishment cutting with an abundant seed year, combined with understory control using mist-blown herbicides, is essential. Maintaining the pine component becomes increasingly difficult as site quality improves. Lancaster and Leak (1978) recommended allowing the site to revert to hardwoods if the site index is 70 or higher. These measures are unnecessary on excessively well-drained sandy outwash soils, where hardwoods are not serious competitors.

Problems with understory encroachment can also be overcome by growing pine as isolated emergents in stratified mixtures with a lower stratum of hemlock, red spruce, or balsam fir (Seymour, 1992b). Pine will outgrow these associates, even if spruces or hemlocks have an initial height advantage at stand establishment (Fajvan and Seymour, 1993). The dense spruce shade also minimizes weevil damage and causes enough branch shedding that pruning may be unnecessary. Intensive application in such mixed-conifer stands can employ an irregular shelterwood system, where the pines are grown to large sawtimber size during two rotations (120 to 150 years or more) of the other species. If hemlocks and spruces are also left as reserve trees, stands will eventually develop multicohort structures that can be managed using an irregular selection system (Fajvan and Seymour, 1993).

White pine blister rust is a serious malady in the Northeast. Silvicultural control measures are discussed in Chapters 3 and 9.

Oak Type Group

In central and southern New England, valuable mixed-hardwood forests dominated by red oak are common. These even-aged stands originated from advance growth or sprouts after clearcuttings for fuelwood or old-field pine. Reconstruction studies (Oliver, 1978; Kelty, 1986) found that red oak will eventually outgrow and stratify above its common associates (red maple, black birch, and hemlock) if well-established advance regeneration is present. Oak emergence may be delayed or not occur, however, if advance growth is small and aggressive intolerant competitors occupy the site (Smith and Ashton, 1993).

Red oak density management and regeneration in the Northeast generally follow similar practices as in the Central Region and the Southern Appalachian Hardwood Region (see Chapters 4 and 5). Basal area growth of oaks is reduced by competition from other nearby oaks but not from maples and birches (Kittredge, 1988). Optimum stocking for sawtimber production was 40 to 50 trees per acre (Oliver, 1978), so most silvicultural systems follow a crop-tree approach that culminates with shelterwood cuttings. In addition to maple and birch, hemlock can also be maintained in the lower stratum, where it grows well, does not compete with the oak (Kelty, 1989), and prevents invasion by red maple or mountain laurel. The importance of advance regeneration and even-aged stand structures dictate the shelterwood method. In a survey of shelterwood cuttings in southern New England, oak advance growth increased with the time elapsed since cutting and was best under light overstory densities of 20 to 40 square feet of basal area (Kittredge and Ashton, 1990). Where heavy deer browsing eliminates acorns and prevents advance seedlings from becoming established, protection from deer using tree shelters may be effective, but it is costly (Kittredge et al., 1992). Another problem is episodic gypsy moth defoliation that reduces acorn production and overall tree vigor.

MANAGING FOR NONTIMBER VALUES

Where Are the Conflicts?

Production silvicultural systems using heavy-handed, artificial practices such as mechanical site preparation and planting monocultures of genetically improved trees have never received widespread application in the Northeast (Seymour, 1992b). In this region, criticism of forest practices focuses on exploitative logging that has no silvicultural intent but is motivated only by short-term financial gain. Another historical trend that arguably has created an even more profound change on the landscape, but which receives less attention from the public, is the extensive deforestation and reforestation of agricultural land throughout the region. Centuries of human utilization of the northeastern landscape has undeniably altered ecosystems. Habitat fragmentation is also a concern. Silvicultural practices are largely not responsible for these changes, but they do provide the best hope for ameliorating their ecological and economic consequences.

Diversity Paradigm

Concurrently with the development of this tension, a new paradigm has evolved to replace the traditional multiple-use doctrine of the past. Rather than emphasizing tradeoffs among individual resources, this new concept holds that maintaining biological diversity (and restoring it where it has been reduced) has inherent value (Hunter, 1990). If one accepts this premise, then managing for a diversity of habitats at every scale, from small vernal pools to large landscapes, will sustain ecological values. In practice, managing for diversity usually leads away from a single-minded focus on the requirements of a few conspicuous wildlife species, toward more holistic treatments for all organisms.

Seymour and Hunter (1992) discuss how New Forestry might be implemented in eastern spruce–fir forests to enhance biodiversity. Key principles include patterning silvicultural systems after natural disturbance regimes, and restoration of species and age diversity where logging has reduced them. Specific stand-level practices include widespread retention of reserve trees using two-aged silvicultural systems (Fig. 2–10), reservation of rare species and enrichment planting to restore depleted species, longer rotations to restore age diversity, and limited whole-tree harvesting. Special treatment of riparian zones and avoidance of fragmentation by clustering even-aged stands are important landscape-level practices. Nyland (1991) outlines similar ideas for northern hardwood forests.

Figure 2-10. *Irregular shelterwood management in mature spruce–fir–northern hardwoods in northern Maine 15 years after the final incomplete removal cutting, which left red spruce and hardwood reserve trees. Overstory hardwoods were subsequently killed in an aerial herbicide treatment, releasing developing spruce–fir saplings, forming dead snags of value for wildlife habitat, and replenishing large down woody debris.*

Seymour and Hunter also discuss how a landscape *triad,* combining areas devoted to production silviculture, ecological reserves, and New Forestry silvicultural systems, could coexist on the landscape. The triad concept is especially relevant to the nothern New England landscape, which has been characterized by low-intensity management but which is now intensely utilized for forest products and by recreationists. Paradoxically, expanding areas under high-yield management (employing many practices that reduce stand-level diversity) could actually enhance landscape diversity. The dramatic yield increases possible under production silviculture (Seymour, 1992b) could permit other areas to be set aside as reserves or managed under New Forestry principles, since less area would be needed to supply the large industrial demands.

Potential Conflicts and Conclusions

Although there are many situations where wood production and management for biological diversity do not conflict, other situations require clear tradeoffs. A growing problem (except in heavily utilized industrial forests) is the management of early-successional forest types (aspen–paper birch, black cherry, oak) that require moderate to heavy disturbances. The proven even-aged practices used to regenerate these forests in the past are viewed with increasing disdain by a public concerned with visual quality. Aesthetic concerns can be partially addressed by scrupulous attention to the appearance of logging operations, especially slash accumulations on roadsides and landings. Concerns about lack of vertical structure and the temporarily "devastated" appearance of clearcuts can be addressed by substituting low-density shelterwoods with reserve trees that do not suppress the developing reproduction. Landscape aesthetics can be enhanced by carefully embedding small even-aged stands within larger areas of mature forest, but this increases the danger of fragmenting residual habitats unless the total area under regeneration is kept small (Hunter 1990).

Another source of tension between efficient wood production and diversity involves the practice of *green retention*. Although growing high-quality trees on long rotations can restore age diversity to biologically young forests, requirements for standing dead snags and replenishing large woody debris on the forest floor dictate that some large trees never be harvested. Specific guidelines for numbers and species of retention trees have not been developed for the Northeast, but it is certain that leaving even a few large trees to die inevitably reduces timber yields. One partial solution would be to retain both high- and low-quality stems and harvest only the valuable stems on long rotations. Standing dead snags also pose a serious hazard to workers and thus conflict directly with logging safety practices.

Nonindustrial landowners who own much of the northeastern forest have never rated wood production very high, but neither are they averse to enhancing wildlife habitat and biological diversity. Foresters, landowners, and the public must all redefine their vision of silviculture as a positive means of improving productivity for all values, not just wood. If this consensus emerges, then the recent public attention and criticism can be the best opportunity in history for advancing silvicultural practice in the Northeast.

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