Using Silviculture to Improve Health in Northeastern Conifer and Eastern Hardwood Forests

Kurt W. Gottschalk[1]

Abstract.—The traditional role of silviculture was to manipulate forest vegetation to provide wood and related forest products for humanity's benefit over a long period. Silviculturists soon noticed that such manipulation influenced other components of the ecosystem. In particular, insects and diseases responded dramatically to silvicultural practices—both positively and negatively. The use of silviculture to improve the health of northeastern conifers is most used in spruce-fir forests for spruce budworm, white pine and mixed white pine-oak forests for white pine blister rust and white pine weevil, and jack pine forests for jack pine budworm. Major pests that can be treated silviculturally in eastern hardwood forest types include beech bark disease in northern hardwoods, gypsy moth and oak decline in oak-hickory types, and defoliators in several types. The long-term role of silvicultural treatments in maximizing forest health needs to be evaluated for its influence on other ecosystem components.

INTRODUCTION

Forests are dynamic and ever changing biological systems. For thousands of years they have been growing, developing, maturing, dying, and being replenished to start the process anew. Natural catastrophic events, fires, insects, and diseases eliminate and recycle the old, and prepare the way for the new. The traditional role of silviculture was to protect forests from these natural events and manipulate forest vegetation to provide wood and related forest products for humanity's benefit over a long period. Silviculturists soon noticed that these changes in vegetation had influenced other components of the ecosystem. Sometimes these influences produced desirable effects, so silvicultural practices for forest values other than wood were developed. But some influences produced less desirable effects, resulting in problems associated with other biotic and abiotic factors. In particular, insects and diseases responded both positively and negatively to silvicultural practices.

[1]*Project Leader, USDA Forest Service, Northeastern Forest Experiment Station, Morgantown, WV.*

There are many definitions of forest health currently being debated. At this point in the program, the last thing you want to hear is another definition. All of them are similar with respect to the maintenance and integrity of the forest ecosystem. While forest health is a broad area that encompasses many ecosystem components, I will focus only on the insect and disease-related components of northeastern conifer and eastern hardwood forests, and the use of silvicultural treatments to improve forest health. Properly timed stand treatments provide a balance by slowing or accelerating the pace of natural succession and by reducing susceptibility, vulnerability, hazard, and risk from insects and diseases.

Definitions

Susceptibility

Susceptibility is defined as tree or stand biological/ecological conditions that result in some probability of insect attack, disease infection, or a buildup of fire fuel loads. Susceptibility can reflect conditions such as composition, stand structure, developmental stage, site factors like soil type, soil depth, aspect, and climatic factors such as rainfall/drought stress, and frosts. Susceptibility is a continuum, it ranges from susceptible to resistant to immune (high, moderate, and low probability).

Vulnerability

Vulnerability is defined as tree or stand damage resulting from successful attack, infection, or hot fire. By this definition, damage equals mortality, species, nutrient, and habitat loss, reduced aesthetics, compositional change, structural change, and many other indicators of forest health or decline.

Hazard

Hazard is defined as the probability that susceptibility or vulnerability will affect management objectives for the affected area. It is easy to identify situations in which both susceptibility and vulnerability are high but hazard is low. As a result, change due to the disturbance is acceptable and perhaps even desirable.

Risk

Risk is defined as the imminence or probability of arrival, outbreak phase of population cycle, infection phase of population cycle, or climatic conditions conducive to successful attack, infection, or hot fire. For example, an area might be highly susceptible/vulnerable and have high hazard from gypsy moth defoliation, but have low risk because gypsy moth has not yet invaded the area.

Role of Silviculture in Forest Health

As mentioned earlier, using silviculture to manage vegetation to influence other components of ecosystems in addition to producing commercial timber products is an integral part of influencing forest health. The subset of components related to insects and diseases is addressed here. Most of our experience in this area is in managing insects and diseases as pests. Although many insects and diseases perform valuable ecosystem processes, we know little about how to influence these situations to increase ecosystem benefits (Muzika and Gottschalk 1995). Silviculture can alter both susceptibility and vulnerability as these are biological/ecological features. Hazard is a management-related component, so it can be affected only by changing management objectives or changing susceptibility/vulnerability. Risk, a temporal feature, also is less likely to be influenced by silviculture, though it is possible to influence some risk factors (e.g. length of population phase) by changing susceptibility and vulnerability.

Altering Susceptibility to Insects and Diseases

There are three basic philosophies for altering susceptibility: 1) maximizing stand growth and vigor, 2) manipulating insect/disease habitat, or 3) increasing forest diversity. Many insects and diseases have evolved in a role of killing weakened trees and removing them from the system. When conditions are such that many weakened, low-vigor, slow growing trees are present, stands can be made healthier by treatments that increase the vigor and growth of trees and stands, making them more resistant and less vulnerable. Manipulation of insect/disease habitat includes treatments like changing the composition, structure, or age class of the stand to make it less susceptible by reducing the size of contiguous areas to limit outbreaks.

Altering Vulnerability to Insects and Diseases

Similarly, there are three philosophies for altering vulnerability: 1) maximizing tree growth and vigor, 2) removing high-risk trees and stands, or 3)manipulating the habitat of secondary organisms. Vigorous, fast-growing trees usually are better able to survive attack or infection or successfully resist it, so treatments that increase growth and vigor usually will reduce vulnerability. Where high-risk, vulnerable trees and stands are present, the best treatment is to remove those stand conditions through regeneration or other silvicultural treatments. Many insects and diseases act as secondary mortality agents attacking trees weakened by other insects, diseases, or other stressors.

When conditions favoring the habitat of secondary organisms are reduced, vulnerability also is reduced.

NORTHEASTERN CONIFERS

Northeastern conifers are not a specific entity but a wide-ranging mixture of forest types ranging from the extensive spruce-fir forests of northern New England and the Lake States to scattered pine stands interspersed with hardwood stands, to mixed conifer-hardwood stands that include the following types and species: red pine (*Pinus resinosa*), jack pine (*P. banksiana*), black spruce (*Picea mariana*), tamarack (*Larix laricina*), northern white-cedar (*Thuja occidentalis*), spruce-fir (balsam fir (*Abies balsamea*), red spruce (*P. rubens*), white spruce (*P. glauca*)), eastern white pine (*Pinus strobus*), hemlock (*Tsuga canadensis*), and pitch pine (*P. rigida*). Various insect and disease organisms infest these stands, but most of them have relatively minor local impacts and are host-specific as to the species they attack. The use of silviculture to improve forest health is most used in spruce-fir forests for eastern spruce budworm (*Choristoneura fumiferana*), white pine and mixed white pine-oak forests for white pine blister rust (*Cronartium ribicola*) and white pine weevil (*Pissodes strobi*), and jack pine forests for jack pine budworm (*Choristoneura pinus pinus*). Dwarf mistletoe (*Arceuthobium pusillum*), while not usually serious or widespread, also can be treated effectively by silviculture (Ostry and Nichols 1979).

Eastern Spruce Budworm

The spruce budworm prefers to feed on balsam fir, but white, red, and black spruce are suitable hosts. Heavy feeding sometimes occurs on hemlock, with lesser feeding on pines and larches. Defoliation of needles and mining of buds by the budworm on millions of acres of spruce-fir forest in the Northeast has resulted in heavy mortality and growth loss. Natural outbreaks occur in mature and over mature stands, especially those containing large numbers of balsam fir. Shelterwood cuts are highly effective in reducing budworm impacts. Such cuts will increase the amount of spruce and reduce the amount of balsam fir in the regenerated stand, reducing susceptibility (Blum and MacLean 1985, Frank 1986). Shelterwoods also favor birds that prey on spruce budworms. Shortening rotations (45 to 70 years for spruce-fir) by clearcutting both mature and overmature stands also will reduce susceptibility (Blum and MacLean 1984). The silvicultural management of spruce budworm has even been the subject of a philosophical/psychological study (Miller and Rusnock 1993).

White Pine Weevil

The white pine weevil prefers eastern white pine and jack pine but also attacks Norway spruce, and Scots, pitch, and red pine. Adults and larvae feed on the previous-year's leader and kill all of the branches above the feeding site. One or more lateral shoots may replace the leader, resulting in a crooked or forked stem and small, bushy trees. Open-grown plantations of white and jack pine are highly susceptible, especially in the northeastern and central portions of white pine's range. Silvicultural treatments for reducing damage by white pine weevil are some of the best ways to improve forest health. Regenerating white pine under 30- to 50-percent shade (or tree cover) by shelterwood cutting will reduce weevil attacks on the leaders and branches of these trees (Lancaster 1984, Stiell and Berry 1985). Once the white pines are 12 to 25 feet tall, the shelterwood can be removed. The weevil will then attack the trees, but the damage will be above the first log of the tree, greatly reducing the economic impact of the weevil. However, shelterwoods will not reduce damage by white pine weevil in jack pine because that specie does not regenerate under a shelterwood canopy.

White Pine Blister Rust

White pine blister rust is a disease that begins in needles, spreads to the branches and stems, and eventually kills the tree via trunk infections. The disease has eliminated white pine from some portions of its range and restricts planting on certain sites within that range. Practices to reduce white pine blister rust include not planting white pine on high-hazard sites (off site), planting resistant seedlings, and pruning infected branches to prevent the tree from being killed and the disease from spreading to other trees (Lancaster 1984, Robbins 1984).

Jack Pine Budworm

The jack pine budworm, closely related to the spruce budworm, prefers to feed on jack pine but also feeds on small red, Scots, and white pine trees in the understory. Defoliation of needles and mining of buds by this budworm results in top-killed and stagheaded jack pine trees, though mortality is rare in larger trees. Mortality can be heavy in younger understory pine trees (poles, saplings, and seedlings) that are defoliated beneath a jack pine overstory. The jack pine budworm currently is the most serious conifer insect pest in the Lake States. Heavily infested areas of jack pine budworm should be regenerated to salvage losses and prevent infection of the new stand. Prescribed burning of regeneration areas also will reduce infection of new stands and encourage dense regeneration to minimize tree loss (McCullough and Kulman 1991a). Removing top-killed and stagheaded trees by thinning can reduce the economic impact of jack pine budworm (McCullough and Kulman 1991b).

EASTERN HARDWOODS

The eastern hardwood forest is a mixture of many species and forest types, including oak-hickory (numerous oaks (*Quercus* sp.), hickories (*Carya* sp.), other hardwoods, some conifers), bottomland hardwoods (cottonwood (*Populus deltoides*), willows (*Salix* sp.), sycamore (*Platanus occidentalis*), gums (*Nyssa* sp.), silver maple (*Acer saccharinum*), several oaks), oak-pine (many species from oak-hickory, various pines), northern hardwoods (sugar maple (*Acer saccharum*), American beech (*Fagus grandifolia*), yellow birch (*Betula alleghaniensis*), black cherry (*Prunus serotina*), red maple (*Acer rubrum*)), and aspen-birch (bigtooth (*Populus grandidentata*) and quaking aspens (*P. tremuloides*), paper (*Betula papyrifera*) and gray (*B. populifolia*) birches). Many insects and diseases attack the more than 200 species in the eastern hardwood forest, though most of these pests cause minor, local impacts. The major pests that can be treated silviculturally include the beech bark disease complex in northern hardwoods, gypsy moth (*Lymantria dispar*) and oak decline in oak-hickory types, and other defoliators in several types.

Beech Bark Disease Complex

Beech bark disease is an introduced insect-fungus complex that kills or injures American beech. Two scale insects (*Cryptococcus fagisuga* and *Xylococculus betulae*) pierce the bark of beech and then feed. The fungi (*Nectria coccinea* var. *faginata*) then infects the bark through feeding wounds. The tree walls off the damaged area, creating defects and slow growth. Many trees are killed as the bark becomes girdled. In 1987, beech bark disease was the second most important disease in New York in terms of volume loss. Some individual beech trees show genetic resistance to scale infestation. This resistance can be utilized in silvicultural treatments by favoring resistant trees and clones and those with smooth bark. Infected, large, overmature, and rough-barked trees can be removed by thinning, and single-tree and group-selection cutting (Burns and Houston 1987). Diseased trees and sprouts should be herbicided during regeneration cuts (Ostrofsky and McCormack 1986). Increased species diversity can reduce the effects of beech bark disease in pure stands.

Oak Decline

Dieback and decline are complex diseases triggered by biotic or abiotic stress factors, e.g., drought and defoliation (Houston 1981, 1987). One of the most significant is oak decline across the southern and central United States (Oak and others 1991, Starkey and others 1989). Terminal branches of trees dieback and trees often became stagheaded. Affected tree mortality usually is the result of stressed trees being attacked by secondary organisms (Wargo and Shaw 1985). Since oak decline is related to increased physiological maturity, stands should be regenerated when the site index/age ratio is less than 1.0 to maintain vigorous trees (Oak and others 1991). It is advisable to remove declining trees by thinning and group-selection cuts. Maintaining tree growth and vigor through periodic thinning may be important as many susceptible trees showed growth reductions 30 to 40 years before oak decline symptoms (Tainter and others 1990).

Gypsy Moth

An introduced pest, the gypsy moth is a defoliator of leaves of more than 500 species, but it especially favors oaks. When half-grown, larvae eat many hardwoods and conifers except for the ashes, yellow-poplar, black walnut, and some other species. Defoliation occurs in May and June and usually is followed by a new growth of leaves in July. This refoliation process weakens the tree considerably, allowing other insects and disease agents to attack and kill it. Mortality ranges from very light to complete and is increased by drought stress. The nuisance of gypsy moth larvae also poses problems in recreation areas, rural housing areas, and small cities and towns. The gypsy moth continues to expand its range in the United States and eventually will be present over much of the eastern hardwood area. Only several of the silvicultural treatments designed to minimize gypsy moth effects are discussed here (Gottschalk 1987, 1993).

Presalvage thinning

Presalvage thinning is designed to reduce damage by removing highly vulnerable (high hazard) trees before they are defoliated and die; its primary objective is to reduce stand vulnerability. Secondary objectives are to increase stand and tree vigor (and crown condition), remove structural features or refuges for gypsy moth larvae and pupae, and promote habitat for predators and parasites. In stands with more than 50 percent of the basal area in gypsy moth-preferred species, normal thinning prescriptions will not reduce the preferred species sufficiently to significantly alter stand susceptibility. Instead, presalvage thinning emphasizes reducing vulnerability. Presalvage thinning must be implemented 1 to 3 years before defoliation because the stand needs time to recover from the stress and disturbance caused by this treatment. Priorities for marking trees to be removed are (highest to lowest): 1) oaks with poor crowns, 2) non-oak species with poor crowns, 3) oaks with fair crowns, and 4) non-oak species with fair crowns. These priorities are integrated with the normal marking priorities of maintaining the desired residual stand density, removing unacceptable growing-stock trees before better quality trees (also could include species priorities), and achieving the desired stand structure. Additional measures can be taken to enhance predator and parasite habitat, for example, removing trees with abundant structural features or refuges for larvae, leaving snags, leaving cavity or den trees, and creating brush piles. In heavily overstocked stands with few good crowns, light thinnings to develop and build crowns are favored over a heavy thinning.

A recent demonstration stand in West Virginia received a presalvage thinning. Estimated stand susceptibility and vulnerability before and after treatment were:

	Before treatment	*After treatment*
Susceptibility	High	High
Vulnerability	Moderate	Low

This treatment accomplished the objective of reducing vulnerability of the stand, but did not change its susceptibility (Atkins 1989).

Sanitation thinning

Sanitation thinning is designed to prevent the spread and establishment of damaging organisms. Its primary objective is to reduce stand susceptibility. Sanitation thinning eliminates trees that are current or prospective sources of infestation. With gypsy moth, this process entails removing preferred food species, as well as structural features or refuges, and promoting habitat for predators and parasites. Secondary objectives are to increase stand and tree vigor and remove high-hazard trees. These treatments also need to be done 1 to 3 years before defoliation. Stands that can be considered for sanitation thinning are similar to those for presalvage thinning. The major difference is that these stands have less than 50 percent of the basal area in preferred species. As a result, it is possible to reduce this percentage sufficiently to alter stand susceptibility. There is some evidence that a minimum of 15 to 20 percent basal area of preferred food species is required for a sufficiently large gypsy moth population to develop to the stage where it can survive on nonpreferred hosts. Reducing the percentage of preferred food species to 15 to 20 percent or less should make the stand less susceptible to defoliation. Priorities for marking trees to be removed are (highest to lowest): 1) preferred food species, 2) trees with abundant structural features or refuges for larvae, 3) trees with poor crowns, and 4) trees with fair crowns.

Recently, a second demonstration stand received a sanitation thinning treatment (Atkins 1989). Estimated stand susceptibility and vulnerability before and after treatment were:

	Before treatment	*After treatment*
Susceptibility	Moderate	Low
Vulnerability	High	High

This treatment reduced the susceptibility of the stand, but not its vulnerability.

Salvage thinning

With salvage thinning, the economic value from the dead trees is salvaged and the remaining live trees are thinned to reduce susceptibility and vulnerability. Stands that qualify for salvage thinning have greater than C-level density of acceptable growing stock, are more than 10 years from maturity, and have more than 60 percent stand density in live trees. They are sufficiently well stocked to be managed to maturity. These thinnings will improve stand vigor, growth, and quality, and could make the salvage cut economically feasible by supplementing the volume of dead trees with green trees. Priorities for marking trees to be removed are (highest to lowest): 1) dead trees, 2) oaks with poor crowns that are likely to die, 3) other species with poor crowns that are likely to die, and 4) trees with fair crowns. These priorities are integrated with the normal ones of maintaining the desired residual stand density, removing unacceptable growing stock trees before better quality trees, and achieving the desired stand structure. It may be desirable to leave several dead trees per acre as snags, cavity, or den trees, and to remove trees with structural features or refuges for larvae.

In recent demonstration salvage thinning in West Virginia, estimated stand susceptibility and vulnerability before and after treatment were:

	Before treatment	*After treatment*
Susceptibility	Moderate	Moderate
Vulnerability	Moderate	Low

In addition to reducing the future estimated vulnerability of this stand, dead trees (7 percent of the stand) were economically salvaged, mature trees were thinned, poor-crowned trees as a result of the defoliation were thinned, and the landowner received more income for this treatment than a local logger had offered to liquidate the entire stand (Atkins 1989).

Salvage cutting

The objective in stands that qualify for salvage cutting is to economically salvage dead and dying trees. These stands are similar in acceptable growing-stock density and stand maturity to those in the preceding prescription, but have less than 60-percent density in live trees. In this situation, no thinning of live trees is necessary since these stands already are below the optimum residual density. They also have more than 30-percent mortality, which means there is sufficient volume and value of dead trees for a salvage cut (depending on local market conditions). Marking priorities are simple—only dead and dying trees should be cut and removed because all of the live trees are needed to carry the stand to maturity (or to the next thinning). Trees with poor crowns that will not recover are considered the same as dead trees. These dying trees are removed and not counted toward the acceptable growing-stock density. If desired, several dead trees per acre can be left as snags.

Salvage shelterwood

The primary objectives of salvage shelterwood are to salvage economic value from dead trees and develop adequate advanced regeneration by shelterwood cutting. It may be necessary to cut some live trees for the shelterwood in addition to salvaging dead trees. These stands do not have sufficient live trees (less than C-level stocking) to manage them further and they should be regenerated. The lack of adequate advanced regeneration requires the shelterwood treatment to develop it. This is the most common treatment in many areas following initial gypsy moth infestation.

ADVANTAGES OF SILVICULTURAL TREATMENTS

The use of silvicultural treatments to increase forest health has a number of advantages. The treatments usually are inexpensive as they can be done at no net cost or net income. They treat the cause of the problem (unhealthy stands) instead of the symptom (insect and disease outbreaks). They create healthy, mixed forests which usually can withstand problems associated with insects and diseases. The manager can treat highest priority areas first, i.e., high-hazard stands that will provide the greatest return on investment. And the treatments are ecologically preferable to chemical controls for most insects and diseases.

DISADVANTAGES OF SILVICULTURAL TREATMENTS

Of course, silvicultural treatments are not without disadvantages. Only a limited area can be treated each year due to the time and labor required to set up and treat an area. As a result, a long period (minimum of one rotation length) is needed for maximum effect in treating insect and disease habitat. Few, if any, of these treatments will prevent outbreaks of many insects and diseases; they will only reduce their effects when outbreaks occur, or increase the time between outbreaks. Despite our inability to accurately predict insect and disease problems, silvicultural treatments are most effective when installed several years before forest health problems develop. Finally, silvicultural treatments cannot be used in certain areas where cutting is not allowed, for example, wilderness areas.

SUMMARY

The most effective approach for reducing insect and disease-caused damage to forest ecosystems is to apply treatments that will reduce the frequency of outbreak occurrence and minimize the severity of outbreaks. Preventive silvicultural treatments are a practical and long-lasting means for achieving this goal (Gottschalk 1987). High-hazard stands can be manipulated to reduce susceptibility and vulnerability, vulnerable individual trees can be removed, and low-risk stands can be tended to maintain vigor and rapid growth. Managers who want to improve or maintain forest health are encouraged to consider of the positive and negative effects (Muzika and Gottschalk 1995) of insects and diseases on forest ecosystems, and to apply silvicultural treatments when such strategies are compatible with other management goals.

LITERATURE CITED

Atkins, Jerry M. 1989. Applying silviculture guidelines in West Virginia—an update. In: Proceedings of the 1989 national gypsy moth review; 1989 November 6–9; Annapolis, MD: Maryland Department of Agriculture: 115–122.

Blum, Barton M.; MacLean, David A. 1984. Silviculture, forest management, and the spruce budworm. *In:* Schmitt, Daniel M.; Grimble, David G.; Searcy, Janet L., tech. coord. Spruce budworms handbook, managing the spruce budworm in eastern North America. Agric. Handb. 620. Washington, DC: U.S. Department of Agriculture: 83–102.

Blum, B.M.; MacLean, D.A. 1985. Potential silviculture, harvesting, and salvage practices in eastern North America. *In:* Recent advances in spruce budworms research, Proceedings, CANUSA spruce budworms research symposium; 1984 September 16–20; Bangor ME. Ottawa, ON: Canadian Forestry Service: 264–280.

Burns, Barbara S.; Houston, David R. 1987. Managing beech bark disease: evaluating defects and reducing losses. Northern Journal of Applied Forestry. 4: 28–33.

Frank, Robert M. 1986. Shelterwood—An ideal silvicultural strategy for regenerating spruce-fir stands. *In:* Proceedings, integrated pest management symposium for northern forests; 1986 March 24–27; Madison, WI. Madison WI: University of Wisconsin: 139–150.

Gottschalk, Kurt W. 1987. Prevention: The silvicultural alternative. In: Fosbroke, Sandra; Hicks, Ray R., Jr., eds. Proceedings, coping with the gypsy moth in the new frontier; 1987 August 4–6; Morgantown, WV. Morgantown, WV: West Virginia University Books: 92–104.

Gottschalk, Kurt W. 1993. Silvicultural guidelines for forest stands threatened by the gypsy moth. Gen. Tech. Rep. NE-

171. Radnor, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station. 49 p.

Houston, David R. 1981. Some dieback and decline diseases of northeastern forest trees: forest management considerations. In: Proceedings, national silvicultural workshop hardwood management; 1981 June 1–5; Roanoke, VA. Washington, DC: U.S. Department of Agriculture, Forest Service: 248–265.

Houston, David R. 1987. Forest tree declines of past and present: current understanding. Canadian Journal of Plant Pathology. 9: 349–360.

Lancaster, Kenneth F. 1984. White pine management: a quick review. NA-FR-27. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area, State and Private Forestry. 4 p.

McCullough, Deborah G.; Kulman, Herbert M. 1991a. Differences in foliage quality of young jack pine (*Pinus banksiana* Lamb.) on burned and clearcut sites: effects on jack pine budworm (*Choristoneura pinus pinus* Freeman). Oecologia. 87: 135–145.

McCullough, Deborah G.; Kulman, Herbert M. 1991b. Effects of nitrogen fertilization on young jack pine (*Pinus banksiana*) and on its suitability as a host for jack pine budworm (*Choristoneura pinus pinus*) (Lepidoptera:Tortricideae). Canadian Journal Forestry Research. 21: 1447–1458.

Miller, Alan; Rusnock, Paul. 1993. The rise and fall of the silvicultural hypothesis in spruce budworm (*Choristoneura fumiferana*) management in eastern Canada. Forest Ecology and Management. 61: 171–189.

Muzika, Rose-Marie; Gottschalk, Kurt W. 1995. Gypsy moth role in forest ecosystems: the good, the bad, and the indifferent. In: Eskew, Lane, comp. Proceedings, 1995 national silviculture workshop, forest health through silviculture; 1995 May 8–11; Mescalero, NM. Gen. Tech. Rep. Ft. Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Forest Experiment Station. This issue.

Oak, Steven W.; Huber, Cindy M.; Sheffield, Raymond M. 1991. Incidence and impact of oak decline in western Virginia, 1986. Resour. Bull. SE-123. Asheville, NC: U.S. Department of Agriculture, Forest Service, Southeastern Forest Experiment Station. 16 p.

Ostrofsky, William D.; McCormack, Maxwell L., Jr. 1986. Silvicultural management of beech and beech bark disease. Northern Journal of Applied Forestry 3: 89–91.

Ostry, Michael E.; Nichols, Thomas H. 1979. Eastern dwarf mistletoe on black spruce. For. Ins. Dis. Leafl. 158. Washington, DC: U.S. Department of Agriculture, Forest Service. 7 p.

Robbins, Kathryn. 1984. How to select planting sites for eastern white pine in the Lake States. NA-FB/M-8. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area, State and Private Forestry.

Starkey, Dale A.; Oak, Steven W.; Ryan, George W.; Tainter, Frank H.; Redmond, Clair; Brown, H. Daniel. 1989. Evaluation of oak decline areas in the South. Prot. Rep. R8-PR 17. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southern Region. 36 p.

Stiell, W.M.; Berry, A.B. 1985. Limiting white pine weevil attacks by side shade. Forestry Chronicle. 61: 5–9.

Tainter, F.H.; Retzlaff, W.A.; Starkey, D.A.; Oak, S.W. 1990. Decline of radial growth in red oaks is associated with short-term changes in climate. European Journal of Forest Pathology. 20: 95–105.

Wargo, Philip M.; Shaw, Charles G., III. 1985. Armillaria root rot: the puzzle is being solved. Plant Disease. 69: 826–832.