Interference to Hardwood Regeneration in Northeastern North America: Controlling Effects of American Beech, Striped Maple, and Hobblebush

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ABSTRACT: *When American beech (*Fagus grandifolia *Ehrh.), striped maple (*Acer pensylvanicum *L.), and hobblebush (*Viburnum alnifolium *Marsh.) become dense in the understory they interfere with regeneration of other species. This review identifies threshold levels that cause problems in regenerating desirable hardwoods in northeastern North America, and summarizes methods for controlling the interference in conjunction with a reproduction method cutting. It also forwards some ideas about management based on information in published sources. North. J. Appl. For. 23(2):122–132.*

Key Words: American beech, striped maple, hobblebush, understory interference, interfering plants, hardwood regeneration, site preparation, vegetation management.

Stands with a dense understory of American beech (*Fagus grandifolia* Ehrh.) commonly have beech bark disease. Root injuries during logging and by natural causes also promote new suckers that, along with some stump sprouts and seedlings, often maintain or increase the density of understory beech in a stand. Additionally, browsing deer primarily bypass beech in favor of more palatable species, and this makes the situation even worse. Where understory beech has become dense, any type of overstory cutting promotes its development, increasing ground-level shading, and interfering with the establishment of other species (Nyland et al. 2004a).

A dense understory of striped maple (*Acer pensylvanicum* L.) also often interferes with desirable hardwood regeneration after overstory cutting. This species persists in heavy shade, and grows rapidly after release. New seedlings, stump sprouts, and air layers reinforce the density of striped maple, oppressing more desired seedlings. Likewise, hobblebush (*Viburnum alnifolium* Marsh.), a shrub, reproduces by rhizomes that form thickets of new shoots when disturbed by harvesting, or stimulated by some other partial overstory disturbance. Attempts to regenerate desirable hardwood species beneath these thickets, or in stands having a dense understory of beech or striped maple, commonly fail. Yet by managing the interference before overstory cutting, landowners can insure a more favorable outcome (Nyland et al. 2004a).

Managing the Aftermath Forest

Proximity to known areas of infestation dictates the alternatives for managing beech in localities free of scale and beech bark disease, and where beech may not yet dominate the understory. Under those circumstances, or in stands having apparently resistant trees, landowners can maintain the disease-free beech, monitor them for signs of decline, and then salvage infected ones once symptoms appear (Bogenschutz 1983). Light partial cutting will improve the vigor of noninfected main canopy trees and stimulate development of ones in the understory. Simply felling the large beech will also induce suckering from the roots (Ostrofsky and Houston 1988, Houston 1997), particularly around any resistant and apparently disease-free trees that remain in a stand (Houston 2001). In addition, controlled disturbance to injure shallow roots will promote beech suckering (Houston 2001). Both measures will increase the density of understory beech saplings where landowners

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want to promote its development. However, this also increases the interference to other species.

In many areas, noninfected stands within or near diseased forests will likely become infected, and then managers can only take steps to temper the impacts (Mielke et al. 1987, Houston 1997). For stands with high rates of infection, Bogenschutz (1983), Jones et al. (1989), and Houston (1997) suggest cutting all the large beech to salvage the timber, or poisoning or girdling them to reduce the seed supply of nonresistant trees and limit subsequent root suckering by the dying beech. Logging in winter when the soil has a protective cover of snow, keeping skidders on well-designed skid trails, and using low-impact feller-buncher machines will help to limit injuries to beech roots and reduce suckering after a harvesting operation (Ostrofsky and Houston 1988, Jones et al. 1989). In addition, landowners should remove smaller beech that will eventually become infected, and also produce suckers. This will reduce the habitat for crawling scale insects and slow their movement to new trees. Herbicide treatments also help to control existing understory beech. Available evidence suggests that these measures will begin a stand conversion by favoring the establishment and growth of other species (Jarvis 1957, Houston 1997).

During early stages of beech bark disease, while some sawtimber-sized trees lack obvious symptoms, most eventually succumb. Yet even in heavily infected stands, a small percentage of trees (approximately 1%) may show no sign of the beech bark disease (Houston 1997). Resistant ones may have a specialized bark structure that makes them unsuitable as hosts for the scale insect (Lonsdale 1983), a different chemical composition that inhibits a spread of the disease in the bark tissues (Wargo 1988), or a crustose lichen that may prevent insect feeding in the bark (Houston 1983).

Research has not provided reliable methods for identifying the truly resistant or even partially resistant trees. They likely derived (singly or in groups) from seed transported to a site from nearby resistant sources, or as groups of suckers (genetically identical) off the roots of a resistant parent (Houston 1997, 2003, McCullough et al. 2000). Eventually, the resistant clones may spread, but only slowly through time. Susceptible trees eventually become infected and die. During the interim they will produce root suckers having the same degree of susceptibility. Time will show whether the trees have true resistance, or if the infection just developed slowly in the reserved trees.

Once beech dominates the understory, almost any overstory cutting will promote its development. In fact, Kelty and Nyland (1981) demonstrated that forgoing beech removal before shelterwood seed cutting resulted in predominantly beech within the new age class. By contrast, appropriately applied clearcutting and shelterwood methods that included beech understory control using herbicides, and reduction of deer densities where needed, have resulted in predominantly nonbeech regeneration in northern hardwood stands (Richards and Farnsworth 1971, Burns and Houston 1987, Kelty and Nyland 1981, Horsley 1994, Ray et al. 1999). The most effective site preparation would remove both the unmerchantable poles and the saplings. Where Tierson (1967) did this to release seedlings of favored species, he increased the proportion of yellow birch (*Betula alleghaniensis* Britton.), white ash (*Fraxinus ameriana* L.), and sugar maple (*Acer saccharum* Marsh) >3 ft tall.

Leak and Wilson (1958) also found that nonbeech species maintained dominance 10 to 15 years after selection cuttings in New Hampshire stands having only one-third to one-half as much beech as sugar maple among the advance regeneration. As with Tierson's (1967) experiment, releasing the sugar maple from overtopping beech improved the composition even more (Filip 1978). Similarly, on many plots lacking well-developed advance regeneration of desirable species, beech, striped maple, and hophornbeam dominated the tall regeneration (>3 ft in height) by 6 years after single-tree selection cutting in New York. Preferred species succeeded on milacres where they initially occurred as advance seedlings >1 ft tall (Mader and Nyland 1984). Quinlan (1996) also observed that 9 years after selection cutting, milacre plots with 10 or more beech had few tree seedlings of other species, and a reduced diversity and abundance of herbs. Dense striped maple or hobblebush would likely have a similar effect. In another case, beech became predominant after selection cutting (with no site preparation) in a heavily browsed stand having both beech and maple as advance regeneration (Piussi 1966). Other evidence also shows that in heavily browsed stands having a dense understory of beech and striped maple, partial cutting to even a wide range of residual densities (light to complete overstory removal) has not effectively regenerated desirable species (Curtis and Rushmore 1958, Barrett et al. 1962, Richards and Farnsworth 1971, Hannah 1991).

Group selection and patch-selection methods should increase the number of yellow birch and white ash on appropriate sites (Leak and Wilson 1958, Leak and Filip 1977, Filip 1978, Leak 1980, 2003). Yet beech may still dominate the new cohort (Marquis 1965, Leak 1999), particularly beneath small openings (McClure and Lee 1993) or at other places where it overtops more desirable advance regeneration (Marquis 1965, McClure and Lee 1993, Leak 2003, Nyland et al. 2004a). Some managers rely on heavy ground disturbance inside the openings to reduce the understory, but that destroys small trees of desirable species as well as the beech. Also, field trials have provided only circumstantial evidence about the effectiveness of the technique, and extensive surface disturbance would increase the erosion potential on slopes. Further, a lighter disturbance would only damage the beech roots without destroying them, increasing the chance of sucker formation from callus that forms around the wounds (Jones et al. 1989, Houston 2001, Nyland et al. 2004a). Alternately, precutting site preparation could release the more desirable advance seedlings and saplings, or remove the entire understory using methods that do not expose the mineral soil or extensively damage the roots. Periodic tending throughout the stand should also remove poor-quality trees, thin the immature age classes, reduce potentially interfering species, and salvage diseased beech as needed (Filip 1978). That minimizes the presence of beech at the next entry to a stand.

Beech seedlings grow best with ≤45% full light near the forest floor (Jensen 1943, Rushmore 1961, Logan 1973). At high light levels, beech regeneration of all types grows more slowly than sugar maple, birches, and white ash (Bicknell 1982, Borman and Likens 1994, Nyland et al. 2004b). Perhaps for that reason, clearcutting and shelterwood methods, in combination with beech understory control and reductions of deer density, have successfully regenerated desirable species (Kelty and Nyland 1981, Burns and Houston 1987, Horsley 1994, Leak and Smith 1997, Ray et al. 1999), and so has clearcutting in unprepared sites having abundant and well-developed sugar maple advance regeneration (Marquis 1967, Walters and Nyland 1989).

In some cases, summer clearcutting has reduced existing beech seedlings while encouraging the regeneration of shade-intolerant and intermediate species (Houston 2001). Mechanically removing the shade-tolerant understory saplings (including beech) has resulted in a predominance of shade-intolerant species in main canopy positions (Marquis 1981). By contrast, in stands with abundant advance seedlings of shade-tolerant species (e.g., beech and striped maple), few shade-intolerants have become part of the new cohort (Blum and Filip 1963).

Repeated clearcutting on short rotations might also eventually reduce the abundance of beech (Fowells 1965), while maintaining more desirable species (Curtis and Rushmore 1958). Yet some research has documented more root sucker development after clearcutting than after partial cutting (Houston 2001). Harvests leaving residual beech, brightening the understory, and injuring beech roots will promote suckering (Hamilton 1955), and failure to control dense understory beech has resulted in a domination of that species after all types of cutting treatments (Hamilton 1955, Tierson 1967, Richards and Farnsworth 1971, Kelty and Nyland 1981, Horsley 1994, Bohn 2001, Bohn and Nyland 2003). However, although new root suckers eventually develop after clearcutting and shelterwood method seed cutting, even after understory treatment, the new beech remains shorter than sugar maple and the less shade-tolerant species (Liptzin and Ashton 1999, Ray et al. 1999, Nyland et al. 2004b).

Judging the Importance of Understory Interference

Many plants, and especially those reproducing vegetatively, often have a more clumped than uniform spatial distribution (Whitford 1949). Regeneration develops primarily around established parents (e.g., within 30 to 35 ft of a large beech tree), resulting in either no or high numbers of stems on widely spaced sample plots. Furthermore, dispersion of these species into new areas occurs slowly throughout time, except after introduction of viable seed from adjacent sources. As a consequence, areas with only scattered beech saplings or little hobblebush will not change appreciably throughout short periods, unless something promotes aggressive suckering or introduces viable seed and triggers its germination.

That underlies the evaluation criteria by Bohn (2001) and Bohn and Nyland (2003) for assessing the importance of beech in the understory of northern hardwood stands. Among five uneven-aged stands in New York State, they observed that the importance of any species depended on its relative abundance among the advance regeneration, weighted by its height with respect to that of other species. Further, the importance of beech on plots lacking it or having high levels of beech changed little after partial cutting. Conversely, beech importance increased on approximately 75% of plots having low and medium importance values, and where it was tallest. It did not dominate approximately 80% of plots that initially had a taller advance tree of a more desirable species. These observations reinforce Leak's (1988) findings that successful regeneration had not occurred when undesirable species dominated more than 60% of the regeneration plots, with dominance determined as the tallest tree on a milacre plot. Likewise, Leak and Wilson (1958) also found that understory dynamics depended on the distribution, height, and abundance of different species in the advance regeneration. Both sugar maple and beech most likely became dominant (tallest) when present as tall advance regeneration.

Several other studies have also linked regeneration success to the presence of desirable advance regeneration, and particularly tall seedlings or well-developed saplings. Mader and Nyland (1984) found that beech, striped maple, and eastern hophornbeam [*Ostrya virginiana* (Mill.) K. Koch] dominated the 3-ft tall to 1-in. dbh size class at 6 years after selection cutting to 75 ft^2/ac, except with advance regeneration of desirable species taller than 1 ft. Hamilton (1955) reported that success after clearcutting depended on killing the advance beech and having desirable species present as advance regeneration. Likewise, Wang and Nyland (1993) reported that sugar maple grew into overstory positions after clearcutting only on plots where it had occurred as well-developed advance regeneration, or where it developed after cutting as a stump sprout. For even-aged stands, Marquis et al. (1975) and Marquis (1987) found that desirable species failed when more than 30% of 6-ft radius plots had eight or more beech and striped maple, with stems >1 ft in height weighted twice.

Consistent with these observations, Leak (1988) found limited numbers of commercial species in areas having abundant striped maple, and particularly after light cutting. Yet Leak and Solomon (1975) had earlier observed no consistent relationship between residual density and striped maple abundance 9 years after cutting. In fact, past research has not provided definitive guidelines for judging the potential interference from striped maple or hobblebush. More generally, Marquis et al. (1992) suggest controlling any interfering species that dominates more than approximately one-third of the stand area, and Hannah (1987, 1991) recommended site preparation when beech and other undesirable species comprise more than 50% of the advance regeneration. Further, Bohn and Nyland (2003) suggested that desirable species fail on milacre plots where any one of several interfering woody plants has reached a tallest-of-plot status.

Taken together, these studies suggest an evaluation strategy for judging the potential for interference by beech, striped maple, and hobblebush in northern hardwood stands. First, tally understory conditions using an adequate number of appropriately sized regeneration plots, and then stratify the plots into precut condition classes (desirable versus undesirable composition), using the tallest tree on a plot as an indicator of the likely outcome. Next, sum the number of plots in each category to determine what proportion of the stand area will likely have a high level of interference after an overstory cutting. The findings will indicate if interfering species will likely deter regeneration over sufficient area to warrant site preparation, particularly where those species occur at intermediate levels of abundance or in a clumped manner across part of the stand. Generally, at least some understory control would seem appropriate if more than 30 to 40% of the area has undesirable levels of beech, striped maple, or hobblebush.

Managing an Interfering Woody Understory

Where American beech, striped maple, hobblebush, or some other undesirable woody species has become dense in the understory of northern hardwood stands, no reproduction method will succeed in establishing desirable hardwood regeneration. Under those circumstances, site preparation must first remove the interference, particularly in stands where the undesirable woody plants have grown taller than advance seedlings of other species. Landowners must also protect a regeneration area from intensive browsing, or reduce deer density by hunting female deer from the surrounding forest (Sage et al. 2003). These measures must precede overstory cutting to insure success. In addition, landowners should delay complete overstory removal until abundant advance seedlings of desirable species have become established and grown to at least 1 ft tall. That will improve the chances for good stocking of new trees, speed their development, and improve chances that ones of desirable shade-tolerant species will grow into upper canopy positions within the new age class.

The density and size of advance stems will determine the most efficient method to use for site preparation. In stands with fewer than 500 understory stems/ac, and particularly with trees >3 in. dbh, individual stem treatments cost less (Ostrofsky and McCormick 1986, Sage 1987). These include stem injections in frills, basal sprays, and spot-gun applications (Sage 1987, Heiligmann 2004), frilling and girdling without herbicides (Carvell 1956, Heiligmann 2004), and cutting (Mallett 2002). By contrast, broadcast herbicide treatments such as mistblowing have proven most efficient with understory stem density between 500 and 1,400/ac, and trees less than 30 ft tall (Sage 1987). Backpack mistblowers work well for small areas, and ones mounted on tractors or skidders allow efficient treatment of larger areas. Although the machines can potentially blast the herbicide as far as 60 ft, dense understory foliage can inhibit movement of the mist laterally and upward.

Prescribed Burning

Prescribed burning has not adequately controlled understory beech, and would not likely reduce striped maple or hobblebush any better. Swan (1970) observed that because of its root suckering, beech remained the dominant understory species after a light ground fire burned the humus and litter layers. Damage to surface roots apparently promoted suckering of the trees that remained alive. Likewise, prescribed spring surface fires that burned only the upper part of the litter layer killed back but did not effectively reduce the abundance of sapling beech beneath transition oak stands in New York. Twice-burned sites (applied at a 3-year interval) had shorter beech than at the once-burned plots, but the overall importance of beech in both areas increased as a result of the burning (Johnson 2000). Perhaps additional fires at regular intervals would better control the understory beech. But each fire would also kill back seedlings of more desirable species, lengthening the time for adequate advance regeneration to dominate a site.

Herbicide Application

Early work with beech and striped maple understory control included chemicals such as 2,4,5-T, 2,4-D, picloram, and Bromocil applied as sprays or by mistblowing during the growing season (Tierson 1969, Horsley and Bjorkbom 1983, Sage 1987). Injection of chemicals such as 2,4-D and ammonium sulfamate into frills also killed individual understory trees of most species (Curry and Rushmore 1955, Carvell 1956, Barrett et al. 1962, McCormack 1981). Table 1 summarizes general findings from investigations using these methods with several different herbicides for controlling American beech, striped maple, and hobblebush. Users should consult the source publications for more complete details about formulations, application methods, and findings of the research. *Herbicide Handbook* (Vencill 2002) and the Environmental Protection Agency website (www.epa.gov/oppread%201/international/piclist.htm) provide extensive information about currently available compounds, including those approved for use in forestry operations, and conditions of their registration. Along with state and local regulations, they should serve as a final reference with respect to any herbicide application noted here.

Quite important, the timing of treatment, application rate, and concentration of herbicide influence the outcome with each of the common application methods. This seems especially true for broadcast treatments using backpack and tractor-mounted mistblowers, and for ground and aerial spraying. Summer application (after full leafout and before autumn yellowing) has generally given the best results in controlling American beech, striped maple, and hobblebush by mistblowing or spraying (Table 1). Glyphosate, triclopyr, picloram, and fosamine have all effectively controlled understory beech. Results varied more with striped maple

Table 1. Herbicide trials to control American beech, striped maple, and hobblebush in northeastern hardwood forests.[a]

Chemical/trade name	Prescription	Results	Reference
Glyphosate	3 lb/gal or 0.75 lb/gal by stem injection in summer and winter diluted 1:3 in water, by stem injection in all seasons >0.5 kg/ac a.i. broadcast with backpack sprayer in early September	>70% and <50% beech control, respectively	Holt and Reed 1981
		>70% control of beech	Maass 1983
		Effectively killed beech, but not striped maple; results more consistent and more efficient than triclopyr	Pitt et al. 1993
Glyphosate as Roundup	1.68 and 3.36 kg/ha by aircraft in July	Good to excellent suppression of beech	McCormack et al. 1980
	2.2 kg/ha and 4.4 kg/ha by aircraft after dormancy of conifer buds	90% kill of beech with less than 40% kill of sugar maple; 100% kill of all other species	Horsley 1994
	2 ml of 20% and 50% solution in spaced axe cuts in large beech trees in September and November	75% mortality after 2 years; 50 to 80% crown kill on other trees	McCormack and Newton 1980, McCormack 1981
	0.23 gal/ac by skidder-mounted mistblower at mid-summer	83% kill of beech; 51% kill of striped maple; high efficacy on hobblebush	Wendel and Kochenderfer 1982
	0.47 lb/ac by skidder-mounted mistblower between July and August	85% kill of beech; high efficacy on hobblebush and striped maple	Sage 1983, 1987
	1.8 lb/ac a.i. by backpack mistblower; full strength when applied in frills in conjunction with shelterwood cutting	100% kill of beech saplings; 85% kill of defective overstory trees	Sage 1983, 1987
	1 qt/ac in 25 gal of water by tractor-mounted mistblower in early September	Killed 81% of all striped maple, including stems <20 ft tall; adding adjuvants or other herbicides improved results significantly	Ostrofsky and McCormick 1986
	1 qt/ac by tractor-mounted mistblower from early August to leaf yellowing	Controlled ≥95% of beech 1 to 5 ft tall; 81% kill of beech 5 to 20 ft tall; earlier applications required 2 to 4 qt/ac for the same level of control; effective kill of striped maple took 4 qts/ac; adding adjuvants did not improve results	Horsley 1990
	1 qt/ac in 25 gal of water by tractor-mounted mistblower from early August to early October in conjunction with shelterwood cutting	Stocking of beech and striped maple reduced by 16%	Horsley 1991
Glyphosate as Accord	1.2 kg/ha in 3 l water by mistblower during the growing season	≥85% kill of striped maple for July to Sept. application; >90% for beech with Jul. to Oct. treatment	Horsley and Bjorkbom 1983
	1.5 ml/in. dbh by stem injection to beech saplings after full leaf-out in June	100% beech crown control; killed the greatest number of root suckers compared to other chemicals	Kochenderfer et al. 2001
	50% solution in water to small stumps during summer	Prevented 99% of beech stumps from sprouting; significant chemical transfer to nontreated beech trees up to 21 in. dbh	Mallett 2002
	1.5 ml of 50% solution in water per axe cut for stem injection during August	99% control of understory beech	Kochenderfer et al. 2004
Triclopyramine	2.2 kg/ha and 4.5 kg/ha in water by aircraft in July	90% kill of all stems and sprouting stumps; beech suppression minimal	McCormack and Newton 1980, McCormack 1981
	3 lb/gal or 0.75 lb/gal by stem injection in winter and summer	>70% and 50 to 70% beech control, respectively	Holt and Reed 1981
	Diluted 1:1:6 in water in combination with glyphosate by stem injection in winter	Outperformed either chemical alone on beech and striped maple	Maass 1983
	> 0.5 kg/ac active ingredient broadcast with backpack sprayer in early September	Effectively killed beech, but not striped maple; less consistent and less efficient results than glyphosate	Pitt et al. 1993
Triclopyr as Garlon 3A	0.55 gal/ac by skidder-mounted mistblower at mid-summer	Variable results; ≥55% of understory beech killed; high efficacy on hobblebush; 56% kill of striped maple	Sage 1983
	1.2 lb/ac a.i. by mistblowing in August; full strength by frill application in July	93% kill of beech saplings and 87% kill of defective overstory trees (>3.0 in. dbh) when combined with shelterwood harvest	Ostrofsky and McCormack 1986
	1.5 ml/in. dbh by stem injection to beech saplings after full leaf-out in June	100% beech crown control	Kochenderfer et al. 2001

Table 1. (continued)

Chemical/trade name	Prescription	Results	Reference
Triclopyr as Garlon 4	4 qt (plus Clean Cut + Pine in 8 qt emulsified crop oil, totaling 75 gal/ac) using a Cibolo Jr with a Swinglock nozzle to dormant stems in April	Severely injured contacted stems and also some stems beyond the contact area	Lyman et al. 1990
	3 ml/in. dbh as a basal spray after full leaf-out in June	Largely ineffective	Kochenderfer et al. 2001
	2.5 to 5.75 pts/gal diesel oil as spray on small beech stumps and as a basal spray to understory beech stems during summer	Prevented 99% of beech stumps from sprouting; killed the fewest untreated trees when applied to stumps; did not flashback to others when used as a basal spray	Mallett 2002
	10% solution in oil as basal spray in August	99% control of understory beech	Kochenderfer et al. 2004
Picloram as Tordon 101M	0.67 lb/gal or 0.25 + 1 lb/gal 2,4-D by stem injection in winter and summer	>70% and <50% beech control, respectively	Holt and Reed 1981
	1 tsp 10% active ingredient pellets/in. dbh to the soil at the base of stems in April	Most effective control of sprouting of 1 to 3 in. dbh stems (6 to 26 ft tall) when compared to bromacil, AMS, or 2,4-D	Shipman 1982
	1 ml of 50 to 50 water dilution 10.2% active ingredient plus 30.6% active ingredient 2,4-D by stem injection into spaced cuts at the base of trees in June	Significantly lower mean kill than other tested treatments	Shipman 1982
	0.67 lb/gal by stem injection in winter	>70% control of beech stems	Maass 1983
	0.47 gal/ac by skidder-mounted mistblower at mid-summer	82% kill of beech; high efficacy for hobblebush; significant reduction in regeneration of desirable species	Sage 1983, 1987
Picloram pellets as M-3864 and M4180	5% pellet formulation at 6.72, and 12.10 kg/ha a.i., and 10% pellet formulation at 8.96, and 17.92 kg/ha a.i., broadcast by hand in May	>87% kill of striped maple for 5% pellets; >83% kill for 10% pellets; lower dosages less satisfactory	Horsley and Bjorkbom 1983
Fosamine as Krenite	0.75 gal/ac by skidder-mounted mistblower to beech in September; 0.78 gal/ac to striped maple in July; 0.78 gal/ac to hobblebush in July and September	96% beech, 19% striped maple, and high efficacy for hobblebush control without brown-out; cost 1.5 times greater than glyphosate	Sage 1983, 1987
Imazapyr as Chopper	3 ml/in. dbh as a basal spray after full leaf-out in June	Largely ineffective	Kochenderfer et al. 2001
	8 oz/gal water as a basal spray to small understory beech stems and stumps during summer	Prevented sprouting in 100% of treated stumps; flashback observed in larger beech, yellow birch, sugar maple, and white ash	Mallett 2002
Imazapyr as Arsenal	1.5 ml/in. dbh by stem injection to saplings after full leaf-out in June	100% beech crown control and significant kill of root suckers; damaged many adjacent larger trees	Kochenderfer et al. 2001
Ammonium sulfamate (AMS)	1 tbs of 95% active ingredient crystal/in. dbh to "V" notched cut on 1 to 3 in. stumps in June	Treated striped maple stumps had significantly fewer sprouts than the controls (cut, no herbicide)	Shipman 1982
Bromacil	1 tsp of 10% active ingredient pellets/in. dbh to soil at base of 1 to 3 in. dbh (6 to 26 ft tall) stems in April	Effective control of basal sprouting on striped maple; not significantly different than picloram treatments	Shipman 1982
	80% wettable powder at 8.96, 19.92, 26.88, and 53.76 kg/ha a.i. in water to a final volume of 2.4 l (411 l/ha), in May	>90% kill of striped maple	Horsley and Bjorkbom 1983
Dicamba	2 lb/gal or 0.5 lb/gal (+ 2 lb/gal 2,4-D + 2 lb/gal mecroprop) by stem injection during winter and summer	>70% and 50 to 70% beech control, respectively	Holt and Reed 1981
	2 lb/gal by stem injection during winter and summer	>70% control of beech	Maass 1983
	0.5 + 2 lb/gal of 2,4-D mecoprop by stem injection of during winter and summer	50 to 70% control of beech	Maass 1983
	0.71 gal/ac by skidder-mounted mistblower at mid-summer	77% kill of understory beech	Sage 1983
2,4-D	1 ml of 40.3% active ingredient by tree injector into spaced cuts at base of the trees during June	Significantly lower mean kill of beech than other treatments	Shipman 1982

[a] Columns list the compound, the dosage, and method of application, key effects of the treatment, and the source and publication date.

and hobblebush. Increasing the dosage of glyphosate increased the kill of striped maple, but at a higher cost. Also, mistblowing methods generally have killed vegetation only up to approximately 30 ft from the ground, and trees less than 3 to 4 in. dbh (Sage 1983, 1987). To insure a more complete stand-level treatment, Ostrofsky and McCormack (1986) and Ostrofsky and Houston (1988) recommend coupling the mistblowing with stem injection of the larger beech trees, and later poisoning of any beech sprouts that develop after the harvesting. Kelty and Nyland (1981), Ostrofsky and McCormack (1986), and Horsley 1994) also recommend linking the chemical site preparation to a two-stage shelterwood method to promote desirable regeneration, using the seed cutting to remove any merchantable beech trees that remain. This has significantly increased the stocking of desirable seedlings and promoted favorable herbaceous development.

Plain cutting, cutting with stump spraying, complete girdling without chemicals, and frilling with injection of herbicides into spaced ax cuts have been recommended for killing individual trees (Heiligmann 2004), particularly where they occur at a low density (e.g., <500/ac; Sage 1987). Carvell (1956) and Heiligmann (2004) reported that injecting a herbicide into ax-cut frills increases the rate of kill, compared to just girdling the trees. Likewise, McKinney and Korstian's (1932) comparison of girdling, felling, and killing with herbicides showed that although all reduced basal sprouting of unmarketable trees, appropriate methods using herbicides proved the most effective.

Heiligmann and Kraus (2002) summarized the relative effectiveness of currently registered compounds for stem injection, as a basal spray, or sprayed onto freshly cut stumps. Most northern hardwood species (ashes, aspen, basswood, beech, birches, cherry, maples, and oaks) showed susceptibility to triclopyr, picloram, and imazapyr when applied as water solutions into frills or girdles, or sprayed on stumps of cut trees. They rated susceptibility to 2,4-D + 2,4-DP and glyphosate as intermediate to susceptible. For oil-soluble herbicides applied as a basal spray or sprayed onto cut stumps, these species had a susceptible or susceptible-to-intermediate rating with respect to triclopyr and imazapyr, and mostly intermediate-level ratings for 2,4-D + 2,4-DP (with white ash and red maple more resistant than others). They observed that even with an intermediate ranking, the herbicides killed most of the treated trees or woody vines. However, the ratings did not distinguish between effects of herbicides that translocate into the aboveground portion of trees versus movement into the root system (as occurs with glyphosate).

Heiligmann (2004) noted that the timing of application and dosage has varied among herbicides when used with stem injection, but all can be put into spaced ax cuts that penetrate into the sapwood. Tree size does not seem to limit effectiveness. Glyphosate, a glyphosate-triclopyr mixture, triclopyr alone, and imazapyr have provided the best control with stem injection. Applying imazapyr by stem injection, as a basal spray, or sprayed onto stumps has caused flashback into untreated beech trees of even large diameter, and to nonbeech species as well (Kochenderfer et al. 2001, 2004, Mallet 2002). Abrahamson (1983) and Kochenderfer et al. (2004) have also demonstrated that injecting glyphosate into large beech trees would kill nearby small beech (including root suckers), with minimal risk to trees of other species. Abrahamson (1983) and Jones et al. (1989) suggested that this would also prevent new root suckers from developing, and seems useful as one means for beech understory control.

Basal sprays have proven effective for trees up to 4 to 6 in. dbh when applied to the lower 12 to 18 in. of the stem (Kochenderfer 2001, 2004, Heiligman and Kraus 2002, Mallett 2002). Triclopyr and imazapyr have effectively controlled treated stems. Yet because excess herbicide will run down the bark into the soil and may enter adjacent trees through their roots, workers must use care to control the amount applied, particularly with imazapyr. That is true for stump treatments as well (Mallett 2002). For that use, water-soluble glyphosate and imazapyr applied to the sapwood area of freshly cut stumps have effectively controlled understory beech. Glyphosate also caused flashback to larger untreated trees of the same species. Similarly, imazapyr killed untreated large-diameter beech, but also yellow birch, sugar maple, and white ash. Oil-soluble triclopyr allows more flexibility in timing, but must be applied to the entire stump, the bark, and any exposed roots (Heiligmann 2004). It has not caused flashback to untreated trees (Kochenderfer et al. 2001, Mallett 2002).

Mobility of herbicides into the soil, and their persistence there, might cause concern among landowners. To address this question, Thompson et al. (2000) examined the forest floor and mineral soil in Acadian forests for persistence of glyphosate, and triclopyr. After September application, glyphosate at all formulations had an average half-life of 12 and 10 days, respectively, in forest floor and mineral soil layers. Triclopyr had an approximate average half-life from 39 to 69 days, depending on depth in the soil. Neither chemical was mobile in forest terrestrial substrates, suggesting an ecologically suitable outcome when applied appropriately by well-trained workers. Despite this, some landowners object to using herbicides, and public sentiment generally favors restrictions over their application in the forest. Yet Obermyer (1992) found that after the Siuslaw National Forest stopped using herbicides, people came to better appreciate the benefits from an appropriate vegetation management program. These could include alternative methods for site preparation, such as cutting (Harvey et al. 1998) and other mechanical means.

Cutting to Control an Interfering Woody Understory

Mechanical methods have not been widely used or extensively examined for controlling understory interference. Nyland (2004) observed that a double-kerf girdle done with a small hand saw killed trees up to approximately 3 in. dbh in 1 year, and others as large as 5 in. by 3 years. Even so, the method would prove inefficient for treating large areas, or stands with a high density of understory stems. Similarly, single-stem cutting methods (e.g., using brush saws) would also have a high cost, varying with stem size and density, and limited to trees <4 in. stump diameter (De Franceschi and Bell 1990, Bell et al. 1997). De Franceschi and Bell (1990) found that workers would average just under 8 hours to cut approximately 500 trees/ac (>1 in. dbh and averaging 10 ft tall), or a rate of approximately 1 minute per tree. Worker efficiency would approximately double with a stem density of 1,000/ac. In other trials, Bell et al. (1997) reported that workers cut 46 trees per hour when removing small (>0.3 in. and <15 ft tall) hardwoods during conifer release treatments, averaging 1.3 minutes per tree. At that rate, brush saw felling proved more cost-effective than aerial application of glyphosate or triclopyr in plots where stem density of small trees averaged <3,600 stems/ac (Bell et al. 1997).

Field trials have only begun to explore the best time of year for cutting (Mallett 2002), as well as the effects of tree size and vigor on subsequent sprouting (Babeux and Maufette 1993). Past research suggests that cutting during the active growing season will improve the effectiveness (Buell 1940, Wagner and Rogozynski 1994), limiting the numbers and the growth of first-year stump sprouts because of the lower level of reserve carbohydrates in the roots at that time of year. The shorter photoperiod and lower level of insolation late in the growing season also should limit growth of sprouts that emerge after late-season cutting (Wargo 1971, 1975).

Mallik et al. (1997) suggest that while cutting methods provide short-term control, they may actually promote a denser understory of beech. This corroborates an observation by McCormack (1981), that beech has shown resistance to some understory treatments by later producing large numbers of stump sprouts and root suckers. Yet other research also indicates that while cutting treatments applied during the dormant season promoted significant root suckering (Tew 1970), cutting in June and July resulted in fewer suckers (Converse and Eckardt 1987). Mallett (2002) also found that fewer stumps sprouted after cutting during July and August, compared to earlier or later treatment dates. Furthermore, 83% of sprouts originated around the rim of a stump, rather than off the side. Mallett suggested that these have low rates of survival.

Work by Mallett (2002) and Mallik et al. (1997) shows that landowners can use brush saws to efficiently remove understory beech from small acreages, but likely only in stands with a moderate density of small-diameter saplings (e.g., requiring approximately 1 minute per tree with stocking of approximately 500/ac; De Franceschi and Bell 1990). In addition, worker efficiency decreases with tree size, with a practical limit of approximately 4 to 5 in. at the stump. For large tracts, mechanized feller-bunchers may offer an alternative, particularly for removing small understory trees in conjunction with a harvesting operation. Operators can efficiently cover larger areas, mowing down the small understory trees as they move between the larger ones designated for cutting (Lanford and Siorois 1983). However, the work slows a harvesting operation, making the logging less efficient.

Management Implications

Most of the time, landowners want to regenerate trees of potential commercial value, or that serve some other specific management objective. Where the list of desirable species does not include beech, they should reject any cutting treatment that inadvertently fosters beech-dominated forests (Tierson 1967, Sage 1996). Actions that mistakenly promote the spread of striped maple and hobblebush may also have undesirable consequences. This includes high grading of desired species, partial cutting or complete overstory removal in stands with a dense understory of interfering plants, and almost any kind of overstory cutting in areas with high deer densities. All have resulted in regeneration failures, or left stands with high proportions of striped maple or poor quality beech (Jensen 1943, Curtis and Rushmore 1958, Barrett et al. 1962, Marquis 1965, Leak and Solomon 1975, Ostrofsky and McCormack 1986, Mielke et al. 1987, Hannah 1991, Nyland et al. 2004a).

To prevent these potential problems, landowners should remove beech and striped maple from the overstory and mid-story, favoring more desired species (Curtis and Rushmore 1958, Tierson 1967). In addition, they must control understory interference by these species and hobblebush, and also invest in deer density management where appropriate (Tierson 1967, Kelty and Nyland 1981, Marquis 1981, Horsley 1994). In fact, among areas with extensive browsing pressure, simply reducing understory interference is not enough (Bancroft 1990). Landowners must also control deer density by hunting of does or fencing to reduce the browsing pressure (Behrend et al. 1970, Richards and Farnsworth 1971, Marquis and Brenneman 1981). When linked to an appropriate reproduction method cutting, this combination of site preparation and deer density control has successfully regenerated new northern hardwood stands of high value (Richards and Farnsworth 1971, Kelty and Nyland 1981, Ray et al. 1999, Sage et al. 2003).

Mistblowing the understory with glyphosate or triclopyr has proven the most cost efficient and most effective way to treat a dense interfering understory across large areas (Table 1). Further, summer application (July to August) has given the best kill. Landowners should consult the *Herbicide Handbook* (Vencill 2002) and the Environmental Protection Agency website (www.epa.gov/oppfead1/international/piclist.htm), as well as state and federal registration requirements, for approved dosages and other conditions for use. Further, they should use well-trained workers to insure that the materials are applied safely and effectively.

In stands with fewer than approximately 500 understory trees to remove per acre, individual stem treatments will cost less than broadcast herbicide methods. Basal spraying with triclopyr will effectively kill small understory trees without injury to adjacent ones. Likewise, stem injection with glyphosate and triclopyr also gives a good kill. Glyphosate will move into the root system, also killing the trees in the process. Further, injecting even large beech with glyphosate will prevent later suckering, and should also kill existing suckers attached to their root system. Some other chemicals may flash back into untreated trees of a different species, requiring caution in their use. Table 1, Heiligmann (2004), the *Herbicide Handbook* (Vincill 2002), and the Environmental Protection Agency website, along with state and federal registration requirements, present information about chemicals approved for these single-stem treatments, how to use them, and what to expect as a result.

At least small understory stems may be killed by girdling or removed using brush saws before a harvesting operation, or even by feller-bunchers during the logging. Cutting or girdling the trees during the growing season (July to August) will minimize the number of stump sprouts that develop afterward. Further, most of the sprouts will emerge from callus that forms at the top of a stump, and most shoots of that origin do not persist and develop. Research has not clearly documented the effects of growing season cutting on root sucker development, but some evidence suggests that summer cutting will also minimize the numbers of new suckers that form around the cut beech trees. Although costly, cutting or girdling may prove more acceptable to some landowners, and may have a place in understory control programs on small woodlots or in sensitive areas.

Literature Cited

Abrahamson, L.P. 1983. Control of beech root and stump sprouts by herbicide injection of parent trees. For. Res. Notes RN-SOF-83-001. SUNY Coll. Environ. Sci. For., Sch. For. 4 p.

Babeux, P., and Y. Maufette. 1993. The effects of early and late spring cuts on the sprouting success of red maple (*Acer rubrum*) in northwestern Quebec. Can. J. For. Res. 24:785–791.

Bancroft, B. 1990. Response of aspen suckering to pre-harvest stem treatment. P. 55–56 *in* Vegetation management: An integrated approach. Proc. 4th Annu. Veg. Manage. Workshop, E. Hamilton (ed.). Can. For. Serv. FRDA Rep. 109. 127 p.

Barrett, J.W., E.C. Farnsworth, and W. Rutherford Jr. 1962. Influence of site disturbance and removal of shade on regeneration and certain aspects of microclimate in northern hardwoods. J. For. 60:630–638.

Bell, F.W., R.A. Lautenschlager, R.G. Wagner, D.G. Pitt, J.W. Hawkins, and K.R. Ride. 1997. Motor-manual, mechanical, and herbicide release affect early successional vegetation in northwestern Ontario. For. Chron. 73(1):61–68.

Behrend, D.F., G.F. Mattfeld, W.C. Tierson, and J.E. Wiley. 1970. Deer density control for comprehensive forest management. J. For. 68(11):695–700.

Bicknell, S.H. 1982. Development of canopy stratification during early succession in northern hardwoods. For. Ecol. Manage. 4:41–51.

Blum, B.M., and S.M. Filip. 1963. A demonstration of four intensities of management in northern hardwoods. USDA For. Serv. Res. Pap. NE-4. 16 p.

Bogenschutz, H. 1983. Management of beech stands infected by *Cryptococcus fagisuga* in West Germany. P. 115–119 *in* Proc., IUFRO Beech Bark Disease Working Party Conference, Sept. 26–Oct. 8, 1982. Hamden, Canada. USDA For. Serv. Gen. Tech. Rep. WO-37. 140 p.

Bohn, K.K. 2001. Methods for predicting American beech development in the understory of uneven-aged northern hardwood stands after cutting. MSc thesis. SUNY Coll. Environ. Sci. and For., Syracuse, NY. 143 p.

Bohn, K.K., and R.D. Nyland. 2003. Forecasting development of understory American beech after partial cutting in uneven-aged northern hardwood stands. For. Ecol. Manage. 180:453–461.

Bormann, F.H., and G.E. Likens. 1994. Pattern and process in a forested ecosystem. Springer-Verlag, New York, NY. 253 p.

Buell, J.H. 1940. Effect of season of cutting on sprouting of dogwood. J. For. 38:649–650.

Burns, B.S., and D.R. Houston. 1987. Managing beech bark disease: Evaluating defects and reducing losses. North. J. Appl. For. 4:28–33.

Carvell, K.L. 1956. The use of chemicals in controlling forest stand composition in the Duke Forest. J. For. 54:525–530.

Converse, C.K., and N. Eckardt. 1987. The Nature Conservancy element stewardship abstract for *Populus spp.* North American invasive poplars/aspens. The Nature Conservancy, Arlington, VA. 17 p.

Curry, J.R., and F.M. Rushmore. 1955. Experiments in killing northern hardwoods with sodium arsenite and ammonium sulfamate. J. For. 53:575–580.

Curtis, R.O., and F.M. Rushmore. 1958. Some effects of stand density and deer browsing on reproduction in an Adirondack hardwood stand. J. For. 56:116–121.

De Franceschi, J.P., and F.W. Bell. 1990 Labour productivity and costs of motor-manual release of spruce from hardwoods in Manitoba. For. Can., Northwest Reg., North. For. Cent., Edmonton, Alberta. Inf. Rep. NOR-X-312. 14 p.

Filip, S.M. 1978. Impact of beech bark disease on uneven-aged management of a northern hardwood forest (1952 to 1976). USDA For. Serv. Gen. Tech. Rep. NE-45. 7 p.

Fowells, H.A. 1965. Silvics of forest trees of the United States. USDA For. Serv. Agric. Handbk. 271. 762 p.

Hamilton, L.S. 1955. Silvicultural characteristics of American beech. USDA For. Serv., Northeast. For. Exp. Stn., Beech Util. Ser. No. 13. 39 p.

Hannah, P.R. 1987. Potential of beech and striped maple to dominate regeneration on eastern hardwood sites. P. 511–512, *in* Proc. of the 6th Central Hardwood Forest Conference, Feb. 24–26, 1987, Knoxville, TN. Hay, R.L., and K.W. Gottschalk (eds.). University of Tennessee, Knoxville, TN. 526 p.

Hannah, P.R. 1991. Regeneration of northern hardwoods in the northeast with the shelterwood method. North. J. Appl. For. 8(3):99–104.

Harvey, E.M., F.W. Bell, and J.O. Boateng. 1998. Manual, motor-manual and mechanical brushing tools for conifer release. Ont. Min. Nat. Resourc., Northwest Sci. and Technol. Note TN-42. 11 p.

Heiligmann, R.B. 2004. Controlling undesirable trees, shrubs, and vines in your woodland. Ohio State Univ. Extension. Sch. Nat. Resourc., Ohio State Univ. Available online at www.wildlifemanagement.info/publications/forestru_mgt_17.htm.

Heiligmann, R.B., and D. Krause. 2002. Relative effectiveness of herbicides commonly used to control woody vegetation in forest stands. Ohio State Univ., Sch. Nat. Resourc., Extension Fact Sheet F-51-02. 4 p.

Holt, H.A., and E.H. Reed. 1981. Controlling beech with injected herbicides. Proc. North Cent. Weed Control Conf. 36:80–91.

Horsley, S.B. 1990. Tank mixing Roundup with adjuvants and other herbicides for striped maple control. North. J. Appl. For. 7(1):19–22.

Horsley, S.B. 1991. Using Roundup and Oust to control interfering understories in Allegheny hardwood stands. P. 281–290. *in* Proc. of the 8th Central Hardwood Forest Conference, Mar. 4–6, 1991, University Park, PA. McCormick, L.H., and K.W. Gopttschalk (eds). USDA For. Serv. Gen. Tech. Rep. NE-GTR-148. 605 p.

Horsley, S.B. 1994. Regeneration success and plant species diversity of Allegheny hardwood stands after Roundup application and shelterwood cutting. North. J. Appl. For. 11(4):109–116.

Horsley, S.B., and John C. Bjorkbom. 1983. Herbicide treatment of striped maple and beech in Allegheny hardwood stands. For. Sci. 29(1):103–112.

Houston, D.R. 1983. American beech resistance to *Cryptococcus fagisuga.* P. 38–42 *in* Proc. of the IUFRO Beech Bark Disease Working Party Conference, Sept. 26-Oct. 8, 1982, Hamden, Canada. USDA For. Serv. Gen. Tech. Rep. WO-37. 140 p.

Houston, D.R. 1997. Exotic pests of eastern forests: Beech bark disease. P. 29–41 *in* Proc. of the Conference on exotic pests of eastern forests, Apr. 8–10, 1997, Nashville, TN. Britton, K.O. (ed.). USDA For. Serv. and Tenn. Exotic Plant Council. 198 p.

Houston, D.R. 2001. Effect of harvesting regime on beech root sprouts and seedlings in a north-central Maine forest long affected by beech bark disease. USDA For. Serv. Res. Pap. NE-717. 20 p.

Houston, D.R. 2003. New England Botanical Club—Minutes of the 992nd meeting, November 2003. Jennifer Forman, Recording Secretary. Available online at www.huh.harvard.edu/nebc/Meetsum.

Jarvis, J.M. 1957. The effectiveness of ammonium sulphamate for killing defective tolerant hardwoods. For. Chron. 33:51–53.

Jensen, V.S. 1943. Suggestions for the management of northern hardwood stands in the Northeast. J. For. 41:180–185.

JOHNSON, K.S. 2000. Composition of two oak-northern hardwood stands 18 years after springtime prescribed burning. MSc thesis. SUNY Coll. Environ. Sci. and For., Syracuse, NY. 176 p.

JONES, R.H., R.D. NYLAND, AND D.J. RAYNAL. 1989. Response of American beech regeneration to selection cutting of northern hardwoods in New York. North. J. Appl. For. 6:34–36.

KELTY, M.J., AND R.D. NYLAND. 1981. Regenerating Adirondack northern hardwoods by shelterwood cutting and control of deer density. J. For. 79:22–26.

KOCHENDERFER, J.D., S.M. ZEDAKER, J.E. JOHNSON, D.W. SMITH, AND G.W. MILLER. 2001. Herbicide hardwood crop tree release in central West Virginia. North. J. Appl. For. 18(2):46–54.

KOCHENDERFER, J.D., J.N. KOCHENDERFER, D.A. WARNER, AND G.W. MILLER. 2004. Preharvest manual herbicide treatments for controlling American beech in central West Virginia. North. J. Appl. For. 21(1):40–49.

LANFORD, B.L., AND D.L. SIOROIS.1983. Drive-to-tree rubber-tired feller buncher production studies. USDA For. Serv. Gen. Tech. Rep. SO-45. 14 p.

LEAK, W.B. 1980. Influence of habitat on silvicultural prescriptions in New England. J. For. 78:329–333.

LEAK, W.B. 1988. Effects of weed species on northern hardwood regeneration in New Hampshire. North. J. Appl. For. 5:235–237.

LEAK, W.B. 1999. Species composition and structure of a northern hardwood stand after 61 years of group/patch selection. North. J. Appl. For. 16(3):151–153.

LEAK, W.B. 2003. Regeneration of patch harvest in even-aged northern hardwoods in New England. North. J. Appl. For. 20(4):188–189.

LEAK, W.B., AND S.M. FILIP. 1977. Thirty-eight years of group selection in New England northern hardwoods. J. For. 75:641–643.

LEAK, W.B., AND M.L. SMITH. 1997. Long-term species and structural changes after cleaning young even aged northern hardwoods in New Hampshire, USA. For. Ecol. Manage. 95:11–20.

LEAK, W.B., AND D.S. SOLOMON. 1975. Influence of residual stand density on regeneration of northern hardwoods. USDA For. Serv. Res. Pap. NE-310. 7 p.

LEAK, W.B., AND R.W. WILSON JR. 1958. Regeneration after cutting of old-growth northern hardwoods in New Hampshire. USDA For. Serv., Northeast. For. Exp. Stn., Stn. Pap. 103. 6 p.

LIPTZIN, D., AND P.M. ASHTON. 1999. Early-successional dynamics of single-aged mixed hardwood stands in a southern New England forest, USA. For. Ecol. Manage. 116:141–150.

LOGAN, K.T. 1973. Growth of tree seedlings as affected by light intensity. V. White ash, beech, eastern hemlock, and general conclusions. Dept. Environ., Can. For. Serv. Pub. No. 1323. 11 p.

LONSDALE, D. 1983. Wood and bark anatomy of young beech in relation to *Cryptococcus* attack. P. 43–49 *in* Proc. of the IUFRO Beech Bark Disease Working Party Conference. USDA For. Serv. Gen. Tech. Rep. WO-37. 140 p.

LYMAN, G.T., A.E. GOVER, L.J. KUHNS, N.L. HARTWIG, AND T.L. WATSCHKE. 1990. Dormant stem brush control study. P. 6–16 *in* Roadside vegetation management research, fourth year report. Penn. State Univ. Rep. No. PA 90-4620 + 85-08. 71 p.

MAASS, D. 1983. Timing-species-herbicide interactions for tree injection treatments. Proc. Annu. Meet. Northeast. Weed Sci. Soc. 37:268–272.

MADER, S.F., AND R.D. NYLAND. 1984. Six-year response of northern hardwoods to the selection system. North. J. Appl. For. 1:87–91.

MALLETT, A.L. 2002. Management of understory American beech by manual and chemical control methods. MSc thesis. SUNY Coll. Environ. Sci. and For., Syracuse, NY. 152 p.

MALLIK, A.U., K. WOOD, C. HOLLSTEDT, M.S. MCLAUGHLAN. 1997. Cut stump herbicide treatments to reduce sprouting and root suckering. Ont. Min. Natur. Resourc., Northwest Sci. and Technol. Note TN-39. 12 p.

MARQUIS, D.A. 1965. Regeneration of birch and associated hardwoods after patch cutting. USDA For. Serv. Res. Pap. NE-32. 12 p.

MARQUIS, D.A. 1967. Clearcutting in northern hardwoods: Results after 30 years. USDA For. Serv. Res. Pap. NE-85. 13 p.

MARQUIS, D.A. 1981. Removal or retention of unmerchantable saplings in Allegheny hardwoods: Effect on regeneration after clearcutting. J. For. 79:280–283.

MARQUIS, D.A. 1987. Assessing the adequacy of regeneration and understanding early development patterns. P. 143–144 *in* Managing northern hardwoods, Nyland, R.D. (ed.). SUNY Coll. Env. Sci. For., Fac. For. Misc. Publ. 13 (ESF 87-0002). Soc. Am. For. Publ. 87-03. 430 p.

MARQUIS, D.A., AND R. BRENNEMAN. 1981. The impact of deer on forest vegetation in Pennsylvania. USDA For. Serv. Gen. Tech. Rep. NE-GTR-65. 7 p.

MARQUIS, D.A., T.J. GRISEZ, J.C. BJORKBOM, AND B. ROACH. 1975. Interim guides to the regeneration of Allegheny hardwoods. USDA For. Serv. Gen. Tech. Rep. NE-GTR-19. 14 p.

MARQUIS, D.A., R.L. ERNST, AND S.L. STOUT. 1992. Prescribing silvicultural treatments in hardwood stands of the Alleghenies (revised). USDA For. Serv. Gen. Tech. Rep. NE-96. 101 p.

MCCLURE, J.W., AND T.D. LEE. 1993. Small-scale disturbance in a northern hardwoods forest: Effects on tree species abundance and distribution. Can. J. For. Res. 23:1347–1360.

MCCORMACK, M.L. JR. 1981. Chemical weed control in northeastern forests. Weed control in forest management. P. 108–115 *in* Proc of the 1981 John S. Wright forestry conference, Feb. 3–5, 1981. Holt, H.A., and B.C. Fischer (eds.). Dept. For. Nat. Resourc., Purdue University, W. Lafayette, IN. 305 p.

MCCORMACK, M.L. JR., AND M. NEWTON. 1980. Aerial application of triclopyr, phenoxies, picloram and glyphosate for conifer release in spruce-fir forests of Maine. Proc. Weed Sci. Soc. Am. 47–48. 128 p.

MCCORMACK, M.L. JR., L.B. LYNN, AND E.B. SPRAGUE. 1980. Results with glyphosate for forestry in Maine. Proc. Annu. Meet. Northeast. Weed Sci. Soc. 304. 434 p.

MCCULLOUGH, D., B. HEYD, AND J.G. O'BRIEN. 2000. Biology and management of beech bark disease: Michigan's newest exotic forest pest. Available online at www.forestry.msu.edu/msaf/ForestInfo/Health/BBdisease.htm.

MCKINNEY, A.L., AND C.F. KORSTIAN. 1932. Felling, girdling, and poisoning undesirable trees in forest stands. J. For. 30:169–177.

MIELKE, M.E., D.R. HOUSTON, AND A.T. BULLARD. 1987. Beech bark disease management alternatives. P. 272–280 *in* Proc. Integrated pest management symposium for northern forests, Mar. 24–27, 1986. Coop. Ext. Ser., Univ Wisc.-Ext. Madison, WI. 333 p.

NYLAND, R.D. 2004. Simple girdle kills small American beech (*Fagus grandifolia* Ehrh.). North. J. Appl. For. 21(4):220–221.

NYLAND, R.D., A.L. BASHANT, K.K. BOHN, AND J.M. VEROSTEK. 2004a. Interference to hardwood regeneration in northeastern North America: Ecologic characteristics of American beech, striped maple, and hobblebush. North. J. Appl. For., 23(1):53–61.

NYLAND, R.D., D.G RAY, AND R.D. YANAI. 2004b. Height development of upper-canopy trees within even-aged Adirondack northern hardwood stands. North. J. Appl. For. 21(3):117–122.

OBERMYER, E.L. 1992. Manual cutting of competing vegetation in conifer plantation of the Siuslaw National Forest. P. 123–127 *in* Proc. from a Workshop on forest vegetation management without herbicides. Oregon State University, Corvallis, OR. 129 p.

OSTROFSKY, W.D., AND D.R. HOUSTON. 1988. Harvesting alternatives for stands damaged by the beech bark disease. P. 173–177 *in* Healthy forests, healthy world. Proc. Soc. Am. For. Natl. Conv. Rochester, NY. Soc. Am. For., Bethesda, MD. 424 p.

OSTROFSKY, W.D., AND M.L. MCCORMACK JR. 1986. Silvicultural management of beech and the beech bark disease. North. J. Appl. For. 3:89–91.

PITT, D.G., D.G. THOMPSON, AND N.J. PAYNE. 1993. Response of woody eastern Canadian forest weeds to fall foliar treatments of glyphosate and triclopyr herbicides. Can. J. For. Res. 239(12):2490–2498.

PIUSSI, P. 1966. Some characteristics of a second-growth northern hardwood stand. Ecology 47(5):860–864.

QUINLAN, P.M. 1996. An assessment of wildlife habitat characteristics in Adirondack selection system stands. MSc thesis. SUNY Coll. Environ. Sci. and For. Syracuse, NY. 110 p.

RAY, D.G., R.D. NYLAND, AND R.D. YANAI. 1999. Patterns of early cohort development following shelterwood cutting in three Adirondack northern hardwood stands. For. Ecol. Manage. 119:1–11.

RICHARDS, N.A., AND C.E. FARNSWORTH. 1971. Effects of cutting level on regeneration of northern hardwoods protected from deer. J. For. 69:230–233.

RUSHMORE, F.M. 1961. Silvical characteristics of beech. US For. Serv., NE Forest Exp. Sta., Sta. Pap. 161. 26 p.

SAGE, R.W. JR. 1983. An evaluation of several herbicide applications used for site preparation in northern hardwood stands. MSc thesis. SUNY Coll. Environ. Sci. and For. 160 p.

SAGE, R.W. JR. 1987. Unwanted vegetation and its effects on regeneration success. P. 298–316 *in* Managing northern hardwoods. Nyland, R.D. (ed.). SUNY Coll. Environ. Sci. and For., Fac. For. Misc. Publ. 13, ESF 87-0002, Soc. Am. For. Publ. 87-03. 430 p.

Sage, R.W. Jr. 1996. The impact of beech bark disease on the northern hardwood forests of the Adirondacks. Adk. J. Env. Studies. 3(1):6–8.

Sage, R.W. Jr., W.F. Porter, and H.B. Underwood. 2003. Windows of opportunity: White-tailed deer and the dynamics of northern hardwood forests in the northeastern US. J. Nat. Conserv. 10:213–220.

Shipman, R.D. 1982. Selective herbicide treatment of striped maple. Proc. Annu. Meet. Northeast. Weed Sci. Soc. 36:215–220.

Swan, F.R. Jr. 1970. Post-fire response of four plant communities in south-central New York State. Ecology 51(6):1074–1082.

Tew, R.K. 1970. Root carbohydrate reserves in vegetative reproduction of aspen. For. Sci. 16(3):318–320.

Thompson, D.G., D.G. Pitt, T.M. Buscarini, B. Staznik, and D.R. Thomas. 2000. Comparative fate of glyphosate and triclopyr herbicides in the forest floor and mineral soil of an Acadian forest regeneration site. Can. J. For. Res. 30:1808–1816.

Tierson, W.C. 1967. Influence of logging, beech control, and partial deer control on northern hardwood reproduction. MSc thesis. SUNY Coll. Environ. Sci. For., Syracuse, NY. 96 p.

Tierson, W.C. 1969. Controlling understory beech by use of mistblowers. N. Logger Timber Processor 17(12):40–41.

Vencill, W.K. (ed). 2002. Herbicide handbook, 8th Ed. Weed Sci. Soc. Am., Lawrence, KN. 493 p.

Wagner, R.G., and M.W. Rogozynski. 1994. Controlling sprout clumps of bigleaf maple with herbicides and manual cutting. West. J. Appl. For. 9(4):118–124.

Walters, R.S., and R.D. Nyland. 1989. Clearcutting in central New York northern hardwood stands. North. J. Appl. For. 6:75–78.

Wang, Z., and R.D. Nyland. 1993. Tree species richness increased by clearcutting of northern hardwoods in central New York. For. Ecol. Manage. 57:71–84.

Wargo, P.M. 1971. Seasonal changes in carbohydrate levels in root of sugar maple. USDA For. Serv. Res. Pap. NE-213. 8 p.

Wargo, P.M. 1975. Estimating starch content in roots of deciduous trees. USDA For. Serv. Res. Pap. NE-313. 9 p.

Wargo, P.B. 1988. Amino nitrogen and phenolic constituents of bark of American beech, *Fagus grandifolia*, and infestation by beech scale. Eur. J. For. Pathol. 18:279–290.

Wendel, G.W., and J.N. Kochenderfer. 1982. Glyphosate controls hardwoods in West Virginia. USDA For. Serv. Res. Pap. NE-497. 6 p.

Whitford, P.B. 1949. Distribution of woodland plants in relation to succession and clonal growth. Ecology 30:199–208.