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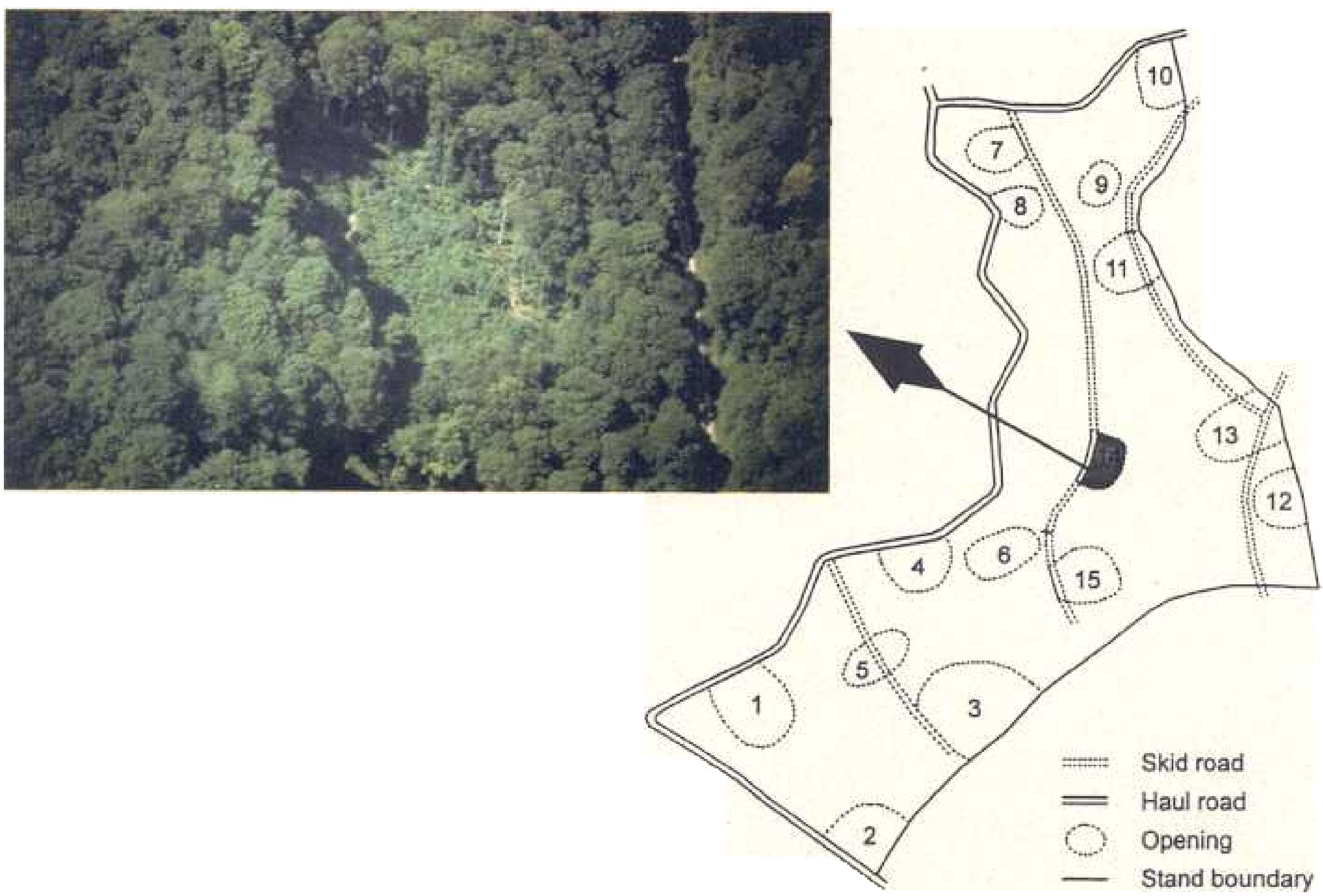

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ASTRACT

Practical forest management guidelines developed from long-term silvicultural research in the central Appalachian region of the United States may be useful on similar forest cover types in southern and central Ontario. This paper describes practical methods for managing central Appalachian hardwood forests for the production of high-quality sawtimber, veneer, and related non-timber objectives. Research was conducted in second-growth stands of northern and Allegheny hardwoods, mixed Appalachian hardwoods, and upland oaks. These guidelines are used on public and private forests in the central Appalachians to promote stands with even-age, two-age, or uneven-age stand structures as determined by management objectives. Regeneration harvest practices include single-tree selection, group selection, deferment cutting (clearcutting with standards), and shelterwood methods. Preliminary guidelines are described for the use of tree shelters in regenerating northern red oak. Cultural practices for improving quality, composition, and growth of immature hardwoods include thinning treatments based on relative density and crop tree management and guidelines for managing wild grapevines.

INTRODUCTION

The forests of southern Ontario have many characteristics in common with forests of the eastern United States. In particular, the central Appalachian hardwood region includes a variety of forest cover types such as northern and Allegheny hardwoods that include American beech (*Fagus grandifolia* Ehrh.), sweet birch (*Betula lenta* L.), yellow birch (*Betula alleghaniensis* Britton), sugar maple (*Acer saccharum* Marsh), red maple (*Acer rubrum* L.), and black cherry (*Prunus serotina* Ehrh.), mixed Appalachian hardwoods that include yellow-poplar (*Liriodendron tulipifera* L.), northern red oak (*Quercus rubra* L.), American basswood (*Tilia americana* L.), sugar maple, and American beech, and upland oaks that include northern red oak, scarlet oak (*Quercus coccinea* Muenchh.), chestnut oak (*Quercus prinus* L.), and white oak (*Quercus alba* L). Silvicultural research and resulting management guidelines applicable to the central Appalachian region may be useful in similar stands located in Ontario.

This report summarizes preliminary silvicultural guidelines now in use for managing central Appalachian hardwoods for the production of high-quality sawtimber, veneer, and other related non-timber objectives. These methods are applied by silviculturists on non-industrial private forests, public forests on federal and state land, and on forests owned by forest industry. Information presented in this report has been previously published, and the Literature Cited provides more detailed references for practicing forest managers who are interested in analytic methods and the results of specific silvicultural treatments.

These recommendations are based on long-term studies conducted on the Fernow Experimental Forest and nearby research areas on the Monongahela National Forest in north central West Virginia. The oldest studies were initiated in 1949 and provide data on the long-term implications of repeated partial harvest practices. More recent studies focused on the response of even-aged stands to thinning, crop tree management, and the development of two-age stand structures.

Practical methods are described for applying regeneration harvest practices to promote even-age, two-age, and uneven-age stands in second-growth hardwoods characteristic of the central Appalachians. Cultural practices also are described for improving quality, species composition, and growth in immature even-aged stands and in two-age or uneven-aged stands where tending of immature trees is necessary or desired.

STUDY AREAS

Guidelines were developed from data collected on permanent research plots located in the Allegheny Mountain region near Parsons, West Virginia (N 39° 3', W 79° 41') (Figure 1). Elevation ranges from 1,800 to 3,700 feet (550 to 1,130 m), and annual precipitation averages 59 inches (150 cm) distributed throughout the year with 145 frost free days. Annual snowfall averages 35 inches (89 cm) and snow cover averages 60 days per year. The normal daily temperature averages 30° F (-1° C) in January and 65° F (18° C) in July. Site productivity varies from site index 60 to 80 (18 to 24 m) for northern red oak, base age 50 years. Soils are well-drained, medium-textured loams and silt loams derived from sandstone and shale. Average soil depth is about 3 feet (1 m).

Figure 1. The central Appalachians are characterized by relatively steep slopes and dendritic drainage patterns.

Studies were installed in second-growth hardwoods that originated from heavy logging between 1905 and 1910. These stands contained three age classes when most silvicultural treatments began in the early 1950's: old residuals, new reproduction that followed the early logging, and reproduction that was established following the death of the American chestnut (*Castanea dentata* Marsh. Borkh.) in the 1930's. Upland oaks are the most common species group, with some second-growth northern red oak found on nearly all sites. Chestnut oak, white oak, and red maple are common species on poorer sites, while sugar maple, yellow-poplar, black cherry, hickory (*Carya* spp.), and American basswood are found on better sites. American beech is common on all sites and more abundant on better sites.

REGENERATION METHODS

More than 15 commercial species can be harvested and successfully regenerated using appropriate techniques in the central Appalachian region. These species have diverse silvical characteristics such that a wide variety of regeneration methods can be used effectively to sustain the production of various high-quality wood products. Partial harvest practices, used to promote uneven-age stand structures, include single-tree selection and group selection. Practices such as deferment cutting (clearcutting with standards) or shelterwood with reserves are relatively new to the region, particularly on public and industrial land, and are used to create and maintain two-age stand structures. Shelterwood practices and clearcutting are used to promote even-age stand structures. The following sections describe the management objectives, application guidelines, and long-term implications of each of these major silvicultural systems.

Single-tree selection

A true application of the selection system is one in which periodic partial harvests are planned such that the residual stand structure provides for a sustainable flow of desired outputs and benefits. Each partial cut stimulates regeneration of desired species, yields merchantable products, enhances growth and improves residual stand quality, and maintains a certain number of residual trees in each size (age) class over time. The residual stand structure goal is defined by the forest manager and varies according to stand characteristics, management objectives and the chosen cutting cycle (time between periodic harvests). Once a stand structure goal is established, periodic harvests remove selected trees from size classes in which there are excess trees (Figure 2) and will result in continued or enhanced growth of individual trees in the residual stand.

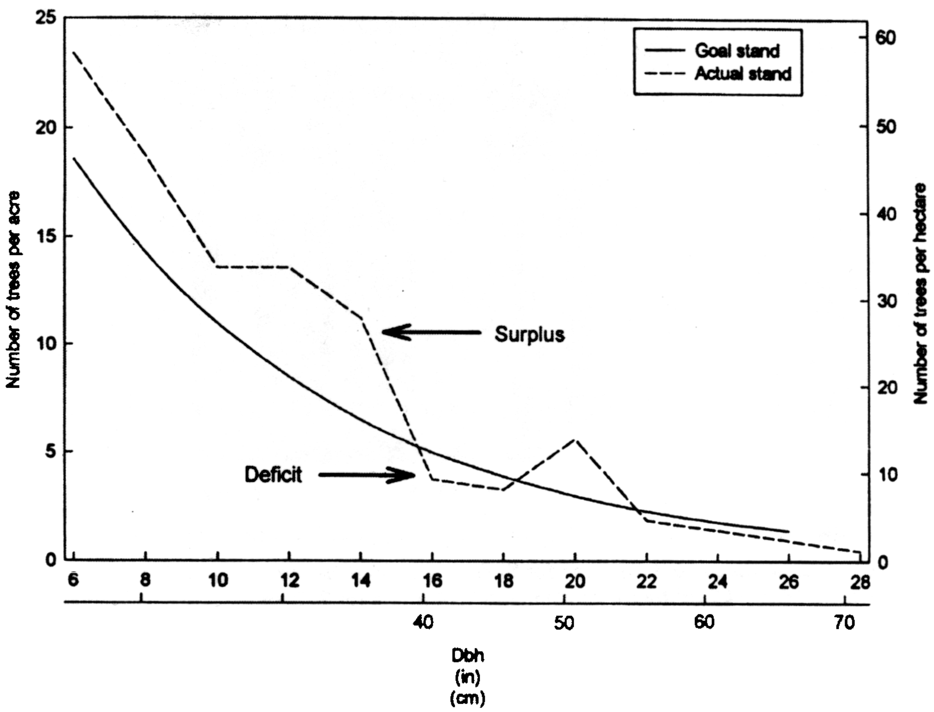

Figure 2. An example of a residual stand structure goal compared to actual stand structure from cruise data (From Miller 1993).

Three parameters are used to define the residual stand structure goal: residual basal area (RBA), largest diameter residual tree (LDT), and the q-value, which defines how residual trees are distributed among diameter classes (Smith and Lamson 1982). The recommended residual stand structure goals for central Appalachian hardwoods vary by site productivity (Table 1). While the q-value is 1.3 for sawtimber production on most sites, the recommended RBA and LDT increase as site productivity increases. Although a range of residual stand structure goals are feasible, financial returns from single-tree selection are maximized when LDT is from 20 to 22 inches (50.8 to 55.9 cm) diameter breast height (dbh) (Martin 1982; Miller 1993). The cutting cycle ranges from 10 to 20 years, depending on site quality, logging economics, and market constraints.

Table 1. Number of residual trees per unit area suggested for production of sawlogs from uneven-age central Appalachian hardwood stands.[a]

	Oak site index[b]		
Dbh	60 ft (18m)	70 ft (21m)	80 ft (24m)
in (cm)[c]	-------------Number stems per acre (per hectare)-------------		
6(15)	19.1(47.2)	18.6(45.9)	19.4(47.9)
8(20)	14.7(36.3)	14.3(35.3)	14.9(36.8)
10(25)	11.3(27.9)	11.0(27.2)	11.5(28.4)
12(30)	8.7(21.5)	8.5(21.0)	8.8(21.7)
14(36)	6.7(16.6)	6.5(16.1)	6.8(16.8)
16(41)	5.2(12.8)	5.0(12.4)	5.2(12.8)
18(46)	4.0(9.9)	3.9(9.6)	4.0(9.9)
20(51)	3.0(7.4)	3.0(7.4)	3.1(7.7)
22(56)	--	2.3(5.7)	2.4(5.9)
24(61)	--	1.8(4.5)	1.8(4.5)
26(66)	--	1.4(3.5)	1.4(3.5)
28(71)	--	--	1.1(2.7)
30(76)	--	--	0.8(2.0)
32(81)	--	--	0.6(1.5)
Total	72.7(179.6)	76.3(188.5)	81.8(202.5)

[a]From Smith and Lamson (1982).

[b]Residual basal area 50 ft^2/ac for SI 60 ft, 65 ft^2/ac for SI 70 ft, and 80 ft^2/ac for SI 80 ft; 11.5 m^2/ha for SI 18m, 14.9 m^2/ha for SI 21m, and 18.4 m^2/ha for SI 24m.

[c]Metric equivalents in parentheses.

Single-tree selection is sustainable where merchantable shade-tolerant species can be regenerated after each periodic cut. Removing a few individual trees according to a defined cutting cycle (every 10 to 20 years) creates small, temporary openings in the canopy. Seedlings of shade-intolerant species such as black cherry, yellow-poplar, American basswood, and the oaks may germinate and grow for a few years, but as the canopy closes between periodic cuts they soon die. Shade-tolerant species such as red maple, sugar maple, American beech, and Eastern hemlock (*Tsuga canadensis* (L.) Carr.) can survive and grow in the understory between cuts and will eventually replace overstory trees removed in future cuts. Although there may be a diversity of overstory species present when this practice is initiated in a second-growth stand, repeated partial harvests using single-tree selection will result in stands dominated by shade-tolerant species (Miller 1993; Trimble 1973), thereby reducing overall tree species diversity.

Group selection

Uneven-age stand structures also can be developed by periodically removing groups of trees as opposed to removing individual trees scattered throughout the stand. Similar to single-tree methods, periodic group selection cuts establish regeneration, yield merchantable products, improve the residual stand, and result in a sustainable residual stand structure. In group selection, however, the periodic cuts create larger openings in the canopy compared to single-tree selection, thus providing light conditions suitable for regenerating a much greater variety of species. Key parameters for applying group selection include size and shape of openings, location of openings, cutting cycle, and a method for regulating periodic cuts (area, volume [or basal area]).

The size of openings can range from the crown of a single tree to whatever size is necessary to provide the forest floor conditions necessary to meet regeneration goals and other management objectives (Figure 3). For regenerating shade-intolerant species such as black cherry and yellow-poplar and intermediate species such as northern red oak, white oak, American basswood and white ash (*Fraxinus americana* L.), the diameter of group selection openings must be at least 1.5 times the height of adjacent, mature trees on a given site. For most stands in the central Appalachians, minimum opening size is about 150 feet (46 m) in diameter if a good species mix is the objective at maturity (Trimble 1973). The shape of the opening can vary according to management objectives so long as opposite edges of an opening are far enough apart to provide the forest floor conditions, primarily light, required for the regeneration of desired species.

Figure 3. A small opening created by a group selection harvest in central Appalachian hardwoods.

Group openings should be placed within the stand using a *worst first* approach, that is, where potential growth or value returns are low compared to other parts of the stand. Such locations include groups of mature trees, undesirable species, or poor quality trees that exhibit relatively low potential growth or financial returns. Groups of large, mature trees have lower rates of return, even though they are still growing, compared to groups of smaller trees that have not reached financial maturity (Trimble and others 1974). Parts of the stand that are occupied by poor quality trees or species not suited to the management objectives also have lower potential returns and should be harvested to reallocate site resources to more thrifty reproduction. In general, for each periodic cut, group openings should be located to enhance the productivity of the residual stand. Parts of the stand with the lowest potential for future returns should be cleared and allowed to regenerate so that overall stand productivity is increased.

Group selection cuts can be regulated using either area or volume control (Miller and others 1995a). In either case the manager still needs to establish appropriate residual basal area and stand structure guidelines (Table 1, Figure2).

Area control entails creating and maintaining age classes within the stand such that the total area in group selection openings is approximately equal for each periodic cut. In the central Appalachians, group selection cuts are scheduled to harvest the oldest age classes when they are 70 to 80 years old, approximately equal to the optimal even-age rotation for sawtimber production. In applying area control, the number of group selection openings (N) needed at each periodic cut is a function of cutting cycle (CC, years), harvest age of mature trees (H, years), stand area (A, acres), and average group opening size (G, acres) defined by: $N = (CC/H)*(A/G)$.

Volume control is based on harvesting periodic growth and leaving sufficient residual stand basal area to provide for sustained yield. Residual basal area goals for trees ≥ 11.0 inches dbh (27.9cm) by northern red oak site index are:

SI 60 ft	**40 to 55 ft^2/acre**	**SI 18 m**	**9.2 to 12.6 m^2/ha**
SI 70 ft	**55 to 70 ft^2/acre**	**SI 21 m**	**12.6 to 16.1 m^2/ha**
SI 80 ft	**70 to 85 ft^2/acre**	**SI 24 m**	**16.1 to 19.5 m^2/ha**

These guidelines assume that the residual stand also will contain 15 to 20 ft^2/acre (3.4 to 4.6 m^2/ha) in poletimber and that logging damage will reduce residual basal area by as much as 10 percent (Trimble and others 1974). In relatively dense stands that have not been cut previously, the residual stand basal area should be near the top of the range. A stand inventory before each harvest is used to determine the maximum allowable cut to maintain adequate residual basal area. Total periodic cut volume (V) is a function of periodic annual growth per unit area (P, volume/year), stand area (A), and cutting cycle (CC, years) defined by: $V = P*A*CC$. The following periodic annual growth estimates are appropriate for most central Appalachian hardwoods (Trimble 1968).

SI 60	**200 bf/acre/year**	**SI 18 m**	**2.18 m^3/ha/year**
SI 70	**300 bf/acre/year**	**SI 21 m**	**3.26 m^3/ha/year**
SI 80	**400 bf/acre/year**	**SI 24 m**	**4.35 m^3/ha/year**

As the stand is marked for cutting, cumulative cut volume and cut basal area are tallied. For volume control, marking is complete when either maximum cut volume or cut basal area is achieved.

In conjunction with the regeneration harvest of group selection openings, partial cuts may be applied between the openings to increase growth and improve quality of the residual stand. Individual trees are cut between openings based on management objectives, potential value increase, and risk (Table 2). The improvement cut between openings must be estimated during the stand inventory and included in the total cut when computing the maximum allowable cut to avoid over cutting the stand. To meet the target, average, residual stand basal area, it will be necessary to keep the between opening areas at higher basal areas in order to compensate for the openings which have a basal area of zero.

Table 2. Marking guidelines for improvement cut—sawtimber-size classes, 11.0 inches (27.9 cm) dbh and larger[a].

For individual trees, mark:

1. Culls and near culls, unless needed for other resource goals
2. Trees with significant rot (40 percent or more) in the butt log
3. Low-grade trees that are not expected to attain sawlog quality[b]
4. Short-lived species or other species with low vigor expected to die before the next periodic cut
5. Undesirable species that conflict with management objectives

[a]From Miller and Smith (1993).
[b]Rast and others (1973).

Two-age regeneration methods

The application of two-age regeneration methods to manage eastern hardwoods is growing rapidly. Research trials designed to study the effects of deferment cutting (clearcutting with standards) were initiated from 1979 to 1983 on the Monongahela National Forest and Fernow Experimental Forest in West Virginia (Smith and others 1989). Similar regeneration harvests that promote two-age stand structures have since been initiated on other national forests, state forests, industrial forests and to a lesser degree on some non-industrial private forests throughout the eastern hardwood region (Miller and others 1995b). The primary objectives of this practice are: 1) to regenerate a variety of hardwood species, particularly those that are shade-intolerant, 2) to mitigate the negative visual impacts of clearcutting, 3) to maintain vertical structure and mast sources for wildlife habitat, and 4) grow relatively large diameter trees.

Two-age regeneration methods have been called clearcutting with reserves, clearcut with standards, irregular shelterwood, shelterwood with reserves, insurance silviculture, deferment cutting, and crop tree management with site preparation (Smith 1995). The terminology varies according to management objectives and the experience of the silviculturist who prescribes the treatment.

Immediately after logging, two-age stands resemble those following a seed-tree regeneration harvest (Figure 4). The residual stand includes 10 to 20 co-dominant trees/acre (25 to 50 trees/ha) and all other stems 1.0-inch (2.54 cm) dbh and larger are cut to prepare the site for reproduction of a new age class. The abundance, composition, and distribution of hardwood reproduction following two-age harvests is similar to that observed after clearcutting (Miller and Schuler 1995). The residual basal area is low enough, usually 20 to 30 ft^2/acre (4.6 to 6.9 m^2/ha), so that species of wide-ranging shade tolerance can become established and develop after logging (Table 3). Moreover, the residual trees have little effect on the abundance, composition, or distribution of the new age class after the two-age cut is made (Trimble 1973). Advance reproduction, sprouts from the cut trees, and seed stored in the forest floor contribute to total reproduction after harvest. As well, weed species such as pin cherry, poplar and raspberry have significant opportunities to become established.

The characteristics of residual trees in two-age stands vary by management objective and the intended use of individual trees. Residual trees could include potential sawtimber products or mast trees, den trees, flowering shrubs or conifers to promote other benefits such as aesthetics and wildlife habitat diversity. In two-age stands in the central

Appalachians, residual trees usually are left to satisfy multiple objectives within the same stand. For example, guidelines for crop tree management can be used to select residual trees within a stand to help meet both timber and wildlife objectives (Perkey and others 1994).

Figure 4. A two-age central Appalachian hardwood stand immediately after a regeneration harvest; residual basal area averaged 30 ft^2/ac (6.9 m^2/ha).

Timber crop trees. If residual trees are to be harvested as timber products in the future, then species, potential log quality, growth, and risk are key considerations. For a given stand, select the most valuable species available (black cherry, northern red oak, white ash, and sugar maple in the central Appalachians), but always consider longevity, quality, and risk. Residual trees should be vigorous, co-dominant or dominant, and have no evidence of stress such as epicormic branches on the bottom 33 feet (10 m) of the bole (Miller 1996). Trees in subordinate crown classes tend to develop more epicormic branches and eventually lose quality. Residual trees will be retained for many years after the initial cut, thus it is wise to avoid low forks on the bole, poor rooting, or other signs of risk.

Wildlife crop trees. Mast production and den trees are important factors that affect the quality of wildlife habitat. Co-dominant and dominant trees with relatively wide crowns produce the most mast. White oaks and American beech are preferred over red oaks, although red oaks usually produce mast at an earlier age and in larger quantities than white oaks. Good seed crops are more frequent for hickory compared to oak. Trees with active cavity nests are excellent wildlife crop trees. Diversity also is enhanced by retaining snags, dead trees, and perhaps conifers, if available, regardless of the management objective.

Table 3. Summary of reproduction of commercial species 10 years after a two-age regeneration harvest[a].

Species	Total	Co-dominant	Good, Co-dominants
	Number stems per acre (per hectare)[b]		
		SI 70 ft (21 m)	
Black cherry	392 (968)	316 (781)	220 (543)
Beech	110 (272)	59 (146)	35 (86)
Red maple	105 (259)	63 (156)	47 (116)
Red oak	86 (212)	54 (133)	45 (111)
Black birch	77 (190)	54 (133)	52 (128)
Sugar maple	50 (124)	26 (64)	13 (32)
Chestnut oak	48 (119)	32 (79)	22 (54)
Yellow-poplar	44 (109)	21 (52)	16 (40)
Other	87 (215)	48 (119)	38 (94)
Total	999 (2,468)	673 (1662)	488 (1,205)
		SI 80 ft (24 m)	
Yellow-poplar	383 (946)	206 (509)	190 (469)
Sugar maple	136 (336)	49 (121)	40 (99)
Black birch	85 (210)	50 (124)	46 (114)
Beech	65 (161)	20 (49)	10 (25)
Red maple	45 (111)	19 (47)	12 (30)
Basswood	36 (89)	9 (22)	9 (22)
Red oak	31 (77)	11 (27)	10 (25)
White ash	29 (72)	10 (25)	6 (15)
Other	172 (425)	91 (225)	84 (207)
Total	982 (2,426)	465 (1,149)	407 (1,005)

[a]From Miller and others (1995b). [b]Metric equivalents in parentheses.

Ontario comment: Although the two-aged system may have some application in continuous forest landscapes where managers are trying to move away from clear cutting, it would generally be considered too severe a cutting system in the fragmented forests of southern Ontario. Higher initial residual basal areas associated with single-tree selection, group selection and shelterwood allow for more flexibility in controlling weed species (including invasive non-natives), aesthetics, windthrow, and interior forest habitat.

Oak regeneration

Reliable regeneration of northern red oak on high-quality sites is a continuing problem. The usual case in the central Appalachian region is that small oak seedlings do not compete well with other species following most commercial harvest operations (Sander 1988). Increased light and other site resources that are made available after overstory trees are removed stimulate germination and/or height growth of sweet birch, yellow-poplar, sugar maple, striped maple (*Acer pensylvanicum* L.), and black cherry as well as any oak seedlings that are present. However, early height growth of the oaks is slower, and usually by the tenth year after canopy trees are removed the survival of the oaks is very low.

For oaks, advance reproduction is the primary mechanism for natural regeneration (Beck 1988) (Table 4), and specific silvicultural treatments may be required to develop advance oak seedlings for several years prior to a regeneration harvest. The probability that an advance oak seedling will successfully compete for crown position and become a co-dominant tree in the new stand is related to the initial seedling size at the time overstory trees are removed (Sander and others 1984; Loftis 1990a). For example, less than 10 percent of advance oak seedlings with a 0.5-inch (1.27 cm) basal diameter will become co-dominant 20 years after the regeneration harvest (Table 5). In most central Appalachian hardwood stands, advance oak seedlings are very small due to a dense, sapling-size stratum of shade-tolerant species. Consequently, even if there are numerous oak seedlings present, they are usually small and have little chance of surviving and competing with other faster growing species. By the time the canopy closes, 10 to 15 years after the regeneration harvest, the smaller oak seedlings are suppressed and subject to high mortality rates.

Table 4. Primary regeneration mechanisms[a] for important Appalachian hardwood species[b].

	Seeds	Advance seedlings	Stump sprouts	Root sprouts
Yellow-poplar	X		X	
Sweet birch	X	X		
Basswood		X	X	
Red maple	X	X	X	
Sugar maple		X		
Northern red oak		X		
Black oak		X		
White oak		X		
Chestnut oak		X		
Hickories		X		
White ash	X	X	X	
Black cherry	X	X	X	
Cucumber magnolia		X		
Black locust				X
American beech			X	X

[a]Form of regeneration at the time of the final harvest [b]From Beck (1988).

Table 5. Dominance probabilities, at age 20, for northern red oak advance reproduction and stump strouts[a]

	Site index		
Basal diameter of advance reproduction	70 (21 m)	80 (24 m)	90 (27 m)
inches (cm)			
0.1 (0.25)	0.01	0.00	0.00
0.2 (0.51)	0.02	0.01	0.00
0.3 (0.76)	0.03	0.01	0.01
0.4 (1.02)	0.05	0.02	0.01
0.5 (1.27)	0.07	0.03	0.02
0.6 (1.52)	0.10	0.05	0.02
0.7 (1.78)	0.13	0.07	0.03
0.8 (2.03)	0.17	0.09	0.04
0.9 (2.29)	0.20	0.12	0.06
1.0 (2.54)	0.24	0.14	0.07
1.1-1.5 (2.8-3.8)	0.34	0.24	0.14
1.6-2.0 (4.1-5.1)	0.44	0.38	0.28
dbh[b]		Stump sprouts[c]	
2-5 (5-13)	0.49	0.42	0.35
6-11 (15-28)	0.46	0.39	0.32
12-16 (30-41)	0.38	0.31	0.24
17+ (43+)	0.24	0.17	0.10

[a]From Loftis (1992). [b]dbh of the cut tree. [c]Adapted from Sander and others (1984).

Two methods have been proposed to develop more competitive oak seedlings. One method involves understory reduction treatments to stimulate natural oak seedling growth before canopy trees are removed (Loftis 1990b). The other method involves planting superior oak seedlings in forest openings after cutting, immediately sheltering them with translucent plastic tubes to enhance height growth, and periodically releasing their crowns to maintain vigor (Schuler and Miller 1996). Both methods involve making substantial investments, and the probability of success in the central Appalachians is unknown.

Understory reduction treatments are designed to reduce low shade, thus increasing the available light enough to stimulate the growth of existing natural oak seedlings, but not enough to stimulate the growth of competitors (Figure 5). This is a shelterwood method that is appropriate for oak stands in which canopy removal is planned for the future. A closed canopy is maintained so that the growth and germination of shade-intolerant competitors is inhibited. Herbicides are used to reduce stand stocking from below, eliminating all trees except oaks in successively larger size classes, starting at 0.6 inches (1.5 cm) dbh., until the desired reduction in percent basal area is achieved. For the southern Appalachians, current recommendations call for reducing initial basal area by

40%, 35%, and 30% on oak site index 70, 80, and 90 (21, 24, and 27 m), respectively (Loftis 1992). These treatments are being tested in the central Appalachians.

Figure 5. A relatively large advance northern red oak seedling; probability of successful oak regeneration increases as the size of advance seedlings increases.

Tree shelters also are used to develop larger oak seedlings that can compete with other species that are regenerating on the same site. However, tree shelters are most successful when used immediately after a regeneration harvest such as clearcutting, group selection, or two-age regeneration harvest. Tree shelters accelerate the growth of planted oak seedlings, natural seedlings, or seedlings that germinate from planted acorns. Sheltered seedlings and acorns can reach the top of a 5-foot (1.5 m) tall tree shelter in 2 or 3 growing seasons, respectively. Unsheltered seedlings usually have lower survival and are less than 2.5 feet (0.8 m) tall after the same amount of time (Figure 6).

Preliminary guidelines for regenerating northern red oak using tree shelters were developed based on field trials observed for 5 to 8 years after planting (Smith 1993; Schuler and Miller 1996). Maximum survival of sheltered seedlings occurs in full sunlight, usually in forest openings or in stands where residual relative density is less than 30 percent. Residual saplings and poles should be felled within the planting area to provide maximum light to planted seedlings. Sheltered seedlings should not be located near stumps of any species that will sprout profusely and exhibit rapid height growth. Although root-pruned, 2-0 planting stock is recommended, planting viable acorns can also be successful if rodent predation is not too severe. Plastic shelters should be installed immediately after planting to avoid damage to the seedling by deer and rodents. Plastic or fiberglass stakes provide a reliable support system for the shelter, and like the shelter, can be reused to reduce cost. The cost of planting and sheltering seedlings varies from $3 to $5 per unit. Follow-up treatments to control encroaching vegetation become necessary about 5 years after planting. Periodic control of competitors can help oak seedlings maintain a co-dominant position, thus improving their long-term survival.

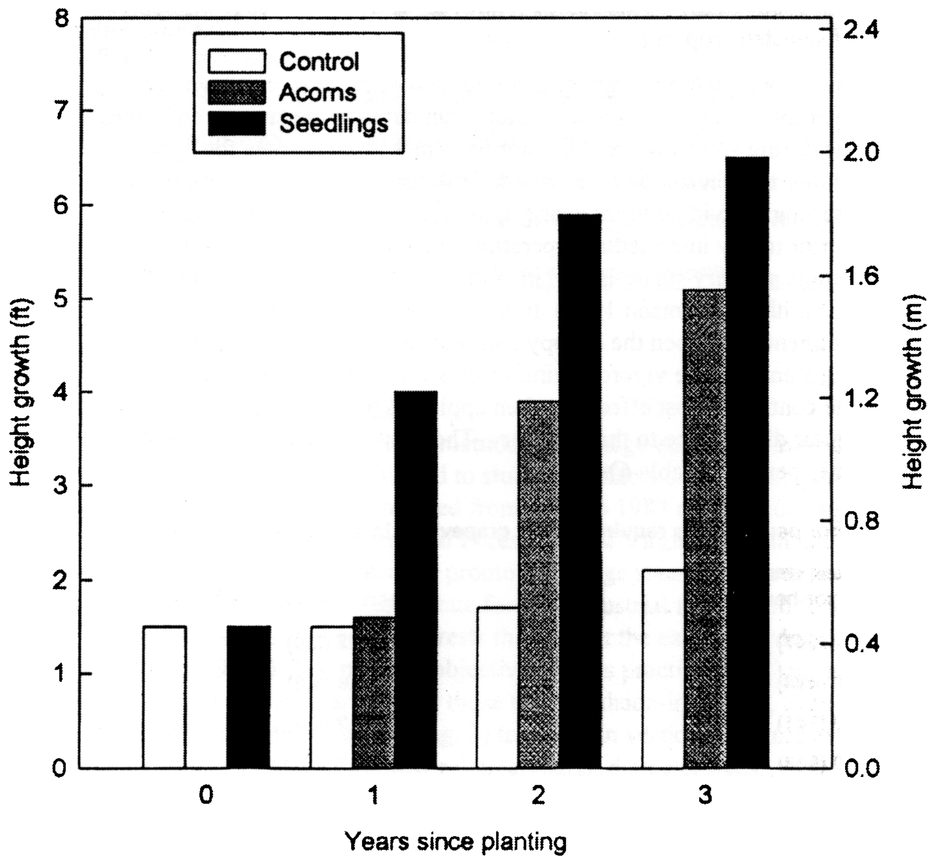

Figure 6. Height growth of northern red oak: unsheltered planted seedlings as controls, planted acorns in shelters, planted seedlings in shelters.

INTERMEDIATE CULTURAL PRACTICES

Once regeneration has been established in an even-aged or two-aged stand, cultural practices may be scheduled to improve the quality, composition, and distribution of trees in the new age class. For uneven-aged stands managed by group selection, cultural practices also may be applied to groups of immature trees in conjunction with periodic harvests. In general, cultural practices in immature stands are best applied when: 1) the canopy formed by co-dominant trees has closed, 2) stem exclusion has begun and the stand is accessible to field crews, 3) dominance among favored crop trees has been expressed, and 4) when merchantable products are available for commercial thinning operations.

Precommercial treatments

In young Appalachian hardwood stands, canopy closure occurs from 10 to 15 years after the regeneration harvest. The time required for canopy closure is inversely related to site quality. As competition increases, the less vigorous of the shade-intolerant trees succumb to those with more rapid height growth, and the number of stems per unit area diminishes. Once the canopy closes, two important cultural practices can be applied to improve the long-term productivity of the stand: control of wild grapevines (*Vitis* spp.) and crown release of selected crop trees.

Wild grapevines growing within the canopy of a young hardwood stand can severely reduce growth and quality. Vines matted in the canopy can damage the crowns and boles of valuable crop trees during wet snows and ice storms. Vines also compete for light resources during summer months and reduce growth. Wild grapevines can be controlled in young stands by cutting individual vines near ground level under dense overstory shade several years prior to any intermediate operations. Grapevines sprout prolifically when cut, but the sprouts are very shade-intolerant and will die within 2 to 3 years after cutting (Smith 1984; Smith and Lamson 1986). It is important to avoid cutting vines in conjunction with treatments that open the canopy and provide light to the vine sprouts, particularly in sapling stands where vigorous vine sprouts can climb as much as fifteen feet in one year. Vine control is most effective when applied 4 or 5 years before a thinning or other similar disturbance to the overstory. The cost of vine control depends on the number of vines per acre (Table 6).

Table 6. Estimated labor per unit area required to cut grapevines in sapling stands[a].

Number vines per acre (per hectare)[b]	Manhours per acre (per hectare)[b]
100 (247)	1.2 (3.0)
200 (494)	1.6 (4.0)
300 (741)	2.2 (5.4)
400 (988)	2.7 (6.7)
500 (1,235)	3.2 (7.9)
600 (1,482)	3.7 (9.1)
700 (1,729)	4.2 (10.4)
800 (1,976)	4.7 (11.6)
900 (2,223)	5.2 (12.8)
1,000 (2,470)	5.7 (14.1)

aFrom Smith and Lamson (1986); metric equivalents in parentheses.

bStand averages 1,900 trees/acre ≥ 1.0 inches dbh; 4,693 trees/ha ≥ 2.5 cm dbh

Crown release of selected crop trees is another important cultural practice that is best applied soon after canopy closure, when co-dominant trees average 25 to 30 feet (7.6 to 9.1 m) tall. Crop trees are selected based on species, quality, vigor, and distribution within the stand to meet timber, wildlife, or other management objectives. Each crop tree should receive a full crown release by eliminating adjacent trees that touch the crop tree crown by cutting or with herbicides (Figure 7). Crown release in sapling stands can increase dbh growth of individual trees by 30 to 50 percent for 5 to 10 years after treatment (Lamson and Smith 1989). In addition, release treatments can be planned to favor selected species and promote a gradual improvement in species composition as the stand matures.

In stands 10 to 15 years old, releasing 50 to 75 crop trees per acre (124 to 185 trees/ha) usually focuses site resources on the best trees available. A 25-foot (7.5 m) spacing between crop trees is practical in most cases. However, in parts of the stand where good crop trees are not available, it is not advisable to release low-value, or low-quality trees unless they are needed for wildlife or other non-timber objectives. Treatments usually are economical if the crop trees include high-value species such as northern red oak or black cherry (Miller 1986).

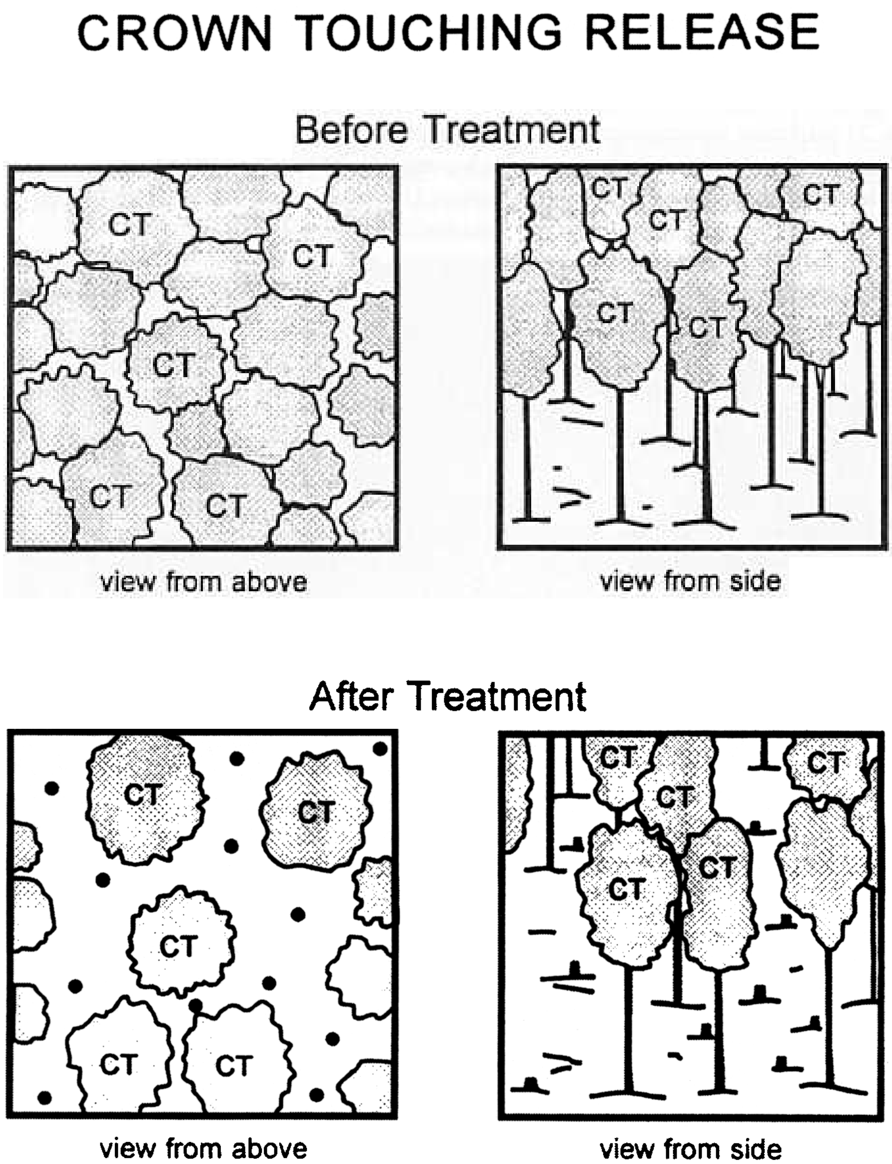

Figure 7. Aerial and side views of a sapling stand before and after crop trees (CT) receive a crown-touching release (From Lamson and others 1989).

Commercial thinning

The appropriate stand age for commercial thinning in even-age stands usually is determined by local wood product markets, harvesting economics, and site quality. Traditionally in the central Appalachians, commercial logging operations require a minimum cut of 2,500 board feet per acre (27 m^3/ha) and a total sale volume of 50,000 board feet (220 m^3). Thus, commercial thinnings involving the sale of sawtimber can begin when the stand is 50 to 60 years old. Stand development and the opportunity to conduct commercial operations occurs at an earlier age as site quality increases. The presence of pulpwood or other small-product markets also reduces the age at which commercial thinnings are possible.

Commercial thinnings are planned to: 1) reduce the time required to grow trees to a particular size, 2) reallocate site resources to the best trees in the stand as defined by production goals, and 3) capture stand mortality by harvesting and utilizing trees that would die due to competition in the absence of thinning. Crown thinning reduces stand density and increase the average stand diameter. Residual trees grow faster as they capture site resources that are freed by reduced competition, and the stand grows to a more advanced stage of development. In addition, thinning can improve average residual stand quality and increase the proportion of preferred species in the stand.

Guidelines for thinning Appalachian hardwood stands are based on a target residual stand density and proper distribution of the cut. The initial commercial thinning should leave the residual stand at about 60 percent relative density. Several stocking guides can be used to measure relative density on various forest cover types (Marquis and others 1992; Gingrich 1967; Leak and others 1987). Absolute basal area also can be used to control stand density. A general guideline used in southern Appalachian hardwoods (Beck 1986) and mixed species central Appalachian hardwoods (Trimble 1968) is to equate average residual stand basal area with site index. For example, where site index is 70 (21 m) for northern red oak, residual basal area after commercial thinnings should equal about 70 ft^2 per acre (16.1 m^2/ha), including trees 5.0 inches dbh (12.7) cm and larger.

Distribution of the cut also is an important factor in applying commercial thinnings. Marquis and Ernst (1991) demonstrated that thinnings result in maximum benefit when the reduction in relative density is distributed according to the following rule: 75 percent of the cut is from trees smaller than the average dbh and 25 percent is from trees larger than the average dbh. Alternative treatments in which cut trees were concentrated in either the smallest or largest size classes tended to result in less volume and value growth.

Commercial thinning can be applied using a crop tree management approach (Perkey and others 1994). Guidelines for residual stand density and distribution of the cut are coupled with marking that focuses on providing preferred residual crop trees with a full crown release after thinning (Figure 8). Similar to treatments in sapling stands, any competing tree whose crown touches the crown of the selected crop tree is cut. Crown release has been shown to increase dbh growth by 50 to 100 percent in sawtimber trees (Figure 9).

Marking guidelines can be based on the appropriate number of residual sawtimber and poletimber crop trees needed to meet residual stocking goals. For example, a 60-year-old Allegheny hardwood stand on site index 70 (21 m) had about 40 sawtimber (99/ha) and 35 poletimber (86/ha) crop trees per acre when thinned to 60 percent relative density

(Miller and Sarles 1986). Similar marking guidelines can be developed for a given stand, depending on residual stand goals, and converted to an average spacing between crop trees.

Figure 8. A commercial central Appalachian hardwood stand immediately after crop tree release.

Discussion

The appropriate silvicultural method for managing hardwoods depends on many factors: silvical characteristics of individual species, site quality, forest product objectives, and nontimber objectives such as aesthetics or wildlife habitat. For most Appalachian hardwood species, several regeneration methods can be used to produce desired products and establish adequate regeneration to grow future stands. For some species, northern red oak for example, specific treatments are needed for successful regeneration. The key to planning effective silvicultural systems is to first clearly define management objectives. The next step is to identify workable alternatives based on wood products markets, local soil-site conditions, and a careful projection of the growth and/or regeneration potential of the stand. From this analysis should come one or two practical options for the forest manager.

Site quality and regeneration method have important effects on the regeneration found in central Appalachian hardwood stands (Trimble 1973). Stands on low-quality sites usually have a lower stand density and less dense understory compared to stands on high-quality sites of the same age. Consequently, mature stands on lower quality sites have advance reproduction that is more abundant and more widely distributed compared to stands on high-quality sites before cutting. Advance reproduction is dominated by shade-tolerant species, particularly on high-quality sites where there has been little or no disturbance to the canopy for many years. Advance oak reproduction becomes more abundant as site quality decreases.

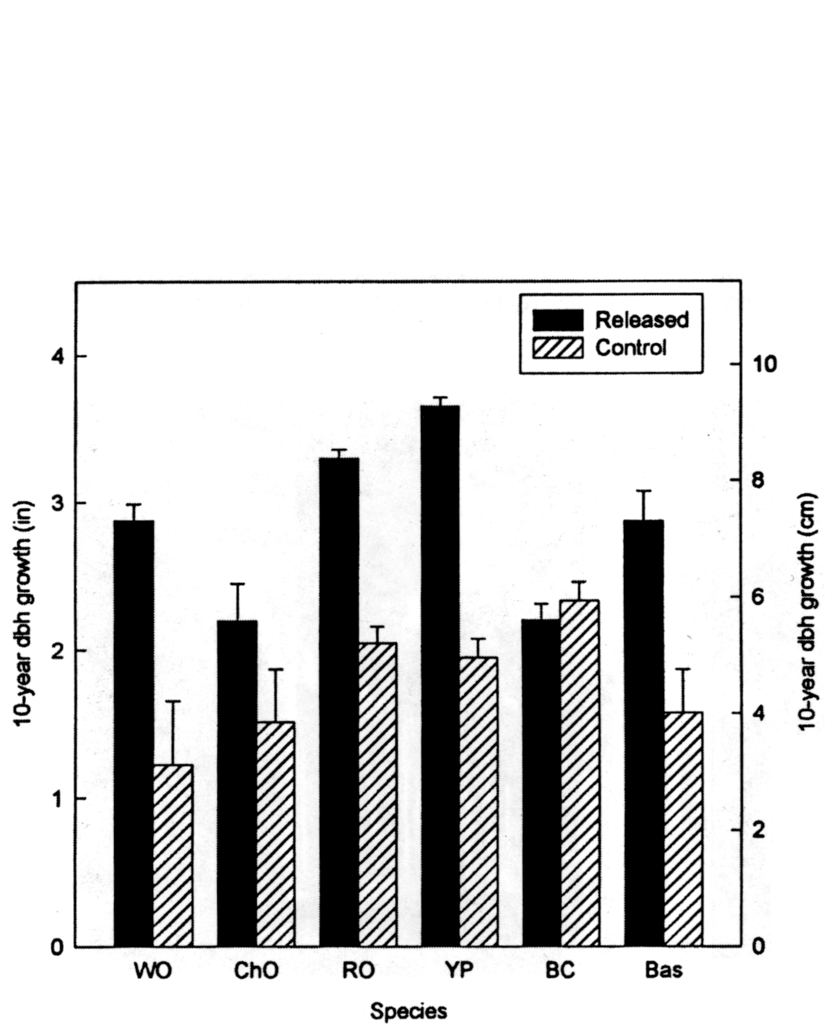

Figure 9. Mean 10-year dbh growth of co-dominant trees in 75-year-old even-age Appalachian hardwood stands, controls versus complete crown release for white oak (WO), chestnut oak (ChO), northern red oak (RO), yellow-poplar (YP), black cherry (BC), American basswood (Bas); one standard error is shown above each bar (From Miller and others 1995b).

Partial cutting favors the development of shade-tolerant advance reproduction (Table 7). Single-tree selection practices tend to promote sugar maple and American beech on high-quality sites; red maple and American beech are promoted on low-quality sites. In addition, shade-tolerant shrubs and sweet birch usually develop on all sites under such practices.

To promote the development of shade-intolerant species, overstory density must be dramatically reduced through group selection, clearcutting, or two-age practices (Table 7). On high-quality sites yellow-poplar, basswood, black locust (*Robinia pseudoacacia* L.), and black cherry can be expected to develop and become co-dominant after such practices. Sugar maple and American beech also will develop, but they will not dominate the site as they do following partial cuts. On low-quality sites after heavy overstory removal, red maple, sassafras (*Sassafras albidum* Nutt. Nees.), chestnut oak, northern red oak, and American beech will develop. The presence of advance reproduction before cutting has a strong influence on the eventual species composition on all sites (Beck 1988; Marquis 1988; Sander 1988).

Table 7. Effect of cutting practice on the proportions of tolerant versus intolerant reproduction[a].

Type of cutting	No. of stands	Total area	Oak site index		Stems 1-5 inches dbh		
			Range	Average	Intolerant species[b]	Tolerant species[c]	Stump sprouts
		acres	------feet------		weighted percent		percent
Clearcut	9	110	61-77	70	37	27	58
Diameter-limit	5	151	59-75	69	18	62	18
Selection	7	198	59-82	71	5	78	18

[a]From Trimble (1973).

[b]Includes the following very intolerant, intolerant, and intermediate species: red oak, yellow-poplar, black cherry, white ash, black locust, sassafras.

[c]Includes the following very tolerant and tolerant species: beech, sugar maple, red maple.

Deer browsing can have a devastating effect on tree regeneration. The risk of regeneration failure due to browsing is greatest when the local deer population is relatively high and regeneration harvests are isolated in areas where the availability of food is relatively low. Deer tend to concentrate their feeding in recently harvested stands where new seedlings and sprouts are abundant. Harvests should be planned such that deer browsing pressure is dispersed over a large area on the landscape. Additional methods include fencing to exclude deer using tree shelters and fertilizing stands after harvest to accelerate seedling height growth (Marquis and others 1992).

Not all results observed in central West Virginia will be applicable to forest management problems in southern Ontario. However, where stand and site similarities exist, guidelines suggested in this paper could be tested on a small scale to begin to develop practical, site-specific management prescriptions that produce acceptable results.

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