Forest Pathology

For. Path. 40 (2010) 332–346 doi: 10.1111/j.1439-0329.2010.00661.x
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REVIEW

Silvicultural approaches for management of eastern white pine to minimize impacts of damaging agents

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Summary

Since the arrival to North America of *Cronartium ribicola*, management of eastern white pine has been driven by the need to avoid the actual or, in many areas, the perceived damage caused by white pine blister rust. Although white pine has lost much of its former dominance, it remains a valuable species for biotic diversity, aesthetics, wildlife habitat and forest products. Understanding its silvics and damaging agents provides a sound basis for the silvicultural activities of site selection, regeneration and stand tending. The species can be successfully grown in many locations despite herbivory, competition, white pine weevil and blister rust. Forest managers can minimize damage by applying knowledge of local conditions (climate, soils, physiography and vegetation) to hazard assessment, site selection and preparation, vegetation management, and pruning. With appropriate management and a long-term commitment, many eastern forests can be beneficially reforested to eastern white pine with little impact from blister rust and other damaging agents.

1 Introduction

Historical logging practices, destructive wildfires and the introduction of white pine blister rust, *Cronartium ribicola* J.C. Fisch. in Rabh., into eastern North America have significantly influenced the prevalence and silviculture of eastern white pine (*Pinus strobus* L.). The loss of local seed sources and threat of blister rust have deterred reforestation of this valuable species over much of its native distribution (Fig. 1). For example, white pine in the Lake States (Michigan, Minnesota and Wisconsin) was a major forest component prior to the mid-1800s. In Wisconsin alone, over 7.3 million ha included significant white pine populations from which over 104 billion board feet of lumber was removed between 1850 and 1930 (Gevorkiantz and Zon 1930). Logging almost eliminated the mature white pine resource and created conditions for the destructive fires which killed much of the remaining seed sources; recovery has been slow. By the 1980s, the total area of the white pine forest type in the Lake States was only 203,564 ha (Spencer et al. 1992). Although white pine remains a valuable timber species, it is predominantly managed now for biodiversity, aesthetics, Christmas trees and wildlife habitat. Interest is building among managers for the expanded reforestation of this adaptable species throughout its large geographic distribution and across its wide, ecological range (Stine and Baughman 1992).

Few tree species in North America raise more concern over the threat of damage and loss than eastern white pine. Successful management requires silviculture to minimize losses from wildlife herbivory, vegetation competition, white pine weevil (*Pissodes strobi* Peck) and blister rust (Daoust and Beaulieu 2004; Katovich et al. 2004). In many cases,

Received: 23.12.2009; accepted: 30.4.2010; editor: C. G. Shaw

Fig. 1. Potential distribution of white pine blister rust in eastern North America. The expected distribution of *Cronartium ribicola* is mapped over most of the natural distribution of eastern white pine, *Pinus strobus* (adapted from Little 1971: Conifers and important hardwoods. Atlas of trees of the United States. Misc. Publ. 1146. Washington, DC: U.S. Department of Agriculture, Forest Service. [Online]. Available: http://esp.cr.usgs.gov/data/atlas/little/). The mapped blister rust distribution includes all the natural distribution of white pine except for portions of the southern Appalachian mountains and adjacent areas reported by Anderson et al. (1980) as not infested. Many, small, isolated pine populations are not represented; and much of the native distribution is no longer occupied.

a silvicultural approach that does not consider the important local threats usually results in planting failure, decreased tree growth, poor tree form and excessive tree mortality.

Numerous silvicultural guides and reviews for managing eastern white pine are published (Anderson 1973; Lancaster and Leak 1978; Lancaster 1984; Robbins 1984; Stiell 1985; Hodge et al. 1989; Pinto 1992). Because white pine management is dominated by concerns over a few major threats, the species is often viewed as difficult to establish and maintain (Jones 1992). This reputation has produced decades of

reluctance to reforest sites with white pine, in spite of its many, significant values. Recent studies have demonstrated, however, that serious damage and loss from these threats are confined to certain locations and are manageable on most sites (Anderson 1973; Lancaster 1984; Robbins et al. 1988). This review describes the management of eastern white pine with the focus to identify hazardous locations and situations for regenerating and tending the species and the silviculture used to minimize impacts from damage and loss.

2 Factors critical to management of eastern white pine

2.1 Silvics

Eastern white pine grows on nearly every type of upland soil within its distribution and in association with numerous hardwood and conifer species (Stearns 1992). White pine is found most frequently on soils with a high sand content, especially on finer sands or sandy loams. Its best growth is achieved on nutrient-rich mesic soils, but vegetative competition on these soils is often intense during regeneration.

Good seed crops of eastern white pine are produced on an average every 3–5 years; successful natural regeneration is unlikely in a poor seed-year. Seed are wind disseminated over relatively long distances of more than 213 m in open areas or 61 m within stands (Wendel and Smith 1990). Seeds germinate on a variety of seedbeds including moist mineral soils, moss clumps and moderate grass or deciduous-leaf litter; if protected from full sunlight, seedlings can develop on these seedbeds (Wendel and Smith 1990). Dense pine litter or lichens make poor seedbeds. Fire and blow-down are common disturbances associated with white pine recruitment (Abrams 2001). White pine naturally reforests old fields abandoned after agricultural use. Site disturbance that exposes mineral soil, especially tip-up mounds, recent burns and eroded areas are generally favourable to seedling establishment and early growth.

Eastern white pine is intermediate in shade tolerance, although this changes with age. Young seedlings survive and grow with as little as 20% of full sunlight. Without release, however, suppression substantially reduces growth and eventually kills many small trees. Young seedlings typically grow slowly for the first few years and are easily damaged by overtopping vegetation and browsers. A positive growth response after release from competition and shade declines as trees age. White pines less than 30 years old with at least one-third of their height in live crown respond well to release; but the response declines rapidly after age 30 and with a decreasing crown ratio (Wendel and Smith 1990). Because eastern white pine is capable of living 350–400 years, it is a good candidate for retention as a super-canopy tree under extended rotations and as a component of old-growth forests (Rogers and Lindquist 1992).

2.2 Threats and damaging agents

The major damaging agents limiting growth and survival of eastern white pine are: (1) white-tailed deer *Odocoileus virginianus* Zimm. (Kittredge and Ashton 1995) and snowshoe hare *Lepus americanus* Erxl. (Katovich et al. 2004); (2) overtopping vegetation (Smidt and Puettmann 1998; Krueger and Puettmann 2004); (3) white pine weevil (Graham 1918; Wallace and Sullivan 1985); and (4) *C. ribicola* (Hirt 1956; Plourde et al. 1991). Although *Ribes* (currant and gooseberries) are not themselves damaging agents, they pose a threat as the alternate hosts (telial hosts) of blister rust on which the inoculum infective to white pine is produced (Zambino 2010). The white pine cone beetles, *Conophthorus coniperda* (Schwarz), occasionally decimate a developing cone crop (Graber 1964). The impacts of these damaging agents on white pine growth and survival vary in

severity both locally and regionally (Katovich et al. 2004). The challenge in designing and implementing the appropriate silviculture for white pine management is to evaluate the significant, local threats and to develop effective practices for avoiding or mitigating damage and loss.

3 Silviculture

3.1 Site selection

Although eastern white pine can occur on a wide range of sites, several threats limit the sites where investment in white pine silviculture can be made without significant risk. Prudent site selection includes an assessment of the expected populations of wildlife and insect herbivores, the potential for woody and herbaceous competition, hazard for blister rust and the distributions of *Ribes* species. Although nutrient-rich, mesic sites have the greatest potential for white pine seedling growth, these sites often support abundant population of competing vegetation and *Ribes*. To limit potential impacts from damaging agents, managers usually favour sites that are dry to mesic, have poor to medium nutrient levels, and a high potential for establishment, growth, and survival of white pine (Mader 1985; Kotar 1992).

3.1.1 Herbivory

Wildlife herbivory of eastern white pine from browsing by white-tailed deer and hare varies from year-to-year with population cycles. Although herbivory is difficult to predict from site characteristics alone, repeated browsing of young white pine is common. Damage severity is affected by the availability of alternate food sources and the height of the surrounding vegetation (Saunders and Puettmann 1999a). Paper bud-caps are used to protect white pine terminals from browsing (Barnacle 1997); but commercial chemical protectants and home remedies such as placing human hair, soaps and other substances within plantings have had limited success.

3.1.2 Competition and overtopping

Overtopping vegetation in open fields especially on nutrient-rich, mesic sites stresses young eastern white pine by competition and shading. The severity of stress generally decreases as site quality decreases. However, the specific relation between site quality and stand structure is difficult to predict because young trees compete with overstory trees, mid-canopy trees and understory vegetation for light and nutrients (Smidt and Puettmann 1998). Nonetheless, recognizing the potential for competition and mitigating stress by site preparation are critical for successful white pine regeneration.

3.1.3 White pine weevil

Site and stand conditions strongly influence the severity of damage by white pine weevils to young eastern white pine. Trees growing in full sun are vulnerable to weevil attack; whereas shade-grown trees with slow shoot growth and reduced bark thickness are rarely attacked (Graham 1918; Sullivan 1959; Wallace and Sullivan 1985; Major et al. 2009). White pine weevils prefer laying eggs in leaders with a bark thickness of 1.8–2.2 mm (Sullivan 1961) and select fast growing, vigorous trees with thick succulent bark (Kriebel 1954). Growing white pine under shade, however, involves a tradeoff as strong shade itself reduces tree growth and survival. Trees with 50–75% of full sunlight can achieve good growth at tolerable levels of weevil damage (Stiell and Berry 1985).

White pine weevil populations and attack frequency are not uniform across the distribution of eastern white pine (Pike et al. 2003). Weevil attack is usually very common in northern Wisconsin; but weevil populations are so low in southwestern Wisconsin that even open-grown white pine are rarely attacked. Such geographic differences illustrate the value of evaluating the local threat from a potentially damaging agent; in some locations, young white pine could be safely be grown in full sun without weevil damage.

3.1.4 Blister rust

The hazard to eastern white pine for infection by *C. ribicola* depends on the abundance of *Ribes* within the locality and across the landscape, that is at scales of 100s of meters to 10s of kilometers, respectively. Blister rust basidiospores are dispersed by diffusion and mass transport (Van Arsdel et al. 2006). Diffusion in low velocity turbulence occurs on a local scale from a *Ribes* bush, inoculum source; by settling and dilution, spore concentration declines rapidly with distance. Mass transport occurs by laminar air flow at multiple scales and can effect long-distance dispersal to white pine many kilometers from the source (Van Arsdel 1967, 1972). Sites where basidiospores are likely to be deposited and where they are likely to encounter conditions conducive to germination and infection include frost pockets, small canopy gaps, north aspects, west aspects and slope bases (Van Arsdel 1961, 1964). These are high hazard sites where most young white pine are likely to be infected if they are exposed to inoculum from either a local or distant source. In contrast, the tops of hills, slope shoulders, south and east aspects, and under an existing canopy are low hazard sites where many young pine are likely to escape infection (Van Arsdel 1961, 1964).

Blister rust control in eastern white pine largely depends on escape owing to regional climate or landscape–site factors that determine the development and dispersal of blister rust at various life-cycle stages (Geils et al. 2010). Temperature, moisture and air flow are critical environmental conditions that affect pathogen growth, spore dispersal, germination and infection (Van Arsdel et al. 1956; Van Arsdel 1961). The stages most influenced by the environment are the telial stage on *Ribes* which is favoured by cool summers and basidial stage which requires a long, cool, wet period (~48 h, <20°C, ~100% relative humidity) to form basidiospores, disperse, germinate and infect the white pine (Van Arsdel et al. 1956).

White pine blister rust hazard is mapped at a regional scale for distinguishing among broad geographic zones that vary in the environmental risk of supporting an infestation. Such maps are available for the Northeastern and Lake States, Quebec, and Ontario (Charlton 1963; Van Arsdel 1965a,b; Lavallée 1974, 1986b; Anderson et al. 1980; Gross 1985; White et al. 2002; Van Arsdel et al. 2006). When used with site-specific knowledge of local climate, physiography and vegetation, a hazard map helps minimize risk by identifying landscapes where disease control practices such as site selection and pruning could be effective. Sites in low hazard zones usually require no special management for blister rust; whereas in the moderate and high zones, blister rust control or deferred investment in white pine are usually advisable (Van Arsdel 1961, 1964). For example, low hazard zones in Ontario and Quebec are narrow and limited to southern areas where white pine can be grown without blister rust control (Gross 1985; Lavallée 1986b). In the moderate hazard zone, sanitation and preventative pruning provide for adequate survival of plantation white pine (Laflamme et al. 1998). In the high hazard zone to the north, the great likelihood of severe infestation makes white pine silviculture a risky investment.

The hazard on a particular site, however, varies from the regional norm owing to such factors as local climate (frost pockets), topography (aspect), landscape features (lakes) and

vegetation (host abundance). Within a low hazard zone, the location of a site relative to nearby lakes can raise the risk of infection by long-distance dispersal (Van Arsdel 1965a; b); conversely, within a high hazard zone, a scarcity of *Ribes* across the landscape (because of soil, canopy closure, or past removal) permits white pine reforestation with little or no danger from blister rust (Robbins et al. 1988; Dahir and Cummings 2001). This again underscores the importance of assessing specific, local site conditions rather than relying exclusively on regional averages.

Recently, interest in expanded commercial and hobby cultivation of *Ribes* for production of currant and gooseberry fruit has developed in a few locations (Mashburn 2000). Because many agencies have outdated or no regulations on *Ribes* cultivation (McKay 2000), a concern is raised that expanded *Ribes* production increases the threat of blister rust to white pine (Bergdahl and Teillon 2000). Although some cultivars of *R. nigrum* L. are immune to blister rust, susceptive cultivars of the European black currant produce more inoculum than most native *Ribes* species (Zambino 2010). *Ribes* cultivation practices that could minimize the threat to white pine include hazard assessment for selecting plantation and orchard sites, use of resistant cultivars, and cultural practices that reduce inoculum (Muir and Hunt 2000; Hummer and Dale 2010).

3.2 Regeneration

3.2.1 Site preparation

The goal of site preparation for regenerating eastern white pine is to create a seedbed and remove competing vegetation. Mixing litter with mineral soil and protecting seedlings from full sunlight provides an optimum seedbed. A suitable seedbed or planting site has slash and brush cleared and mineral soil exposed over 40% or more of the area (Stiell 1985). Prescribed burning eliminates the duff layer and removes competition, especially from balsam fir (*Abies balsamea* (L.) Mill.). Early spring burning reduces cone beetle populations overwintering in dead cones on the forest floor (Miller 1978).

3.2.2 Regeneration systems

Eastern white pine are successfully regenerated with clearcutting, seed-tree, shelterwood and strip-cutting silvicultural methods (Lancaster and Leak 1978). On many sites, regenerating white pine maintains or returns to the landscape a significant, seral species (Locey 1992). Whether seeding is natural or planted, the choice of seed source is important to maintain genetic diversity (Rajora et al. 2000). The early establishment phase is the most critical period for white pine regeneration. Understory brush control and protection from herbivory reduce the damages to young trees that would seriously reduce growth and survival (Saunders and Puettmann 1999b).

3.2.3 Natural regeneration

Eastern white pine can be naturally regenerated with the silvicultural methods of shelterwood, seed-tree and clearcutting if there is an adequate seed source (Stiell 1985). For avoiding or mitigating damage, each method has its own merits and drawbacks. Generally, the preferred regeneration method for white pine is the two-cut shelterwood system, because the prepared seedbed favours seed germination and early seedling growth and maintenance of the overstory reduces *C. ribicola* infection and weevil attack (Lancaster and Leak 1978). Scarifying the site one year before the first cut maximizes seedling establishment (Burgess and Wetzel 2000); residual trees usually respond favourably to a later release-thinning.

Partial removal of the overstory to 50% full sunlight is usually sufficient to release advanced regeneration but retain an adequate canopy to minimize blister rust infection and weevil attack. The cautions to partial removal are that logging wounds residual trees which develop stain and decay (Whitney 1991) and that opening the canopy permits *Ribes* invasion (Zambino 2010).

Seed-tree and clearcutting methods do not provide adequate shade to control blister rust and weevil damage to acceptable levels. In addition, on many nutrient-rich, mesic sites, the lack of shade is likely to increase herbaceous and woody competition. However, young white pine will grow faster under full sunlight than under shade. Where white pine can be grown at stand densities as high as ~2000 stems per ha weevil damage can be minimized. Even with frequent weevil attack, an adequate number of high-quality crop trees can be produced under open-grown conditions if selective thinning is used to favour crop trees and pruning to correct weevil damage (Pubanz et al. 1999).

Strip cuts can limit white pine weevil attack (Stiell and Berry 1985). In conifer stands, a properly oriented opening with a ratio of strip width to stand height from 0.66 to 1.00 provides adequate shade to significantly reduce weevil damage. Strip cuts are not effective in hardwood stands as the leafless trees in the spring do not provide adequate shade when adult weevils are dispersing.

3.2.4 Artificial regeneration

Planting is used to reforest sites with inadequate seed sources or lacking advance regeneration. Bare-root and containerized stock are planted with success where site preparation removes competing vegetation. Planting in a clearcut, small canopy gap, or open field requires weighing the potential for greater tree growth against the threat of increased rust and weevil damage.

The spacing at which seedlings are planted is based on several considerations, including seedling and planting costs, tree growth and crown closure objectives, thinning opportunities and the prevailing local threats. Dense stocking of ~2000 stems per ha controls crown development, reduces weevil attack, increases natural branch pruning and provides sufficient trees for future commercial thinnings. A common management goal is to produce 250–495 crop trees per ha at the end of the rotation.

Genetically, eastern white pine is highly variable and adapted to a wide range of environments (Kriebel 2004). Families have large differences in average growth rates for height, diameter and volume; individuals within families differ greatly in growth potential. Genetics programs in Canada and United States are selecting and breeding several species of North American white pine for blister rust resistance and timber quality (see King et al. 2010). Eastern white pine has been examined for resistance to white pine weevil, but selection and breeding success has been limited (Daoust and Beaulieu 2004; Kriebel 2004). Although artificial inoculations of eastern white pine failed to identify significant, genetic resistance to *C. ribicola* (Lu et al. 2005), other experimental evidence suggested there is rust resistance in the species (Jurgens et al. 2003; Katovich et al. 2004; Smith et al. 2006a). Improved planting stock is not available that has proved effective genetic resistance to blister rust or weevil.

3.3 Stand tending

3.3.1 Release

On sites with competing hardwoods, periodic release prevents overtopping of young white pine. After partial removal of a hardwood overstory, white pine quickly responds with increased height and diameter growth (Kelty and Entcheva 1993; Puettmann and

Saunders 2000). White pine 40–80 years old, under a canopy of aspen (*Populus*) and paper birch (*Betula papyrifera* Marsh.) can be released (Burgess et al. 2005), but release before age 30 is generally preferred. Removing intolerant hardwoods significantly increases white pine growth across a broad range of residual basal area. But, white pine trees grown under a canopy of oak (*Quercus*) or maple (*Acer*) usually fail to gain position in the upper canopy and die (Wendel and Smith 1990).

Girdling overstory hardwoods may prevent mechanical damage to understory white pine and encourage white pine growth without weevil attack. Little damage from dead overstory oak occurred if girdling were carried out when white pine were 1.5–3.0 m tall (Katovich and Morse 1992).

3.3.2 Pruning

Pruning eastern white pine is conducted to increase quality, remove or prevent blister rust cankers, and correct weevil damage (Weber 1964; Lehrer 1982; Hunt 1991; Lavallée 1992; Laflamme et al. 1998). Early pruning of lower branches can effectively reduce the development of lethal cankers, the majority of which occur in the lower crown (Lavallée 1991). As persistent needles on the lower stems of young trees also serve as blister rust entry courts, these are often removed as well (Katovich et al. 2004). Control of competing vegetation encourages the rapid early growth of seedlings that allows for early pruning. Pruning 2.7–5.2 m of the lower stem and maintaining two-thirds of the live crown of a small tree reduces the likelihood of lethal infection and begins development of a clear bole (knot-free wood). Systematic, preventative pruning is more effective than removal of infected branches and is usually conducted when a plantation is less than 15 years old or earlier on high hazard sites (Lavallée 1991, 1992). Because pruning temporary reduces growth, pruning on high hazard sites is often restricted to only the most vigorous trees (Zenner et al. 2005).

Corrective pruning of white pine is conducted following weevil attack (Hodge et al. 1989; Katovich and Mielke 1993; Lavallée et al. 1997). Although corrective pruning can be performed at any time during the year, pruning in mid-July to mid-August when weevils are present is opportune. Pruning and destruction of dead terminals at this time not only corrects the injury but reduces the weevil population. However, destroying the terminals also kills the natural enemies of the weevil in the infested terminals; Lavallée et al. (1997) described how to prune infested leaders while establishing and maintaining these natural enemies. In Quebec, pruning to control for weevil is performed yearly until trees reach 4.9 m height (Laflamme et al. 1998).

Sanitation pruning and canker excision are sometimes used in intensively managed white pine plantations or for valuable trees in amenity plantings. Branches with blister rust cankers are removed before the fungus gains entrance to the trunk (Nicholls and Anderson 1977), and small trunk cankers are excised by removing visibly affected tissues plus a portion of apparently surrounding healthy tissue. Hagle and Grasham (1988) determined that operational thinning can be 98% effective and canker excision 81% effective in sanitizing a stand.

3.3.3 Thinning

Stocking control increases the stand growth and yield of eastern white pine. For improving stand volume yield, thinning is conducted when trees are 18–20 cm diameter. Earlier thinning reduces the natural, self-pruning of lower branches. As lower branches are retained in young, open stands, a heavy wave of blister rust infection could lead to severe mortality as infections in the lower crown can develop into lethal cankers. In New Hampshire, a release cutting at age 40 that removed sawtimber and retained 247

crop trees per ha substantially increased yield of a white pine stand (Desmarais and Leak 2005). Mature white pine grown in Minnesota at relatively high basal areas (32 m^2 ha^{-1}) maximized volume production and other benefits of long rotation by adjusting for delayed blister rust mortality and reducing hardwood competition (Anderson et al. 2002). Livingston et al. (2005) suggested thinning smaller trees in overstocked stands on drought-stressed sites to maintain growth and survival of crop trees.

3.3.4 Protection

In areas where browsing of young white pine by deer and snowshoe hares is severe, either chemical deterrents or rigid mesh tubes and paper bud-caps are used to reduce damage to terminal leaders (Ward and Mervosh 2008). These treatments are applied as needed depending on tree growth rate, snow depth and population size until the white pine have grown above the browsing height.

Local eradication of *Ribes* from sites intermediate in blister rust hazard can be effective in reducing damage to eastern white pine (Stewart 1957; Pomerleau and Bard 1969; Van Arsdel 1972; Ostrofsky et al. 1988). However, in high hazard areas, dispersal of basidiospores from outside the control area reduces the effectiveness of eradication.

3.4 Additional management opportunities

Planting and maintaining eastern white pine within the various forest types of eastern North America can increase species and age diversity on many sites. Even a small component of white pine in a stand provides a future seed source for the species. Retention of white pine seed-trees within aspen forests can maximize structural and compositional diversity in commercially managed stands (Palik and Pregitzer 1994). However, regenerating white pine in young aspen stands often requires several release cuts to reduce competition from the overstory aspen (Clements 1966; Zenner et al. 2005). Managing advance regeneration or introducing white pine into red pine (*Pinus resinosa* Ait.) stands or

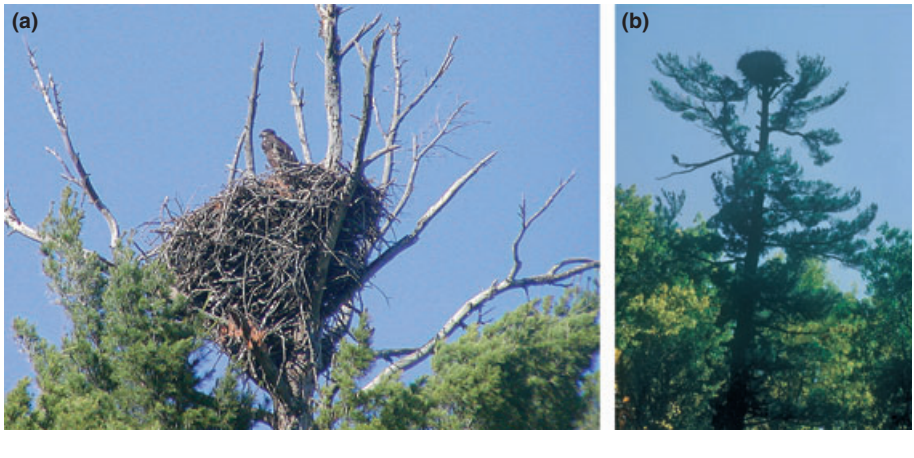

Fig. 2 Super-canopy eastern white pine with eagle's nest. (a) white pine with topkill by blister rust, nest and young bald eagle (photo by T. Nicholls). (b) white pine with upper crown emerging above the general forest canopy and supporting an eagle's nest (Forest Service photo).

declining paper birch stands effectively diversifies these stands; and the shelterwood afforded by these species increases shade and may reduce blister rust and weevil damage. Planting both white and red pine seedlings in plantations increases diversity and provides a seed source for future white pine regeneration. Natural disturbances such as wind and fire provide additional opportunities to reintroduce white pine.

Old-growth eastern white pine maintained as super-canopy trees serve as nesting and foraging sites for a wide variety of wildlife species (Rogers and Lindquist 1992) and as valuable seed sources. A super-canopy tree with a blister rust-killed top can live for many decades and still provide many ecological services (Fig. 2). The silvicultural approaches described in this review can be used to develop additional super-canopy trees.

4 Conclusions

Although planting eastern white pine has been severely curtailed for the last several decades because of the threat of *C. ribicola* and other damaging agents, white pine is flourishing in many eastern forests. Paleoecological studies reveal that white pine has survived in a wide range of environments and adjusted to past climatic changes. Evidence suggests that a warmer climate would favour the establishment of white pine regeneration and that white pine would tolerate the warmer, drier conditions that could reduce infection by blister rust (Jacobson and Dieffenbacher-Krall 1995).

Eastern white pine could be restored to many additional areas in eastern North America if specific factors that adversely impact white pine growth and survival on individual sites are addressed. White pine reforestation would benefit from: (1) proper site selection and planning; (2) application of knowledge of the local environment, including climate, soils, topography, vegetation and animal populations; and (3) timely and appropriate silvicultural intervention.

Management of eastern white pine benefits from a thorough site assessment of the potential impacts and mitigation costs of damaging agents and diseases, including herbivores, competing vegetation, white pine weevil and blister rust. Risks from competing vegetation and blister rust are minimal on warm, dry sites with fine sands or sandy loams and where *Ribes* are absent. Suitable seedbeds include moist mineral soils, moss and moderate grass and deciduous-leaf litter where seedlings are protected from full sunlight. Airflow, temperature and moisture are least conducive for blister rust infestation on hilltops, steep slopes and south or east facing slopes. Sites with low risk for blister rust infection or weevil attack provide an option for growing white pine in full sunlight to maximize tree growth. Densities as high as 2000 stems per ha in large openings or under a 50% canopy cover limit blister rust and weevil damage, promote early branch pruning, and provide sufficient number of trees for future commercial thinnings. Removal of competing vegetation when white pine are 6 m tall or when the pine reach the lower crowns of the upper canopy and thinning stands when trees are 18–20 cm in diameter increase white pine growth. Pruning 247–495 trees per ha beginning at age 2–5 years, retaining two-thirds live crown, and removing *Ribes* within white pine plantings in moderate rust hazard zones reduce blister rust damage.

R. R. Hirt (1956) wrote 'After fifty years of blister rust, perhaps we can truthfully say that the rust is not the greatest deterrent to reforesting with white pine in the northeast. White pine weevil damage, poor growth, early deterioration and death of artificially established stands on poorly chosen sites and soils have discouraged many potential growers. As silviculture, management and protection practices for white pine improve, the species may be looked upon with greater favor'. With new tools and knowledge of how to manage this species today, we believe it is time to renew our efforts to restore white pine in eastern forests.

References

Abrams, M. D., 2001: Eastern white pine versatility in the presettlement forest. Bioscience **51,** 967–979. [Online]. Available: http://www.jstor.org/stable/1313993

Anderson, P. D.; Zasada, J. C.; Erickson, G. W.; Zasada, Z. A., 2002: Thinning in mature eastern white pine: 43-year case study. Forestry Chronicle **78,** 539–549.

Anderson, R. L., 1973: A summary of white pine blister rust research in the Lake States. Gen. Tech. Rep. NC-6. St. Paul, MN: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, 12 p. [Online]. Available: http://www.treesearch.fs.fed.us/pubs/10071

Anderson, R. L.; Artman, J. D.; Doggett, C.; Cordell, C. E., 1980: How to control white pine blister rust in the southern Appalachian Mountains. For. Bull. SA-FB/P23. Atlanta, GA: U.S. Department of Agriculture, Forest Service, Southeastern Area, State and Private Forestry, 2 p.

Barnacle, B., 1997: Protect pine tree seedlings from deer browsing with paper bud caps. Silviculture Field Tip No. 6. Minnesota Department of Natural Resources, Division of Forestry, 1 p.

Bergdahl, D. R.; Teillon, H. B., 2000: White pine blister rust in Vermont: past, present, and concerns for the future. HortTechnology **10,** 537–541.

Burgess, D.; Robinson, C.; Wetzel, S., 2005: Eastern white pine response to release 30 years after partial harvesting in pine mixedwood forests. For. Ecol. Manage. **209,** 117–129. [Online]. doi: 10.1016/j.foreco.2005.01.006

Burgess, D.; Wetzel, S., 2000: Nutrient availability and regeneration response after partial cutting and site preparation in eastern white pine. For. Ecol. Manage. **138,** 249–261. [Online]. doi: 10.1016/S03781127(00)00400-X

Charlton, J. W., 1963: Relating climate to eastern white pine blister rust infection hazard. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Eastern Region, 38 p.

Clements, J. R., 1966: Development of a white pine underplantation in thinned and unthinned aspen. Forestry Chronicle **42,** 244–250.

Dahir, S. E.; Cummings, J. E. C., 2001: Incidence of white pine blister rust in a high-hazard region of Wisconsin. Northern Journal of Applied Forestry **18,** 81–86.

Daoust, G.; Beaulieu, J., 2004: Genetics, breeding, improvement and conservation of *Pinus strobus* in Canada. In: Breeding and Genetic Resources of Five-Needle Pines: Growth, Adaptability and Pest Resistance IUFRO Working Party 2.02.15, Medford, OR, 2001 July 23–27. Ed. By Sniezko, R. A.; Samman, S.; Schlarbaum, S. E.; Kriebel, H. B. Proceedings RMRS-P-32. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, pp. 3–11. [Online]. Available: http://www.fs.fed.us/rm/pubs/rmrs_p032/rmrs_p032_003_011.pdf

Desmarais, K. M.; Leak, W. B., 2005: Ten-year performance of eastern white pine under a crop tree release regime on an outwash site. Northern Journal of Applied Forestry **22,** 139–142.

Geils, B. W.; Hummer, K. E.; Hunt, R.S., 2010: White pines, *Ribes*, and blister rust: a review and synthesis. For. Pathol. **40,** 147–185.

Gevorkiantz, S. R.; Zon, R., 1930: Second growth white pine in Wisconsin: Its growth, yield, and commercial possibilities. Res. Bull. 98. Wisconsin Agricultural Experiment Station, 40 p.

Graber, R. E., 1964: Impact of the white-pine cone beetle on a seed crop. J. Forestry **62,** 499–500.

Graham, S. A., 1918: The white pine weevil and its relation to second-growth white pine. J. Forestry **16,** 192–202.

Gross, H. L., 1985: White pine blister rust: a discussion of the disease and hazard zones for Ontario. In: White pine symposium Suppl. 116. Guelph, ON: Entomological Society of Ontario, pp. 73–79.

Hagle, S. K.; Grasham, J. L., 1988: Biological and economic feasibility of pruning and excising white pine for blister rust control. Rep. 88-6. Missoula, MT: U.S. Department of Agriculture, Forest Service, Northern Region, Forest Health Protection, 14 p.

Hirt, R. R., 1956: Fifty years of white pine blister rust in the Northeast. J. Forestry **54,** 435–438.

Hodge, J. C.; Juzwik, J.; Gross, H. L.; Retnakaran, A., 1989: White pine blister rust and white pine weevil management: Guidelines for white pine in Ontario. Report PM-36. Ontario: Ministry of Natural Resources, Pest Management Section. 21 p.

Hummer, K. E.; Dale, A., 2010: Horticulture of Ribes. For. Pathol. **40,** 251–263.

Hunt, R. S., 1991: Operational control of white pine blister rust by removal of lower branches. Forestry Chronicle **67,** 284–287.

Jacobson Jr, G. L.; Dieffenbacher-Krall, A., 1995: White pine and climate change, insights from the past. J. Forestry **93,** 39–42.

Jones, A. C., 1992: The problem with white pine. In: White Pine Symposium Proceedings: History, Ecology and Management, Duluth, MN, 1992 September 16–18. Ed. By Stine, R. A.; Baughman, M. J. NR-BU-6044-S. St. Paul, MN: Minnesota Extension Service, pp. 64–72.

Jurgens, J. A.; Blanchette, R. A.; Zambino, P. J.; David, A., 2003: Histology of white pine blister rust in needles of resistant and susceptible eastern white pine. Plant Dis. **87,** 1026–1030. [Online]. doi: 10.1094/PDIS.2003.87.9.1026

Katovich, S. A.; Mielke, M., 1993: How to manage eastern white pine to minimize damage from blister rust and white pine weevil. Rep. NA-FR-01-93. Upper Darby, PA: U.S. Department of Agriculture, Forest Service, Northeastern Area, State and Private Forestry 15 p.

Katovich, S. A.; Morse, F. S., 1992: White pine weevil response to oak overstory girdling-results from a 16-year-old study. Northern Journal of Applied Forestry **9,** 51–54.

Katovich, S. A.; O'Brien, J. G.; Mielke, M. E.; Ostry, M. E., 2004: Restoration and management of eastern white pine within high hazard blister rust zones in the Lake States. In: Silviculture in special Places: Proceedings of the National Silviculture Workshop, Grandby, CO, 2003 September 8–11. Ed. By Sheppard, W. D.; Eskew, L. G., comps., Proceedings RMRS-P-34. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, pp. 135–145.

Kelty, M. J.; Entcheva, P. K., 1993: Response of suppressed white pine saplings to release during shelterwood cutting. Northern Journal of Applied Forestry **10,** 166–169.

King, J. N.; David, A.; Noshad, D.; Smith, J., 2010: A review of genetic approaches to the management of blister rust in white pines. For. Pathol. **40,** 292–313.

Kittredge, D. B.; Ashton, P. M. S., 1995: Impacts of deer browsing on regeneration in mixed stands in southern New England. Northern Journal of Applied Forestry **12,** 115–120.

Kotar, J., 1992: Managing white pine: Finding the proper niche. In: White pine symposium Proceedings: History, Ecology and Management, Duluth, MN, 1992 September 16–18. Ed. By Stine, R. A.; Baughman, M. J. NR-BU-6044S. St. Paul, MN: Minnesota Extension Service, pp. 150–156.

Kriebel, H. B., 1954: Bark thickness as a factor in resistance to white pine weevil injury. J. Forestry **52,** 842–845.

Kriebel, H. B., 2004: Genetics and breeding of five-needled pines in the eastern United States. In: Breeding and Genetic Resources of Five-Needle Pines: Growth, Adaptability and Pest Resistance, IUFRO Working Party 2.02.15, Medford, OR, 2001 July 23–27. Ed. By Sniezko, R. A.; Samman, S.; Schlarbaum, S. E.; Kriebel, H. B. Proceedings RMRS-P-32. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, pp. 20–27. [Online]. Available: http://www.fs.fed.us/rm/pubs/rmrs_p032/rmrs_p032_020_027.pdf

Krueger, J. A.; Puettmann, K. J., 2004: Growth and injury patterns of eastern white pine (*Pinus strobus* L.) seedlings as affected by hardwood overstory density and weeding treatments. Northern Journal of Applied Forestry **21,** 61–68.

Laflamme, G.; Blais, R.; Desgagné, D., 1998: Control of *Cronartium ribicola* in *Pinus strobus* plantations. In: 1st IUFRO Rusts of Forest Trees Working Party Conference, Saariselkä, Finland, 1998 August 2–7. Ed. By Jalkanen, R.; Crane, P. E.; Walla, J. A.; Aalto, T. Res. Pap. 712. Rovaniemi, Finland: Finnish Forest Research Institute, pp. 299–303.

Lancaster, K. F., 1984: White pine management, a quick review. Gen. Tech. Rep. NA-FR-27. U.S. Department of Agriculture, Forest Service.

Lancaster, K. F.; Leak, W. B., 1978: A silvicultural guide for white pine the Northeast. Gen. Tech. Rep. NE-41. Broomall, PA: U.S. Department of Agriculture, Forest Service, Northeastern Forest Experiment Station, 13 p. [Online]. Available: http://www.treesearch.fs.fed.us/pubs/4025

Lavallée, A., 1974: Une réévaluation de la situation concernant la rouille vésiculeuse du pin blanc au Québec. Forestry Chronicle **50,** 228–232.

Lavallée, A., 1986b: Zones de vulnérabilité du pin blanc à la rouille vésiculeuse au Québec. Forestry Chronicle **62,** 24–28.

Lavallée, A., 1991: White pine blister rust control in a 5-year-old eastern white pine plantation at Vercheres, Quebec (1984–88 results). In: 3rd IUFRO Rusts of Pine Working Party Conference, Banff, AB, 1989 September 18–22. Ed. By Hiratsuka, Y.; Saamoil, J. K.; Blenis, P. V.; Crane, P. E.; Laishley, B. L. Info. Rep. NOR-X-317. Edmonton, AB: Forestry Canada, Northern Forestry Centre, pp. 378–384. [Online]. Available: http://nofc.cfs.nrcan.gc.ca/bookstore_pdfs/11789.pdf

Lavallée, A., 1992: The spread of white pine blister rust in young white pine plantations. Info. Rep. LAU-X-101. Sainte-Foy, QB: Canadian Forestry Service, Laurentian Forestry Centre, 23 p.

Lavallée, A.; Bonneau, G.; Coulombe, C., 1997: Mechanical and biological control of the white pine weevil. Info. Leaf. LFC 28. Sainte-Foy, QB: Canadian Forest Service, Laurentian Forestry Centre, 11 p.

Lehrer, G. F., 1982: Pathological pruning: a useful tool in white pine blister rust control. Plant Dis. **66,** 1138–1139.

Little, Jr, E.L., 1971: Conifers and Important Hardwoods. Atlas of Trees of the United States. Misc. Publ. 1146. Washington, DC: U.S. Department of Agriculture, Forest Service. [Online]. Available: http://esp.cr.usgs.gov/data/atlas/little/

Livingston, W. H.; Granger, G.; Fries, M.; Granger, C.; Trial, H.; Struble, D.; Steinman, J.; Howell, S., 2005: White pine decline in Maine. 21 p. [Online]. Available: http://extension.unh.edu/forestry/Docs/livingsto.pdf

Locey, C. T., 1992: White pine artificial regeneration system. In: White Pine Symposium Proceedings: History, Ecology and Management, Duluth, MN, 1992 September 16–19. Ed. By Stine, R. A.; Baughman, M. J. NR-BU-6044S. St. Paul, MN: Minnesota Extension Service, pp. 168–169.

Lu, P.; Sinclair, R. W.; Boult, T. J.; Blake, S. G., 2005: Seedling survival of *Pinus strobus* and its interspecific hybrids after artificial inoculation of *Cronartium ribicola*. For. Ecol. Manage. **214,** 344–357. [Online]. doi: 10.1016/j.foreco.2005.04.024

Mader, D. L., 1985: Soil—site relationships for white pine in the Northeast. In: Eastern White Pine: Today and Tomorrow, Durham, NH, 1985 June 12–14. Ed. By Funk, D. T., comp. Gen. Tech. Rep. WO-51. Washington, DC: U.S. Department of Agriculture, Forest Service, pp. 28–31.

Major, J. E.; Mosseler, A.; Barsi, D. C.; Clouthier, A.; Campbell, M., 2009: Impact of three silvicultural treatments on weevil incidence, growth, phenology, and branch-level dynamics of *Pinus strobus* from large and small populations. Can. J. For. Res. **39,** 12–25. [Online]. doi: 10.1139/X08-153

Mashburn, E., 2000: *Ribes*: a view from the other side. HortTechnology **10,** 565–566.

McKay, S., 2000: State regulations of *Ribes* to control white pine blister rust. HortTechnology **10,** 562–566.

Miller, W. E., 1978: Use of prescribed burning in seed production areas to control red pine cone beetle. Environmental Entomology **7,** 698–702.

Muir, J. A.; Hunt, R. S., 2000: Assessing potential risks of white pine blister rust on western white pine from increased cultivation of currants. HortTechnology **10,** 523–527.

Nicholls, T. H.; Anderson, R. L., 1977: How to identify white pine blister rust and remove cankers. Broomall, PA: U.S. Department of Agriculture, Forest Service, North Central Forest Experiment Station, 8 p. [Online]. Available: http://www.treesearch.fs.fed.us/pubs/11061

Ostrofsky, W. D.; Rumpf, T.; Struble, D.; Bradbury, R., 1988: Incidence of white pine blister rust in Maine after 70 years of a *Ribes* eradication program. Plant Dis. **72,** 967–970. [Online]. doi: 10.1094/PD-72-0967

Palik, B. J.; Pregitzer, K. S., 1994: White pine seed-tree legacies in an aspen landscape: influences on post-disturbance white pine population structure. For. Ecol. Manage. **67,** 191–201. [Online]. doi: 10.1016/0378-1127(94)90016-7

Pike, C. C.; Robison, D. J.; Maynard, C. A.; Abrahamson, L. P., 2003: Evaluating growth and resistance of eastern and western white pine to white pine weevil and blister rust in the Northeast. Northern Journal of Applied Forestry **20,** 19–26.

Pinto, F., 1992: Silvicultural practices in Ontario's white pine forests. In: White Pine Symposium Proceedings: History, Ecology and Management, Duluth, MN, 1992 September 16–18. Ed. By Stine, R. A.; Baughman, M. J. NRBU-6044-S. St. Paul, MN: Minnesota Extension Service, pp. 170–178.

Plourde, A.; Lavallée, A.; Corriveau, A., 1991: White pine blister rust in Quebec: past present, and future. In: 3rd IUFRO Rusts of Pine Working Party Conference, Banff, AB, 1989 September 18–22. Ed. By Hiratsuka, Y.; Samoil, J. K.; Blenis, P. V.; Crane, P. E.; Laishley, B. L. Info. Rep. NOR-X-317. Edmonton, AB: Forestry Canada, Northern Forestry Centre, pp. 397–402. [Online]. Available: http://nofc.cfs.nrcan.gc.ca/bookstore_pdfs/11789.pdf

Pomerleau, R.; Bard, J., 1969: Les plantations de pin blanc et la rouille vésiculeuse dans le Québec. Phytoprotection **50,** 32–37.

Pubanz, D. M.; Williams, R. L.; Congos, D. L.; Pecore, M., 1999: Effects of the white pine weevil in well-stocked eastern white pine stands in Wisconsin. Northern Journal of Applied Forestry **16,** 185–190.

Puettmann, K. J.; Saunders, M. R., 2000: Eastern white pine (*Pinus strobus*) growth response to partial hardwood overstory release. Northern Journal of Applied Forestry **17,** 89–94.

Rajora, O. P.; Rahman, M. H.; Buchert, G. P.; Dancik, B. P., 2000: Microsatellite DNA analysis of genetic effects of harvesting in old-growth eastern white pine (*Pinus strobus*) in Ontario, Canada. Mol. Ecol. **9,** 339–348. [Online]. doi: 10.1046/j.1365-294x.2000.00886.x

Robbins, K., 1984: How to select planting sites for eastern white pine in the Lake States. NA-FB/M-8. 48 p. St. Paul, MN. U.S. Department of Agriculture, Forest Service, Northeastern Area, 7 p.

Robbins, K.; Jackson, W. A.; McRoberts, R. E., 1988: White pine blister rust in the eastern Upper Peninsula of Michigan. Northern Journal of Applied Forestry **5,** 263–264.

Rogers, L. L.; Lindquist, E. L., 1992: Supercanopy white pine and wildlife. In: White Pine Symposium Proceedings: History, Ecology, Policy, and Management, Duluth, MN, 1992 September 16–18. Ed. By Stine, R. A.; Baughman, M. J. NR-BU-6044-S. St. Paul, MN: University of Minnesota, Minnesota Extension Service, pp. 39–43.

Saunders, M. R.; Puettmann, K. J., 1999a: Use of vegetational characteristics and browsing patterns to predict deer damage in eastern white pine (*Pinus strobus*) plantations. Northern Journal of Applied Forestry **16,** 96–102.

Saunders, M. R.; Puettmann, K. J., 1999b: Effects of overstory and understory competition and simulated herbivory on growth and survival of white pine seedlings. Can. J. For. Res. **29,** 536–546. [Online]. doi: 10.1139/cjfr-29-5-536

Smidt, M. F.; Puettmann, K. J., 1998: Overstory and understory competition affect underplanted eastern white pine. For. Ecol. Manage. **105,** 137–150. [Online]. doi: 10.1016/S0378-1127(97)00278-8

Smith, J. A.; Blanchette, R. A.; Burnes, T. A.; Gillman, J. H.; David, A. J., 2006a: Epicuticular wax and white pine blister rust resistance in resistant and susceptible selections of eastern white pine (*Pinus strobus*). Phytopathology **96,** 171–177. [Online]. doi: 10.1094/PHYTO-96-0171

Spencer, J. S.; Leatherberry, E. C.; Hansen, M. H., 1992: White pine: status in Lake States forests. In: White Pine Symposium Proceedings: History, Ecology and Management, Duluth, MN, 1992 September 16–18. Ed. By Stine, R. A.; Baughman, M. J. NR-BU-6044-S. St. Paul, MN: Minnesota Extension Service, pp. 54–63.

Stearns, F., 1992: Ecological characteristics of white pine. In: White Pine Symposium Proceedings: History, Ecology and Management, Duluth, MN, 1992 September 16–18. Ed. By Stine, R. A.; Baughman, M. J. NR-BU-6044S. St. Paul, MN: Minnesota Extension Service, pp. 10–18.

Stewart, D. M., 1957: Factors affecting local control of white pine blister rust in Minnesota. J. Forestry **55,** 832–837.

Stiell, W. M., 1985: Silviculture of eastern white pine. In: White Pine Symposium Suppl. 116. Grelph, ON: Entomological Society of Ontario. pp. 95–107.

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

Stine, R. A.; Baughman, M. J., eds., 1992: White Pine Symposium Proceedings: History, Ecology, Policy and Management. NR-BU-6044-S. St. Paul, MN: University of Minnesota, Minnesota Extension Service, 202 p.

Sullivan, C. R., 1959: The effects of light and temperature on the behavior of adults of the white pine weevil, *Pissodes strobi* (Peck). Can. Entomol. **91,** 213–232.

Sullivan, C. R., 1961: The effects of weather and physical attributes of white pine leaders on the behavior and survival of white pine weevil, *Pissodes strobi* (Peck), in mixed stands. Can. Entomol. **93,** 724–741.

Van Arsdel, E. P., 1961: Growing white pine in the Lake States to avoid blister rust. Stn. Pap. 92. Madison, WI: U.S. Department of Agriculture, Forest Service, Lake States Forest Experiment Station, 11 p.

Van Arsdel, E. P., 1964: Growing white pines to avoid blister rust—new information for 1964. Res. Note LS-42. St. Paul, MN: U.S. Department of Agriculture, Forest Service, Lake States Forest Experiment Station, 4 p.

Van Arsdel, E. P., 1965a: Micrometeorology and plant disease epidemiology. Phytopathology **55,** 945–950.

Van Arsdel, E. P., 1965b: Relationships between night breezes and blister rust spread on Lake States white pines. Res. Note LS-60. St. Paul, MN: U.S. Department of Agriculture, Forest Service, Lake States Forest Experiment Station.

Van Arsdel, E. P., 1967: The nocturnal diffusion and transport of spores. Phytopathology **57,** 1221–1229.

Van Arsdel, E. P., 1972: Environment in relation to white pine blister rust infection. In: Biology of Rust Resistance in Forest Trees: Proceedings NATO-IUFRO Advanced Study Institute, Moscow, ID, 1969 August 17–24. Ed. By Bingham, R. T.; Hoff, R. J.; McDonald, G. I. Misc. Publ. 1221. Washington, DC: U.S. Department of Agriculture, Forest Service, pp. 479–493. [Online]. Available: http://www.treesearch.fs.fed.us/pubs/35041

Van Arsdel, E. P.; Geils, B. W.; Zambino, P. J., 2006: Epidemiology for hazard rating of white pine blister rust. In: 53rd Annual Western International Forest Disease Work Conference, Jackson, WY, 2005 September 26–30. Ed. By Guyon, J. C., comp. Ogden, UT: U.S. Department of Agriculture,

Forest Service, Intermountain Region, pp. 49–64. [Online]. Available: http://www.treesearch.fs.fed.us/pubs/25712

Van Arsdel, E. P.; Riker, A. J.; Patton, R. F., 1956: The effects of temperature and moisture on the spread of white pine blister rust. Phytopathology **46,** 307–318.

Wallace, D. R.; Sullivan, C. R., 1985: The white pine weevil, *Pissodes strobi* (Coleoptera Curculionidea): a review emphasizing behavior and development in relation to physical factors. In: White Pine Symposium Suppl. 116. Guelph, ON: Entomological Society of Ontario. pp. 39–62.

Ward, J. S.; Mervosh, T. L., 2008: Strategies to reduce browse damage on eastern white pine (Pinus strobus) in southern New England. For. Ecol. Manage. **255,** 1559–1567. [Online]. doi: 10.1016/j.foreco.2007.11.014

Weber, R., 1964: Early pruning reduces blister rust mortality in white pine plantations. Res. Note LS-38. St. Paul, MN: U.S. Department of Agriculture, Forest Service, Lake States Forest Experiment Station, 2 p.

Wendel, G. W.; Smith, H. C., 1990: *Pinus strobus* L. Eastern white pine. Silvics of North America, Conifers. Agric. Handb. 654. Washington, DC: U.S. Department of Agriculture, Forest Service, pp. 476–488. [Online]. Available: http://www.na.fs.fed.us/pubs/silvics_manual/Volume_1/Pinus/Strobus.htm

White, M. A.; Brown, T. N.; Host, G. E., 2002: Landscape analysis of risk factors for white pine blister rust in the Mixed Forest Province of Minnesota, USA. Can. J. For. Res. **32,** 1639–1650. [Online]. doi: 10.1139/x02-078

Whitney, R. D., 1991: Quality of eastern white pine 10 years after damage by logging. Forestry Chronicle **67,** 23–26.

Zambino, P. J., 2010: Biology and pathology of ribes and their implications for management of white pine blister rust. For. Pathol. **40,** 264–291.

Zenner, E. K.; Puettmann, K. J.; Krueger, J. A., 2005: Early growth responses of naturally regenerated eastern white pine (*Pinus strobus* L.) to partial release from juvenile aspen and pathological pruning. Northern Journal of Applied Forestry **22,** 27–34.

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