Sugar Maple: Its Characteristics and Potentials

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Abstract

Sugar maple dominates the northern hardwood forest, but grows over a broader geographic area. Conditions of soil and climate largely limit its distribution, and account for its less continuous cover along fringes of the range. Sugar maple regenerates readily following a wide range of overstory treatments. Success depends upon its status as advance regeneration, particularly under strategies favorable to less shade-tolerant species. In even-aged stands, trees of upper canopy positions grow well following release by cutting. Those of lower canopy positions do not. In uneven-aged stands, both small and large trees respond well to release. Diameter-limit cutting removes the best trees, often leaving stands in poor condition for growth and health. Damage to trees by natural agents and logging commonly leads to discoloration and decay, and often to dieback. Within the range of northern hardwoods, sugar maple seems generally healthy. Exceptions include stands damaged by defoliation, logging, and similar agents.

Requirements for Ecologic Success

To persist over ecologic time, a species must become established at available sites; survive, grow and develop successfully under prevailing edaphic, climatic, and biologic conditions; produce viable seed in quantity and frequency for establishment at critical times; and endure. Its range expands when seed moves to favorable sites in new areas.

In this context, *site* means the interacting biotic and abiotic factors that determine the potential for a species or tree to become established and develop. Important factors include:

1. the periodicity of extended shortages or excesses of moisture;
2. deficiencies or excesses of nutrients due to the parent material, with uptake influenced by available moisture;
3. mechanical damage by wind, ice and snow, and vertebrate animals (including people);
4. defoliation and other activities by insects and other invertebrates, and effects of fungi and disease organisms; and
5. physical and chemical interference and competition from existing or co-establishing vegetation.

These affect the form, vigor, and growth of individual trees and groups of trees. They also may influence the potential for flowering and pollination, seed development and dispersal, and embryo viability and germination.

Altogether, site factors influence tree success at three levels:

1. across the geographic range of a species, with the best sites likely toward the center of that area;
2. across environmental gradients within the geographic range, based upon soil, climate, and critical biota; and
3. across a single location, with variations of micro-site features that affect young trees before the root systems integrate soil across a larger local space

Generally, species and individual trees best adapted to the local site conditions and competitive effects have the highest vigor, grow the best, and occur in the upper crown positions within a cohort. Further, these trees may suffer fewer environmental stresses over time, live longer, and develop to larger sizes. Sugar maple (*Acer saccharum* Marsh.) exemplifies these principles within its range.

Ecologic Characteristics of Sugar Maple

Sugar maple is a major component of the northern hardwoods forest type group, including six distinct hardwood forest cover types and one mixed hardwood-conifer type (Eyre 1980). It occurs in lesser amounts or occasionally in two other eastern hardwood cover types, three oak-dominated forest cover types, five central hardwoods forest cover types, two boreal hardwood cover types, and six eastern conifer cover types. The current geographic range extends from the Maritimes in Canada westward across the Great Lakes region to the prairie, and southward into Missouri, Tennessee, Virginia, Pennsylvania, northern Maryland and Delaware, and southern New England. Small outliers occur farther south, and in northeastern South Dakota (Figure 1).

Sugar maple accounts for 50% or more of the basal area in northern hardwood stands. The most contiguous area of this cover type currently runs from northern Ohio and Pennsylvania through southern Ontario and Quebec, and eastward through northwestern Massachusetts into western Maine. Northern hardwoods also grow extensively in southern Ohio and west-central Indiana, and along the Appalachians in eastern West Virginia. More dispersed major blocks intermix with other forest cover types around the Great Lakes in Michigan, Wisconsin, Minnesota, and western Ontario; and from central Maine eastward through the Maritimes (Figure 1). This broad region has a generally cool and moist climate, a growing season of 80-260 days, and well-distributed precipitation throughout that period (Godman 1965; Eyre 1980; Godman *et al.* 1990).

Since the early 1900's, northern hardwoods have naturally reforested many former agricultural sites within their natural range, and probably in fringe areas as well. As a consequence, many areas formerly supporting only widely dispersed and disconnected remnant woodland patches now have large tracts of unbroken northern hardwood forest

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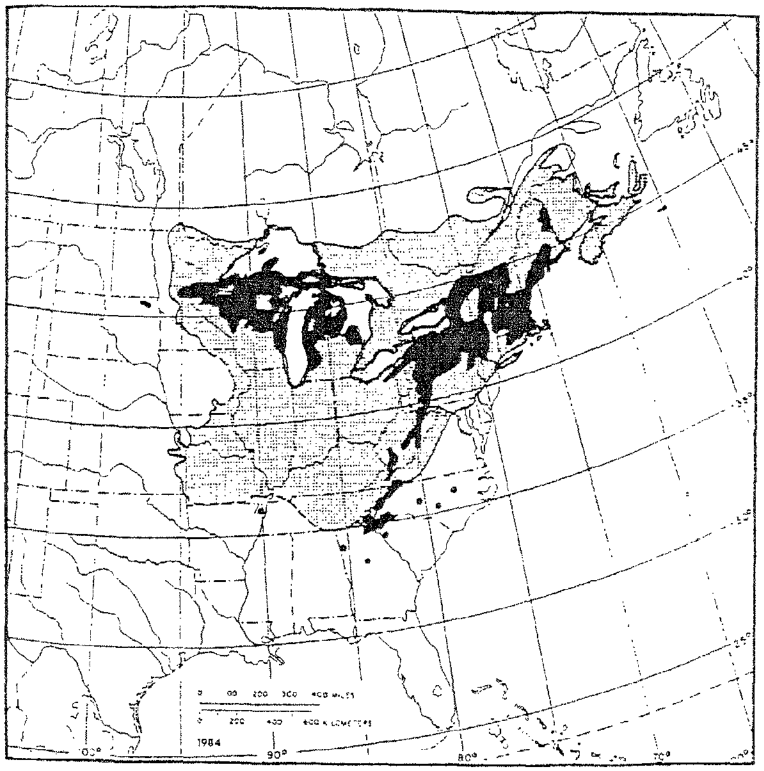

Figure 1.—The geographic range of northern hardwoods (black) in the United States, in comparison to the distribution of sugar maple (stippled) (after Shantz and Zon 1924; Godman *et al.* 1990).

(Nyland *et al.* 1986; Zipperer *et al.* 1988, 1990). Overall, from 1963 to 1992 northern hardwoods increased from approximately 13 to 19 million ha (32 to 46 million ac) (Quigley and Morgan 1969; Powell *et al.* 1993). At upland sites, the naturally reforested stands often contain pure sugar maple, or sugar maple mixed with some white ash (*Fraxinus americana* L.) or another common associate. On more poorly drained soils, red maple (*Acer rubrum* L.) has become dominant, along with white ash and American elm (*Ulmus americana* L.). The reforested stands generally have an even-aged character. Other woodlands commonly contain a broader array of species, and many have an uneven-aged character. (e.g., Nyland *et al.* 1986; Zipperer *et al.* 1990).

The range of northern hardwoods overlaps that of Spodosol and Inceptisol soils (Figure 2). Sugar maple also extends across a major area of Alfisols lying south of the Great Lakes, but primarily on fertile, mesic sites (Smith 1995). It grows in sands through silt loams, but develops best in fairly deep, moist, fertile, well-drained loam soils having ample growing season soil moisture. These conditions enhance leaf litter decomposition, helping to enrich the soil. Sugar maple does poorly in dry soils, and will not occur on wet sites (Godman 1965; Leak 1978; Godman *et al.* 1990). The fine feeding roots develop mainly within or near the organic horizons. They, and the mycorrhizal associations on them, react to variations in soil moisture and texture, and events that sharply reduce overstory shading can affect their development and survival (Fayle 1965; Kessler 1966; Allen 1987).

In the southern portion of its range, sugar maple is important on the highest quality oak sites, moist (but not wet) flats, and in ravines or coves. To the north it dominates mesic ridges between poorly drained areas, the warm upper slopes with good drainage and a middle or better range of pH, and enriched benches and coves. Along with the importance of bedrock and till sources on current soil, best growth occurs at sites with organic material incorporated into the mineral horizons. American beech (*Fagus grandifolia* Ehrh.) often replaces sugar maple on the drier sites, especially at the more northern latitudes. Red maple dominates the poorly drained soils throughout much of the natural range for sugar maple. At high elevations and toward the northern part of their range, northern hardwoods converge with boreal forests. Aside from soil, climate largely limits the distribution of sugar maple in elevation, as well as longitude and latitude. Conditions become too cold to the north, too warm to the south, and too dry to the west (Godman 1965; Post 1969; Hosie 1973; Leak 1978, 1980; Godman *et al.* 1990; Farrar 1995; Heisey 1995).

Biologic Attributes of Sugar Maple

Sugar maple produces some seed by age 50. Amounts increase thereafter, with production related to tree size and stand density (e.g., tree vigor). Large diameter (past 100 years) trees often produce vast quantities. In sawtimber stands, production varies from some seed annually, to medium or better crops in slightly more than one-half of the years within the range of northern hardwoods. Good crops

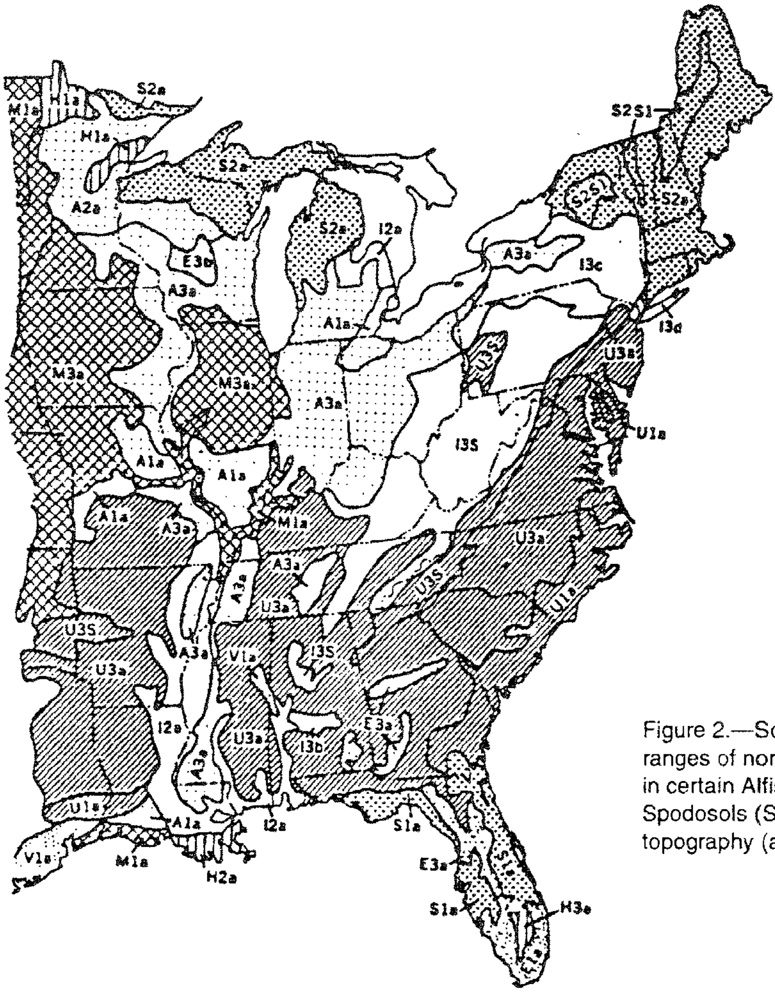

Figure 2.—Soil orders of northeastern United States. The ranges of northern hardwoods and sugar maple largely occur in certain Alfisols (A2a and A3a), Inceptisols (I3a and I2a), and Spodosols (S2a and S2S1) on gentle to steeply sloping topography (after US Soil Conserv. Soc. 1975).

often occur in successive years, with only occasional failures (Godman 1965; Tubbs 1969; Godman and Mattson 1976; Godman *et al.* 1990; Garrett and Graber 1995). At least among developing even-aged stands of seed-bearing ages in Pennsylvania at the fringe of northern hardwoods, annual seed production varies widely, with good seed years only every 7-8 years (Grisez 1975, Long *et al.* 1997).

Seeds will glide up to 107 m (350 ft) down wind into openings, but most fall much closer in closed stands (Godman *et al.* 1990; Nyland 1996). They stratify naturally over winter within the leaf litter. Most germinate the first year under favorable conditions. The high germination capacity commonly results in a carpet of seedlings following good seed years, given favorable environmental conditions during the spring and early growing season. The strong radicle readily penetrates a heavy leaf litter, so that a high proportion of germinants survive if the forest floor remains reasonably moist. Even small and light overstory disturbances, or other events that brighten the understory, trigger regeneration underneath residual stands at mesic sites. Once established, advance seedlings and saplings may persist for many years. They develop rapidly following either partial or complete overstory removal, especially at sites with good moisture and available nitrogen. In addition, young trees, small saplings, and large seedlings readily sprout. These sources, coupled with well-developed advance regeneration, often maintain sugar maple as an important component of new stands where more rapidly growing species also regenerate (Godman 1965; Trimble *et al.* 1986; Godman *et al.* 1990; Tryon *et al.* 1992; Wang and Nyland 1993; Walters and Reich 1997).

Sugar maple shows considerable genetic variability. Sources from warm, dry portions of the range have greater drought resistance than seedlings from cooler and moister sites. Local and individual genetic variation also affects height growth and degree of apical dominance (Kriebel 1969). Also, tests suggest significant genetic effects on individual tree diameter and height growth, and survival. Early responses provide a good indicator of long-term height development (Schuler 1994).

Repeated browsing by ungulates, hare, and rabbits may destroy sugar maple seedlings, making regeneration difficult by any silvicultural method. Also, stands subjected to protracted intense browsing may develop understories of interfering plants that can prevent successful regeneration of sugar maple in both even- and uneven-aged stands. These include ferns and grasses (Tubbs 1973; Marquis 1987), or a dense beech understory (Richards and Farnsworth 1971; Kelty and Nyland 1981; Marquis *et al.* 1984, 1992; Marquis 1987) or striped maple. Failure to control these plants will lead to a failure of sugar maple and other desirable species following cutting to a wide range of densities, and after clearcutting (Richards and Farnsworth 1971; Kelty and Nyland 1981; Marquis *et al.* 1984, 1992). The reproduction method must reduce these obstacles (site preparation and reduction of animal density) to insure success (Kelty and Nyland 1981; Sage 1987; Marquis *et al.* 1992; Horsley 1994; Nyland 1997). For large areas, applications using a skidder-mounted mist blower prove most efficient for controlling an interfering understory (Sage 1987; Horsley 1994).

Growth and Development

On suitable sites, sugar maple lives for 300-400 years, reaching more than 30 m (100 ft) tall and 89-102 cm (35-40 in) dbh (Westveld 1933; Eyre and Zillgitt 1953; Blum 1961; Leak 1975). It annually increases about 0.3 m (1 ft) in height for the first 30-40 years, but little after 140-150 years (Godman *et al.* 1990). Frequent breakage by ice, snow, wind, and logging often limits useable length to about 8-12 m (25-40 ft) at many high elevation and northern latitude sites (Nyland 1989). These injuries commonly lead to discoloration of wood present at the time of injury, and decay may develop in some cases (Shigo 1966).

Large trees add about 2.54 cm (1 in) of diameter per decade in unmanaged stands. Increment even of old trees will increase following release by cutting. In managed uneven-aged stands and even-aged ones of intermediate ages, radial increment of good-vigor trees will increase in proportion to the degree of release (intensity of cutting), and may average 5-8 cm (2-3 in) per 10 years (Nyland 1989). Mortality will decrease inversely with residual density (Eyre and Zillgitt 1953; Gilbert *et al.* 1955; von Althen *et al.* 1994; Majcen 1995; Pothier 1996). Yet net stand-wide production increases in stands thinned down to 60% relative density, due in part to the reduction of mortality losses (Nowak 1996). Also, individual residual tree diameter growth increases following thinning in even-aged stands. But the degree generally correlates with tree size and crown canopy position (Stone 1986; Marquis 1991; Nyland *et al.* 1993). Low vigor trees of intermediate and overtopped positions continue to grow at relatively slow rates, even following fairly heavy release (Figure 3a). By contrast, small (young) trees in managed uneven-aged communities have well developed crowns and good vigor (Kenefic and Nyland 1998). Their radial growth (Figure 3b) and height will increase appreciably if cutting regulates the spacing and density across size classes (Eyre and Zillgitt 1953; Gilbert *et al.* 1955; Mader and Nyland 1984; Donoso *et al.* 1998).

Some Factors Affecting the Health and Condition of Sugar Maple

Several insects, fungi, diseases, and environmental phenomenona affect sugar maple. Few actually kill the trees. They may reduce the vigor, decrease the value for products, or structurally weaken the bole. Sugar maple borer has this effect. Some fungi like *Armillaria* kill sugar maple, and heavy defoliation over successive years may result in mortality. But defoliation mostly kills low-vigor trees, and root diseases and

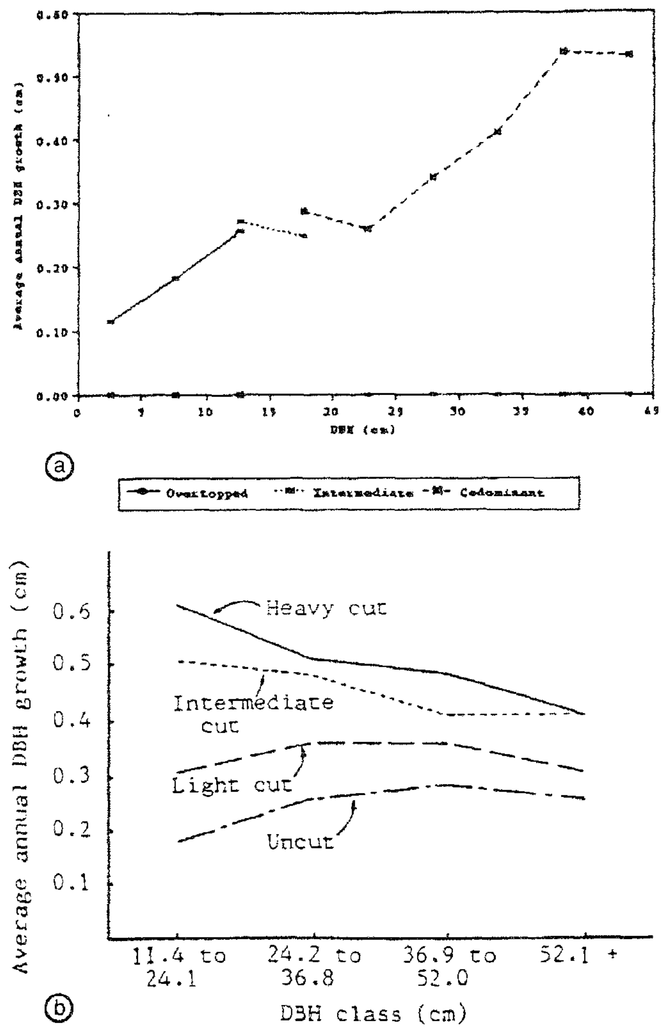

Figure 3.—Growth of sugar maple trees following release. a. After thinning in even-aged stands, radial increment correlates with crown position and tree diameter, with best increment among trees that initially grew in upper-canopy positions (after Lareau 1985; Nyland *et al.* 1993). b. After selection system treatments that cut across the diameter classes in uneven-aged stands, the growth of small trees increases in proportion to the intensity of cutting, and dramatically so at relatively low residual density (after Eyre and Zillgitt 1953).

other fungi commonly enter through wounds to a tree (Allen 1987; Shigo 1966; Shortle 1987). Breaking branches >8 cm (>3 in) diameter and removal of bark from >970 cm^2 (>150 in^2) of the bole triggers discoloration of the wood present and may lead to decay if wood-rotting fungi colonize through the wounds (e.g., see Shigo 1966). Such large wounds appear to increase the chance of measurable decay within 20-25 years (Hesterberg 1957; Silverborg 1959; Ohman 1970; Nyland and Gabriel 1971; Nyland *et al.* 1976).

Landowners cannot prevent damage during storms and actions of fungi. They can spray to protect against defoliation. And they can control injuries from logging and other stand uses to some degree (Nyland 1989). Precluding skidding on saturated soils prevents root wounds that serve as entry courts for diseases and also reduce the size of a root system and its moisture absorption and carbohydrate storage capacities. These injuries can lead to dieback during periods of stress (Shigo 1985; Manion 1991; Cote and Ouimet 1996).

Several assessments suggest either a recent increase of diebacks and declines in sugar maple (Lachance *et al.* 1995; Cote and Ouimet 1996; Auclair *et al.* 1996; Auclair *et al.* 1997), a pattern of periodic growth depressions and recoveries over long time periods (Payette *et al.* 1996), or no anomalies (Lane *et al.* 1993; Hopkin and Dumond 1994; Heisey 1995). Reported problems commonly occur along outer portions of the range for northern hardwoods (e.g., northern Pennsylvania, Quebec, and the Maritimes). Evaluations implicate factors like drought, heat, insect attacks, stand maturation, freezing, freezing-thawing cycles, injuries, soil nutrients, other natural stresses, tree social status within the community, and forest management practices. As with other species, most likely a complex of site factors influence the success of sugar maple, and multiple factors determine its vigor and condition (Houston 1981; Stolte 1997).

Forest health specialists commonly suggest that trees of high vigor better withstand a variety of harmful agents. Appropriate tending to reduce inter-tree crowding and maintaining large and full crowns may help to make sugar maple more resistant, and more resilient in recovery (Boyce 1948; Hawley and Stickel 1948; Graham 1952). Silviculture will not prevent damage during widespread outbreaks of insects or major disease incidents (Baskerville 1975; Wood 1988). Yet a variety of health maintenance measures should become routinely incorporated into the silvicultural system for a stand. These include (after Belanger and Malac 1980; Belanger 1981; Nyland 1996):

1. use of an appropriate reproduction method and the requisite site preparation to insure an abundance of species suited to the site;
2. timely tending to control stand density and insure high tree vigor;
3. selection of sound, vigorous, and well-developed trees as residual growing stock;
4. timely salvage and sanitation cutting to remove weakened and badly injured trees, and to reduce risks to damaging insects and fungi;
5. setting an appropriate life span for an age class;
6. appropriately siting and designing skid trails to minimize affects on soil and residual trees;
7. scheduling skidding and other machine operations for seasons when the soil will support the equipment without rutting and root damage;
8. careful practice in logging to minimize injuries to residual trees; and
9. continual monitoring of potential health problems and their causes to allow prompt response as needs arise

These measures represent part of a landowner's integrated health management program.

Silviculture for Sugar Maple Dominated Stands

Silviculture either regenerates mature age classes, or tends those of intermediate ages. Foresters use both activities to establish and maintain some particular set of ecologically desirable plant community attributes. Uses that serve economic interests derive from those conditions. In this context, foresters use timber harvesting to implement the planned silvicultural treatments. When removals allow a commercial sale, landowners can manage the habitat for indigenous plants and animals, maintain essential hydrologic and other important ecologic functions, influence visual qualities, and serve many other purposes without major investments (Nyland 1996).

Several biologic and ecologic characteristics facilitate the regeneration of sugar maple throughout much of its range, and make it responsive to later management. Important ones include (after Bourdo 1969):

1. consistent and abundant seed production;
2. good dispersion from the parent tree once seeds mature;
3. ready germination and establishment of seedlings;
4. sprouting from stumps of both small and larger trees;
5. a high tolerance to shading;
6. good rates of diameter and height growth at high light levels;
7. strong growth response following release from competition;
8. high resistance to many harmful agents; and
9. good recovery following crown breakage by ice, snow, wind, and logging

Since sugar maple dominates northern hardwood stands, its silviculture parallels that for the forest type as a whole.

Considerations for Regeneration

The extent that sugar maple reforested former agriculture sites and cut-over forest stands attests to the ease of securing natural regeneration under a wide variety of seedbed and residual stand conditions. Yet in forested areas, regeneration often fails on skid trail surfaces devoid of an organic cover and humus, even if seeds fall on them and germinate (Walters and Nyland 1989; Wang and Nyland 1996). A leaf litter does not impede penetration of the radicle following germination (Godman *et al* 1990). Favorable moisture and nutrient supplies in the humus sustain the seedlings until their root systems develop.

Sugar maple seedlings develop best at about 13-45% of full sunlight. Once well established, they persist for many years under even heavy shade (Logan 1965; Tubbs 1969), and respond to release by overstory cutting. If well developed, advance seedlings survive and grow better following complete or heavy overstory removal. For stands lacking such seedlings, clearcutting may delay establishment and development of a new cohort, and shelterwood method commonly proves more effective (Tubbs 1977a, 1977b). Having seedlings greater than 0.3 m (1 ft) tall also speeds cohort development following partial overstory disturbance (Leak and Wilson 1958; Metzger and Tubbs 1971; Mader and Nyland 1984).

Advance seedlings of good vigor grow in proportion to the degree of release, reaching about 1.8 m (6 ft) in 12 years and 3.0 m (10 ft) in 20 years on good sites with full sunlight. Less shade-tolerant associates may grow twice as rapidly, making the advance status of sugar maple critical to insuring its place in the main canopy of even-aged stands (Wang 1990; Wang and Nyland 1996). Depending on how long they grew under shade prior to release, sugar maple saplings reached 3.0 m (10 ft) in 18-23 years after selection system cutting to 17 m^2/ha (75 ft^2/ac). Low light levels under this and higher stocking make conditions unfavorable for faster-growing less shade-tolerant species, so sugar maple commonly dominates the new age class (Tubbs 1969; Nyland 1997; Donoso *et al.* 1998). However, dense interfering plants (e.g., American beech) or intensive and protracted browsing (e.g., white-tailed deer) can preclude success following any cutting strategy.

Uneven-aged Silviculture

Selection system controls the density within different size (age) classes to sustain stand conditions and volume production over successive cutting cycles, the patterns of regeneration across a stand, and the growth and quality of residual trees. At regular intervals, landowners remove excess immature trees to maintain a specified residual number per size (age) class, and harvest the economically or ecologically mature ones to regenerate a new cohort across a fixed proportion of the stand area. Failure to incorporate regeneration, tending, and harvest simultaneously makes the result unpredictable, the residual conditions less consistent over time, and the yields less regular (Nyland 1987; Nyland *et al.* 1993; Nyland 1996).

Research and experience provided guidelines (Table 1) for selection system based upon an 8-12 yr cutting cycle (Eyre and Zillgitt 1953; Arbogast 1957; Gilbert and Jensen 1958; Leak *et al.* 1969). Simulation methods suggest other alternatives for longer treatment intervals, different stand conditions, and various landowner objectives (Hansen and Nyland 1987; Hansen 1987; Nyland 1996). Appropriately structured stands grow between 0.6 and 0.7 m^2/ha/yr (2.5 and 3.0 sq ft/ac/yr) for basal area (Eyre and Zillgitt 1953; Blum and Filip 1963; Leak *et al.* 1969; Mader and Nyland 1984), and 2.2 and 3.2 m^3/ha/yr (200-300 bd ft/ac/yr) of sawtimber volume (Eyre and Zillgitt 1953; Leak *et al.* 1969; Mader and Nyland 1984). Differences in production largely reflect the variation in tree heights across regions and sites. Generally, growth provides sufficient yields for another operable cut at the intended interval.

Partial cutting in uneven-aged stands commonly causes broken branches and basal wounds, and may destroy some trees. The incidence will be proportional to the numbers of trees in a size class, and ones with major injuries may comprise about one-fifth of the residual basal area. Repeated partial cutting might maintain a base level of physical defect in a stand managed with any type of partial cutting strategy (Nyland and Gabriel 1971); Nyland *et al.* 1976; and Nyland 1989).

Even-aged Silviculture

Treatments to regenerate a new age class and tend older ones never occur simultaneously in even-aged communities. So landowners often treat conditions found at a given time, rather than following a pre-planned management strategy for an entire rotation. Most landowners consider pre-commercial treatments financially unacceptable, and delay the first entry for 50-60 years, when they can do a commercial thinning. For this, foresters use an appropriate relative density guide to plan the residual stocking and method for thinning based upon the numbers of trees, their sizes, the basal area, and the species composition (Leak et al. 1969; Roach 1977; Tubbs 1977b; Marquis *et al.* 1984). Most guides recommend leaving increased levels of residual basal area as a stand matures, generally targeted at 60-70% relative density. This threshold insures full site utilization and high net volume production over a thinning cycle, while inhibiting epicormic branching and promoting natural pruning due to inter-tree shading. Stands become ready for another thinning when relative density regrows to about 80% (Leak *et al.* 1969; Roach 1977; Marquis 1986; Stout 1987; Nowak 1996).

Taking about two-thirds of the basal area from below the mean stand diameter, and the remainder from larger trees (crown thinning), concentrates the growth potential onto trees of upper canopy positions (Roach 1977; Marquis et al. 1984). Conversely, cutting the largest trees removes the best growing and volume-producing ones (Marquis 1986; Nyland *et al.* 1993). In fact, simulation work indicates that best sawtimber production will accrue in thinned stands having about 60% of the residual basal area in sawtimber-sized trees, and reduced to B-line relative density as represented on the appropriate stocking guide (Solomon 1977). Such

Table 1.—Alternate residual diameter distributions for selection system under different length cutting cycles (After Eyre and Zillgitt 1953; Arbogast 1957; Gilbert and Jensen 1958; Leak *et al.* 1969; Hansen and Nyland 1987; Hansen 1987 and Nyland 1996).

Diameter class	Cutting cycle length			
	8-12 yrs	15 yrs	20 yrs	25 yrs
Cm	M^2/ha	M^2/ha	M^2/ha	M^2/ha
5-13	2.5	2.3	2.3	2.3
14-28	4.5	5.7	4.5	6.8
29-43	6.8	8.0	6.8	5.7
44+	6.8	3.4	2.3	-
Total	20.6	19.4	15.9	14.8

thinnings increase the sawtimber yields by 50-100% for rotations of 90-125 years (Solomon and Leak 1986). Thinnings that favor trees of upper canopy positions should not cause extensive logging damage if the contractor carefully controls the skidding and uses appropriate machinery (Nyland 1986, 1989).

Both clearcutting and shelterwood methods effectively regenerate new even-aged communities of northern hardwoods when applied appropriately. Sugar maple will arise largely from advance seedlings and small saplings (Jensen 1943; Wendel and Trimble 1968; Grisez and Peace 1973; Marquis et al. 1984, 1992; Tubbs 1977a). Consequently, for stands lacking adequate advance regeneration, managers should use the shelterwood method. Some regeneration guides (e.g., Tubbs 1977a) recommend leaving some mature trees in place until each hectare averages at least 2025 (5000/ac) desirable trees >0.9 m (>3 ft) tall. If landowners find these already in place, they can remove the complete overstory in a single operation (Marquis 1967; 1987; Roberge 1977; Walters and Nyland 1989).

Shelterwood method seed cutting can leave from 11.5 m^2/ha (50 ft^2/ac) or less (Curtis and Rushmore 1958; Richards and Farnsworth 1971; Leak and Solomon 1975; Kelty and Nyland 1981), to as much as 21 m^2/ha (90 ft^2/ac) (Metzger and Tubbs 1971). Generally, 7 to 18 m^2/ha (30 to 80 ft^2/ac) gives acceptable stocking of desirable species, although sugar maple grows best under 7-9 m^2/ha (30-40 ft^2/ac) (Kelty 1987). *Rubus* will dominate most sites where cutting removes one-half or more of the basal area. That poses no problems in eastern regions, where the tree regeneration emerges from the berry bushes by the 6th or 7th year (Kelty and Nyland 1981; Kelty 1987; Walters and Nyland 1989). In the upper Lake States, dense *Rubus* and herbaceous plants may delay the development of sugar maple regeneration (Metzger and Tubbs 1971; Tubbs 1977a), so guides suggest leaving a 60% crown cover (Tubbs 1977b). Time to a removal cutting depends on the stocking of residual seed trees and the rate that regeneration develops. Strip and patch clearcutting may provide acceptable alternatives. Patch size, strip width, and the orientation of either will influence shading patterns and seed dispersal (Marquis 1965a, 1965b; Lees 1987; Nyland 1996)).

Diameter-limit Cutting

Deliberate silviculture controls the growth, composition, and character of forest stands. It also leaves the best trees as growing stock and future sources of seed. Yet many landowners routinely do diameter-limit cutting that removes the salable products with little regard for the nature, density, or distribution of residual trees or the regeneration that follows. Because sugar maple regenerates so readily, at least some seedlings become established even after these exploitive cuts, given a seed source and no interference from browsing or existing vegetation. And while the inconsistent responses and reduced long-term economic value should make diameter-limit cutting undesirable, it remains popular (Nyland 1992; Nyland *et al.* 1993).

Actual effects differ between even- and uneven-aged stands. In the latter, diameter-limit cutting removes the older age classes, and does not necessarily degrade the younger ones. In even-aged communities it leaves low vigor trees of poor growth potential (Marquis 1991; Nyland *et al.* 1993). These often develop extensive epicormic branching after exposure by heavy cutting, and many die back as well. In most cases, diameter-limit cutting leaves an unevenly distributed or patchy residual stand with both high-density patches and areas having little stocking (Nyland 1996).

Often, contractors who do diameter-limit cutting also use little care with the skid trails, and continue to operate on saturated soils. This causes deep rutting, and damage to the root systems of adjacent residual trees. The combination of low-vigor trees and root damage may lead to later dieback in times of environmental stress (e.g., Cote and Ouimet 1996; Manion 1991).

Some Other Important Considerations

Sugar maple has regenerated and then developed to at least moderate ages under a wide range of environmental conditions and management strategies. In fact, since the early 1900's, it has reforested extensive area within the original range, primarily on lands once cleared for agriculture. This resulted in a major consolidation of forests in areas earlier supporting primarily small and widely-scattered remnant stands (Nyland *et al.* 1986; Zipperer *et al.* 1988, 1990). Available records also suggest that during the same period, northern hardwoods spread into areas and sites where they occurred infrequently or not at all early in the 20th Century (Quigley and Morgan 1969). Further, in at least some areas of continuous forest cover and disturbed by only one of a few timber harvests (Whitney 1990; De Steven *et al.* 1991):

1. sugar maple's abundance, importance, and stature increased in stands where it occurred as a limited but noticeable part of the upper canopy in pre-settlement times;
2. sugar maple's distribution widened through regeneration onto sites where earlier it did not occur, or grew as a minor component; and
3. sugar maple's prominence as an overstory tree increased in stands where it persisted primarily in the understory in the absence of important natural or human stand-altering disturbances

As an illustration, in western portions of the Allegheny Plateau of Pennsylvania, sugar maple was a minor component of old-growth stands, and limited primarily to the understory except along upper slopes of the valleys (Hough 1936; Whitney 1990). Following cutting of the old-growth, sugar maple became a more important component of the replacement stands where it had originally occurred as a minor component of the overstory. The cutting also increased the areal extent of forest community types that have sugar maple as an important upper-canopy tree (Whitney 1990).

Recently, observers have reported declines of sugar maple, commonly in fringe portions of the range of northern hardwoods (Figure 2). This suggests that the current condition of sugar maple may reflect local or regional growing conditions, with incidents of poor health in localities with marginal soils and climate. This may include sites where sugar maple occurred only as a minor species in the earlier forests. On a broader range of sites, local diebacks may emanate from physical damage to trees by natural and human causes, and the poor social status of individual trees prior to release by heavy cutting and other modes of stand disturbance. Often the diebacks become apparent during later times of stress (U.S. For Serv. 1979; Houston 1981; Manion 1991; Cote and Ouimet 1996; Stolte 1997). At least in part, this sugar maple conference serves as a forum to examine such possibilities.

Markets for low value and small diameter trees often dictate the management strategy for sugar maple. Landowners can easily sell large-diameter logs of good quality, and can profitably cut among the smaller diameter classes and in younger stands if they have outlets for fiber products (e.g., pulpwood and firewood) as well. Otherwise, they must usually invest in cull removal and small-tree tending, and most have historically opted not to spend the money. Instead, they often revert to diameter-limit cutting.

While diameter-limit cutting has become widespread, northeastern North America does have many examples of silviculture in stands dominated by sugar maple. New research will continue to illuminate the opportunities for influencing stand development and character through silvicultural practice. Still, the management of sugar-maple dominated stands appears at an important juncture. In the absence of better ways to promote deliberate silviculture, landowners seem destined to repeat the exploitive practices historically used across millions of hectares of northern hardwood forest. Under those circumstances, ecologic and economic outcomes may become increasingly less optimal, and forest health issues more common. Only time will tell.

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