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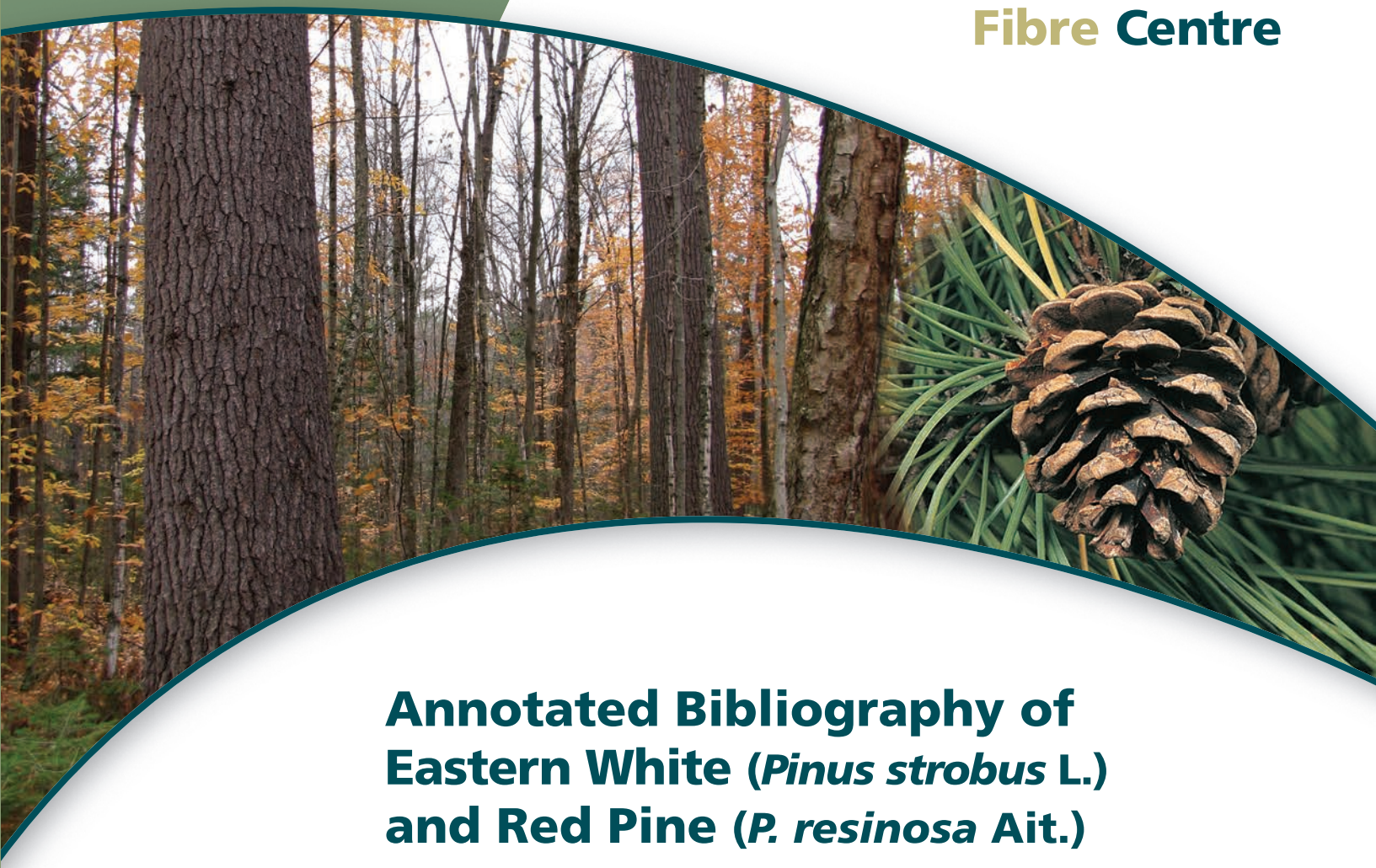

Annotated Bibliography of Eastern White (*Pinus strobus* L.) and Red Pine (*P. resinosa* Ait.) 1960–2007

Darwin Burgess, Katalijn MacAfee, Suzanne Wetzel, and B.S.P. Wang

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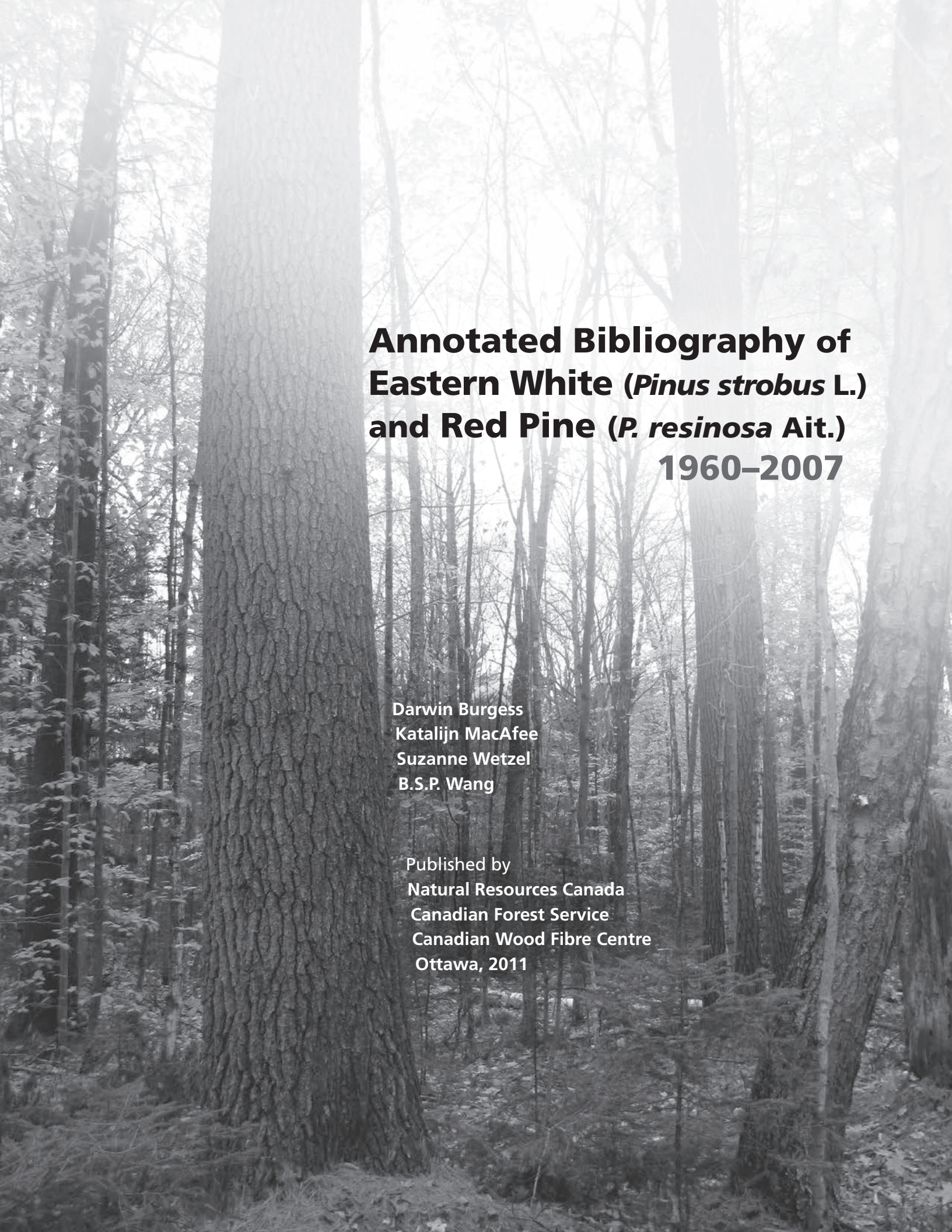

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Introduction

This annotated bibliography was prepared to provide researchers, students, and forest managers with a summary of the published research on eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.) ecology, silviculture, and management from 1960 to the end of 2007. The bibliography contains 640 annotations organized alphabetically by the lead author and numbered consecutively. A subject index is included.

Horton and Bedell (1960)[1] published a review of eastern white and red pine ecology, silviculture, and management, and this was probably the last detailed and extensive coverage of the topic. Much has changed since then, especially the broader recognition of the ecological and social values of eastern white and red pine forests.

About 14 papers were published annually since 1960. Some years were peak years in the number of publications, but this was mostly due to the publication of symposia proceedings.

While compiling the reports for this bibliography, we aimed to include all relevant authors and publications. It was inevitable that we missed some and we apologize to those authors.

In Canada, most research was conducted in Ontario, followed by Quebec and New Brunswick. In the United States, most research was conducted in Wisconsin and Michigan, followed by Massachusetts, Maine, and New Hampshire. Research at the Petawawa Research Forest (formerly known as the Petawawa Forest Experiment Station and later the Petawawa National Forestry Institute) contributed a significant number of reports. Because of the name changes, publications based on research conducted at the Petawawa Research Forest are referred to in the bibliography as situated at Petawawa, Ontario.

We have included a list of significant symposia proceedings on eastern white and red pine that were held between 1960 and 2007, as well as a list of research accomplishments and research gaps identified while completing this bibliography. We hope that you find this publication both useful and informative.

Significant Symposia Proceedings

- Proceedings of the Entomological Society of Ontario, Supplement to Volume 116, 1985.
- White and red pine symposium. D.A. Cameron, comp. Chalk River, ON, 20–22 September 1977. Symposium Proceedings O-P-6. Department of the Environment, Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. 178 p.
- Eastern white pine: today and tomorrow. D.T. Funk, comp. Symposium proceedings, Durham, NH, 12–14 June 1985. USDA For. Serv., Gen. Tech. Rep. WO-51. 124 p.
- The white pine weevil: biology, damage and management. R.I. Alfaro, G. Kiss, and R.G. Fraser, eds. Symposium proceedings, Richmond, BC, 19–21 January 1994. FRDA Rep. No. 226. 311 p.
- White pine symposium proceedings: history, ecology, policy and management. Duluth, MN, 16–18 September 1992. University of Minnesota, Extension Service Distribution Center, St. Paul, MN. 202 p.
- Red and white pine symposium. Chalk River, ON, 5–7 October 1993. For. Chron. 70 (4), August 1994.
- Workshop proceedings. Caroline A. Fox Research Forest, Hillsborough, NH, 9–10 October 2003. 78 p.
- Proceedings of the Great Lakes silviculture summit. B. Palik and L. Levy, comps., eds. 2004. Gen. Tech. Rep. NC-254. USDA For. Serv., North Central Res. Stn., St. Paul, MN. 49 p.

Research Accomplishments

- Ecological characterization of site quality, in some instances related to pine (*Pinus* spp.) productivity.
- Seed production studies confirming the importance of distinguishing between the typically shorter seed-testing treatments for germination in the laboratory and those performed in nursery stock production.
- Studies on the effects of cold stratification, scarification, seedbed preparation, light, soil, temperature, water, nutrients, and fertilizer on seed dormancy and germination.
- Early seedling development in natural eastern white pine stands investigated.
- Economic benefits of pine management positive when input costs were kept low and product quality and values were high.
- Value of maintaining old-growth pine forests acknowledged and generally accepted.
- Pine management recognized as complex, involving interactions among several plant competitors and damaging agents, and various treatments to promote regeneration, growth, and quality.
- Numerous studies on the genetics of eastern white pine; fewer studies for red pine as genetic variation of species is relatively low.

[1] Horton, K.W.; Bedell, G.H.D. 1960. White and red pine: ecology, silviculture and management. Bulletin 124. Department of Northern Affairs and National Resources, Forestry Branch, Ottawa. 185 p.

- Better quantification of the importance of large, old-growth eastern white pine for wildlife such as the American black bear (*Ursus americanus* Pallas) and birds of prey.
- Methods for obtaining natural regeneration of eastern white pine.
- Better understanding of growth responses after silvicultural treatments through use of new technologies for evaluating environmental conditions.
- Vegetation management research showing the beneficial effects of competition control.

Research Gaps

Research on eastern white and red pine suffers from a lack of a coordinated strategic plan to identify needs and to focus efforts at the broader and local scale so that they are cost effective and efficient. For example, although a few studies involved range-wide populations of pine on several sites, most studies were ad hoc and many were local and limited in scope. As the competition for research funding intensifies, those involved in pine research may wish to consider, and we hope will benefit from, taking a more strategic and coordinated research planning approach. Specific areas identified as research gaps:

- Coordinated research across the range of eastern white and red pine; the research effort is mainly local or regional, and in many instances, on a site-specific basis.
- Research on optimizing the growth and value of existing natural stands, not just on regenerating stands (as has been done in the past).
- Knowledge on the stage of stand development between early seedling establishment and early growth and development of eastern white and red pine, especially during the sapling phase until the trees reach a diameter of 9 cm.
- Research on the natural regeneration of red pine, which is more difficult to regenerate naturally than eastern white pine.
- Confirmation that eastern white pine seed can be induced into deeper dormancy (and thus retain its viability longer) when it is stored in subfreezing temperatures.
- Further studies on genetic clinal variation in seed dormancy of eastern white pine (current results do not show the clinal effects).
- Compelling evidence on the negative effects from white pine weevil (*Pissodes strobi* (Peck)) and white pine blister rust (*Cronartium ribicola* J.C. Fischer) damage on eastern white pine planted in open-grown conditions, and how the effects vary from region to region.
- Knowledge on the effect of silvicultural treatments on future wood fiber quality to better assess their cost effectiveness.
- Studies on root growth and development including the biology of mycorrhizae on eastern white and red pine.
- Nutrient management research.
- Research on establishing mixed-species plantations (some potential was shown for using red pine as a nurse crop for establishing regeneration of eastern white pine and red oak (*Quercus rubra* L.)).
- Research on the economics of pine management in plantations and natural stands, which is needed to assess the various management options.
- Strategies for pine restoration after years of high grading.
- Research on vegetation management, especially in regions where herbicides are not an option.
- More investigation into how to best restore degraded sites or plantations to pine mixedwoods because little is known about the dynamics of mixed-species stands.
- Knowledge on the development of older eastern white pine regeneration in understory conditions.
- Research on the impacts of climate change on red and eastern white pine ecology, silviculture, and management.

Bibliography

1 **Abbott, H.G.; Quink, T.F. 1970. Ecology of eastern white pine seed caches made by small forest mammals. Ecology 51:271–278.**
The effects of seed caches of white-footed mice (*Peromyscus leucopus*) and southern red-backed voles (*Clethrionomys gapperi*) on the ecology of eastern white pine (*Pinus strobus* L.) were studied in two managed eastern white pine stands in Sunderland, Massachusetts. Mice made seed caches beneath the litter layer in contact with the mineral soil, placing the seed in a microenvironment highly favorable to germination. Because these food caches were usually consumed to depletion, the number of potential eastern white pine germinants was greatly reduced. The contributions to forest regeneration of seed caches by these small mammals were of minor significance, except when bumper seed crops were produced and the seed supply exceeded the food requirements of the mice and other seed predators.

2 **Abella, S.R.; Shelburne, V.B. 2003. Eastern white pine establishment in the oak landscape of the Ellicott Rock Wilderness, southern Appalachian Mountains. Castanea 68:201–210.**
Evidence was investigated to support the hypothesis that a distributional shift of eastern white pine (*Pinus strobus* L.) from mesic to more xeric sites occurred across the southern Appalachian landscape during the last 100 years. The distributional status of eastern white pine was studied in a landscape dominated by old-growth oak (*Quercus* spp.) in northwestern South Carolina. Eighty 0.03-ha square plots were set up in a 225-ha old-growth eastern white pine forest. On each plot, tree species were identified and breast height diameters measured for all trees >1.0 cm in diameter. The apparent change in site affinity was possibly a consequence of fire suppression on xeric sites, which may have increased the establishment of eastern white pine. The mechanisms for this distributional change were not identified and further research was suggested to increase understanding of the distributional dynamics of eastern white pine during the 1900s.

3 **Abrams, M.D. 2001. Eastern white pine versatility in the presettlement forest. BioScience 51:967–979.**
The ecology of eastern white pine (*Pinus strobus* L.) before European settlement was explored within its range in the United States using data from early land surveys and dendroecological studies of a variety of old-growth forests. Different forest types were discussed incorporating the role of eastern white pine. Comparisons were made between presettlement forests and present-day old-growth forests, and an overall decline was recognized in the abundance of eastern white pine in northeastern and Great Lakes States forests, sometimes up to 35%. Fire and blow-down were two common disturbance agents associated with eastern white pine in eastern forests and they played an important role in the history of the species. Eastern white pine was classified as a disturbance-dependent species that is capable of growing on a wide range of sites.

4 **Abrams, M.D.; Orwig, D.A. 1996. A 300-year history of disturbance and canopy recruitment for co-occurring white pine and hemlock on the Allegheny Plateau, USA. J. Ecol. 84:353–363.**
A 300-year dendrochronology was used to investigate stand development and mechanisms of coexistence for two dominant and ecologically contrasting species, eastern hemlock (*Tsuga canadensis* (L.) Carrière) and eastern white pine (*Pinus strobus* L.), in northwestern Pennsylvania. Trees were cored for age determination, and data from the five oldest eastern white pine and eastern hemlock trees were used to construct the chronology. Both species exhibited unexpected dendrological and successional attributes. Eastern white pine demonstrated plasticity in initial radial growth. High initial growth alternated with below-average growth and growth spikes, and the ability to survive through long periods of depressed growth followed by growth releases. Eastern hemlock was less plastic initially, but several older trees did show dramatic growth after release. The succession of the forest appeared consistent, in part, with an initial floristic composition model.

5 **Abrams, M.D.; Orwig, D.A.; Demeo, T.E. 1995. Dendroecological analysis of successional dynamics for a presettlement-origin white-pine–mixed-oak forest in the southern Appalachians, USA. J. Ecol. 83:123–133.**
Tree species recruitment patterns were examined in relation to disturbance history in a 3.6-ha old-growth forest near Neola, West Virginia. The analysis coupled tree-ring chronologies with recruitment history. Eighteen 0.02-ha circular plots were set up along transects. Species, diameter, and crown class were determined for each tree. The relative importance of each species in each plot was calculated. Three or four representative trees by species and age class were cored for radial-growth analysis. Saplings and seedlings were tallied in nested subplots in the main plots. Eastern white pine (*Pinus strobus* L.) was one of the dominant species in the uneven-aged forest. The older and the larger tree species were mostly white oak (*Quercus alba* L.) and eastern white pine. Cores from the oldest representatives of these species were used to create a three-century

growth chronology. The radial-growth chronologies demonstrated tree releases at regular intervals of about 20–30 years, possibly because of small-scale localized disturbances like fire or windthrow. The methodology could be applied to other forest types to increase understanding of disturbance, successional dynamics, species life-history characteristics, and ecological history.

6 **Abrams, M.D.; van de Gevel, S.; Dodson, R.C.; Copenheaver, C.A. 2000. The dendroecology and climatic impacts for old-growth white pine and hemlock on the extreme slopes of the Berkshire Hills, Massachusetts, U.S.A. Can. J. Bot. 78:851–861.**
The disturbance history, successional development, and response to climatic variation of an old-growth eastern white pine (*Pinus strobus* L.)–eastern hemlock (*Tsuga canadensis* (L.) Carrière) forest was assessed on an extreme slope in Ice Glen Natural Area, southwest Massachusetts. This site and similar forests are useful resources for studying ecological history and climatic response. The study considered the forest composition and structure, long-term tree-ring patterns, disturbance and climate response, and successional dynamics of eastern white pine, eastern hemlock, and northern hardwoods. Twenty 0.02-ha circular plots were laid out along parallel transects across 8 ha. Species, diameter, and crown class were determined for each tree. The relative importance of each species was calculated per plot. Twenty eastern hemlock and 18 eastern white pine were cored for radial-growth analysis. Eastern hemlock was the oldest of the nine tree species in the forest. All species demonstrated a dramatic decrease in recruitment after 1900, which was attributed to deer browsing. Eastern white pine and eastern hemlock tree-ring growth correlated positively with drought severity. The existence of old-growth forests on these extreme sites may have been vulnerable to direct and indirect external factors and climatic variations. Future disturbances like hemlock woolly adelgid (*Adelges tsugae* Annand), hurricanes, and ice storms would possibly create new recruitment opportunities for eastern white pine and other species.

7 **Abubaker, H.I.; Zsuffa, L. 1991. Provenance variation in eastern white pine (*Pinus strobus* L.): 28th-year results from two southern Ontario plantations. Pages 69–85 *in* P.W. Garrett, ed. Proceedings of a symposium on white pine provenances and breeding. IUFRO Working Party S2.02-15. XIX World Congress, Montréal, Quebec, 5–11 August 1990. Gen. Tech. Rep. NE-155. USDA For. Serv., Northeastern For. Exp. Stn., Radnor, PA. 105 p.**
Eastern white pine (*Pinus strobus* L.) seed was collected range-wide from 12 provenances and planted as 2+2 seedling stock at two locations in southern Ontario; one site had a clay soil and the other a well-drained sandy soil. After 28 years, several morphological characteristics were measured and analyzed for quantity both among and within provenances variation. Eastern white pine was highly variable and displayed well-defined patterns of variation. Significant differences among provenances were revealed. Atlantic coast provenances were faster growing with fewer forked stems, whereas the inland provenances (Iowa) were slower growing. Southern provenances had fewer branches/whorls than northern provenances.

8 **Adams, W.T.; Joly, R.J. 1977. Analysis of genetic variation for height growth and survival in open-pollinated progenies of eastern white pine. Pages 117–131 *in* Proceedings of the 25th northeastern forest tree improvement conference, Orono, ME, 27–29 July 1977. School of Forest Resources, University of Maine, Orono, ME.**
Few earlier studies of eastern white pine (*Pinus strobus* L.) genetics have examined patterns of individual traits, knowledge of which could improve the efficiency of tree breeding. This study analyzed genetic variation for height and survival after three years in a randomized block nursery trial at the University of New Hampshire with open-pollinated progenies of 18 eastern white pine clones from two seed years, 1971 and 1973. Analyses of variance and covariance were completed for each seed year, and significant variation among families was evident for each year. Seed size effects varied by year and had significant influence on heritability and genetic correlation. The extent of correlation between seedlings and crop-age trees remains unknown for many traits, such as disease resistance and form.

9 **Ahlgren, C.E. 1976. Regeneration of red pine and white pine following wildfire and logging in northeastern Minnesota. J. For. 74:135–140.**
Natural regeneration of red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.) was compared on sites near the border of Minnesota and Ontario. The sites had been burned by wildfire, logged, or were undisturbed. Natural disturbances occurred too infrequently in this area for successful regeneration of red and eastern white pine. Aspen (*Populus* spp.) domination, white pine blister rust (*Cronartium ribicola* J.C. Fischer), and a lack of abundant seed trees contributed to eastern white pine's inability to establish and regenerate. If red and eastern white pine's perpetuation is desired, knowledge of their silvicultural requirements must be noted and applied to regenerate these species.

10 **Ahlgren, C.E. 1979. Emergent seedlings on soil from burned and unburned red pine forest. Minn. For. Res. Notes No. 273. Minn. Agric. Exp. Stn. Sci. J. Ser. Pap. No. 10930. University of Minnesota, St. Paul, MN. 4 p.**

Soil removed from a recently burned 270-year-old red pine (*Pinus resinosa* Ait.) stand in northeastern Minnesota and from an adjacent, unburned area was used to assess and compare seedling emergence under greenhouse conditions. Three blocks of soil each 30 cm^2 to a depth of 5 cm into mineral soil were collected from each area. Seed was extracted from sieved composite soil samples from each area. The total number of seedlings was higher on the burned soil. Because both soils received the same amount of light, increased light after a fire did not seem to be the major factor in postfire vegetational response.

11 Ahlgren, C.E.; Ahlgren, I.F. 1981. Some effects of different forest litters on seed germination and growth. Can. J. For. Res. 11:710–714.

Germination and early seedling growth were assessed for 12 native herbs, shrubs, and tree species including eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.). Several litter types of various successional stages of northeastern Minnesota forests were collected without distinguishing among physical, nutritional, chemical, or allelopathic influences. The litter types collected included trembling aspen (*Populus tremuloides* Michx.), white birch (*Betula papyrifera* Marsh.), red pine, eastern white pine, and balsam fir (*Abies balsamea* (L.) Mill.), and they were mixed with soil and sand (five parts foliage, five parts sterile potting soil, and two parts clean sand). A mixture of five parts soil and two parts sand was designated as the control. Seeds were collected and planted in August and September. Four 25-seed replicates were planted for each seed–litter type combination. Total germination in eastern white pine litter was high and very similar to germination in the control. Eastern white pine germinated and grew best in eastern white pine litter, suggesting a potential to be self-sustaining in the undisturbed forest. Red pine germinated poorly in its own and several other litters, reflecting its requirements of mineral soil seedbeds for natural seedling establishment.

12 Ahlgren, I.F.; Ahlgren, C.E. 1960. Ecological effects of forest fires. Bot. Rev. 26:483–533.

The ecological effects of forest fires in Quetico Provincial Park were reviewed. The effects of fire were examined on soil moisture, texture, temperature, fertility, and chemical composition as well as on living organisms (bacteria, diseases, insects, animals, grasses, herbs, shrubs, and trees). Eastern white pine (*Pinus strobus* L.) does not necessarily require fire to regenerate, but it does require the opening-up of an area to sunlight that stimulates eastern white pine germination and growth. Earlier studies were discussed showing an increase in seed germination, seedling height, and volume growth associated with fire.

13 Aird, P.L. 1978. Splendour undiminished: A management objective for red pine and eastern white pine ecosystems. Pages 71–75 *in* D.A. Cameron, comp. White and red pine symposium, Chalk River, ON, 20–22 September 1977. Symposium Proceedings O-P-6. Department of the Environment, Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. 178 p.

Some of the environmental implications of more intensive forest management were identified. A thorough environmental assessment of pine management in Ontario could not be conducted until the objectives were clearly defined. An annual biological audit of red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.) ecosystems was suggested to evaluate the success of intensive management.

14 Aird, P.L. 1985. In praise of pine: the eastern white pine and red pine timber harvest from Ontario's Crown forest. Department of Agriculture, Canadian Forestry Service, Petawawa National Forestry Institute, Chalk River, ON. Information Report PI-X-52. 23 p.

A historical account was presented of the harvest of red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.) in Ontario from the 1700s until 1983. Much of Ontario's history and development was directly linked to the harvest of eastern white pine. The historical timeline of eastern white and red pine harvest was followed, starting in the 1700s with the shipbuilding industry in France, followed by the timber export to England, and finally the sawlog trade with the United States. Consequently, eastern white and red pine were significantly less abundant in Canada than they were 200–300 years ago. The decline raised concern about the effectiveness of the political effort to sustain this valuable resource. The former splendor of eastern white and red pine forests could be restored and sustained in many areas by implementing better pine management.

15 Akachuku, A.E. 1993. Recovery and morphology of *Pinus resinosa* Ait. trees 50 years after they were displaced by a hurricane. For. Ecol. Manag. 56:113–129.

After a hurricane hit Massachusetts, 25-year-old red pine (*Pinus resinosa* Ait.) trees were bent or their stems displaced from growing vertically. Fifty years later, some of these trees were used to assess the extent to which the trees had recovered, to characterize their shape, and to determine the relationships between their external morphological features. Thirty-three trees were selected randomly and several parameters were measured including diameter at breast height, bole angle of deviation from vertical orientation, total height, and mean crown diameter. Each leaning red pine tree tended to correct along a line that was approximately a continuation of its original vertical growth. The severity of sweep had no significant effect on growth rate.

16 **Alban, D.H. 1971. Effect of fertilization on survival and early growth of direct-seeded red pine. Res. Note NC-117. USDA For. Serv., North Central For. Exp. Stn., St. Paul, MN. 4 p.**

The effects of fertilization were investigated on survival and growth of direct-seeded red pine (*Pinus resinosa* Ait.) under two moisture regimes during their first two growing seasons. Twelve 0.08-ha plots were set up in a clearcut in north central Minnesota and disked in preparation for direct seeding. In each plot, four 1-m^2 subplots were seeded with 100 red pine seeds. Two subplots were fertilized at the time of seeding (at rates of N, P, and K of 202, 100, and 168 kg/ha, respectively), and the following spring, fertilizer was applied to one subplot fertilized before, and to another subplot not fertilized before. Irrigation was applied after a specific number of days (1, 3, 6, 9, 12, or 15) with <5 mm of rainfall. Seedlings were counted weekly in the first growing season, and in October of the second year. Seedling heights were measured and five seedlings were harvested and analyzed for N, Ca, K, and P. Fertilization resulted in higher mortality and dramatic changes in chemical composition but increased seedling height and shoot weight after one growing season. High levels of watering increased seedling growth but to a lesser extent than fertilization. By increasing seedling growth, fertilization may have reduced the need for future competition control.

17 **Alban, D.H. 1972. An improved growth intercept method for estimating site index of red pine. Res. Pap. NC-80. USDA For. Serv., North Central For. Exp. Stn., St. Paul, MN. 7 p.**

Growth intercept (GI) is typically a measure of the total length of five stem internodes above breast height. This study assessed the GI method for predicting the quality of older red pine (*Pinus resinosa* Ait.). Sixty-nine plots of natural red pine in northern Minnesota were examined, and in each plot three to seven dominant trees were cut and the position of each whorl on the stem measured. Total age was determined by ring counts. Height growth curves were constructed for each plot. GI was estimated from the stem analysis data and related to the height of dominant trees at age 50. Estimating the height at age 50 from GI is most accurate when GI is measured a few metres above breast height. Using GI by starting from the first whorl above 2.4 m was recommended to predict the height at age 50, and an equation was presented for a site index from the GI measurement. The transferability of results was tested from natural stands to plantations. Twenty plantations were sampled similarly to the natural stands, and it was concluded that the GI intercept equation developed for natural stands was applicable to plantations in Minnesota.

18 **Alban, D.H. 1977. Influence on soil properties of prescribed burning under mature red pine. Res. Pap. NC-139. USDA For. Serv., North Central For. Exp. Stn., St. Paul, MN. 8 p.**

Burning to control beaked hazel (*Corylus cornuta* Marsh.) in a 90-year-old red pine (*Pinus resinosa* Ait.) stand in Minnesota was assessed for its potential to establish red pine. A total of 28 plots were set up each with a basal area of 27.5 m^2/ha. Four plots were left unburned. Other plots were burned either during spring or summer at different intervals: annually, biannually, or periodically (six to nine years). Most burns were initiated 5–15 days after a rain when the moisture content averaged 100% (spring) and 40% (summer). Each treatment was replicated four times using a randomized complete block design. Soil and forest-floor samples and three representative hazel plants from each control plot were collected and analyzed. Burning reduced shrub competition, killing most of the aboveground hazel sprouts, but summer burns were more effective in reducing sprouting. Burning also reduced the amount of organic matter and nutrients in the forest floor but increased the nutrients in the mineral soil. The soil changes did not affect red pine growth, suggesting that prescribed fires resulting in volatilization of up to one half of the forest-floor weight have had little effect on site productivity, at least for red pine.

19 **Alban, D.H. 1979. Estimating site potential from the early height growth of red pine in the Lake States. Res. Pap. NC-166. USDA For. Serv., North Central For. Exp. Stn., St. Paul, MN. 7 p.**

There is a close relationship between site index and the total length of the first five internodes beginning at the first whorl above 2.4 m. This relationship was used to develop height growth equations for young natural red pine (*Pinus resinosa* Ait.) stands and red pine plantations in Minnesota first, and now has been expanded for the Lake States. A total of 165 red pine stands in the Lake States were used to develop and evaluate the growth intercept method for plantations and naturally established stands. The equations could be applied to stands from 16 to 30 years old and estimated site index better than conventional site index curves for these young stands.

20 **Alban, D.H. 1985. Red pine site evaluation based on tree growth and soils. Pages 79–100 *in* R. Marty, ed. Managing red pine. Proceedings of the second region V technical conference, Society of American Foresters. SAF Publication 85-02. Bethesda, MD.**

Methods were examined for predicting a forest site's capacity to grow red pine (*Pinus resinosa* Ait.) as a measure of site quality and for introducing the concept of forest productivity–site index. Four ways of estimating site indices were explained with a detailed discussion about

the influences of soil characteristics on red pine growth. The capabilities and limitations of various methods were presented. Site index could not exceed 23 m for a red pine stand over 40 years old. Younger stands had higher values, but indices tended to decrease through time.

21 Alban, D.H. 1988. Nutrient accumulation in planted red and jack pine. Res. Pap. NC-282. USDA For. Serv., North Central For. Exp. Stn., St. Paul, MN. 6 p.

Nutrient accumulation was compared in adjacent plantations of red (*Pinus resinosa* Ait.) and jack pine (*P. banksiana* Lamb.), and models were developed to predict nutrient content in these species as functions of easily measured stand variables. Twenty-four unthinned stands of adjacent red and jack pine plantations were sampled ranging from 19 to 46 years old and all in the upper Great Lakes. Soils were sampled to ensure that the adjacent plantations had the same soil. Jack pine grew faster at first, but by age 20 the accumulation of nutrients, biomass, and volume was similar for both species. Beyond this age, red pine accumulated significantly more biomass and nutrients than jack pine in most cases. The models presented for estimating biomass and nutrients were applicable to typical unthinned red and jack pine plantations from 20 to 50 years old throughout the upper Great Lakes region.

22 Alban, D.H.; Prettyman, D.H. 1984. Height growth of red pine on fine-textured soils. Res. Pap. NC-249. USDA For. Serv., North. Central For. Exp. Stn., St. Paul, MN. 6 p.

This was the first systematic evaluation of the applicability of site index curves to the growth of red pine (*Pinus resinosa* Ait.) on fine-textured soils. Ten planted and 12 natural stands of red pine were sampled in Minnesota and northwestern Wisconsin. The stands ranged from 44 to 86 years old and in site index from 12 to 21 m and included both thinned and unthinned stands. One to four soil pits per stand were sampled to determine soil texture. A single height curve was constructed for each stand. Height growth for plantations younger than 50 years was predicted using the Gevorkiantz site index curves. Adjusted height growth curves closely followed the Gevorkiantz site index curves beyond age 15. Age at breast height is needed to confidently estimate a red pine stand site index from the height curves. An age adjustment was recommended if the age was greater than the region-wide average of eight years.

23 Alban, D.H.; Prettyman, D.H.; Brand, G.J. 1987. Growth patterns of red pine on fine-textured soils. Res. Pap. NC-280. USDA For. Serv., North Central For. Exp. Stn., St. Paul, MN. 8 p.

Site index curves for red pine (*Pinus resinosa* Ait.) growing on sandy soils were shown earlier to accurately describe the height growth of red pine on fine-textured soils. This study was initiated to determine whether diameter and volume growth were also similar. Nine red pine plantations were sampled in northern Minnesota on fine-textured soils with initial spacings of 1.2×1.2 m and 2.4×2.4 m. Tree height and diameter at breast height were measured and net growth and mortality were estimated. Nine additional red pine plantations on sandy soils were also sampled for comparison. STEMS and REDPINE were the two growth projection models tested and they showed no consistent differences in red pine growth patterns comparing fine-textured and sandy soils. No differences were identified for tree mortality, bole form, or live crown ratio between red pine growing on fine-textured and sandy soils, nor were differences apparent in the pattern of individual tree diameter growth or stand basal area or volume growth.

24 Alemdag, I.S.; Stiell, W.M. 1982. Spacing and age effects on biomass production in red pine plantations. For. Chron. 58:220–224.

Oven-dry mass of aboveground portions of red pine (*Pinus resinosa* Ait.) plantation trees were related to diameter at breast height (dbh) and height, and the effects of initial spacing and stand age were examined. Data from 155 trees were collected and analyzed from 16 unthinned red pine plantations near Petawawa, Ontario. Trees were felled, and samples taken and dried to obtain oven-dry mass. Single tree equations for red pine on the basis of dbh and height gave satisfactory oven-dry mass estimates for the whole tree and for stem bark. Addition of spacing and age improved the estimates for other biomass components. If red pine were to be grown as energy plantations, the largest amount of biomass would be obtained at close spacing or at older ages for a given spacing.

25 Alexander, L.; Larson, B.C.; Olson, D.P. 1986. The influence of wildlife on eastern white pine regeneration in mixed hardwood-conifer forests. Pages 40–45 *in* D.T. Funk, comp. Eastern white pine: today and tomorrow. Symposium proceedings, Durham, NH, 12–14 June 1985. Gen. Tech. Rep. WO-51. USDA For. Serv., Northeastern For. Exp. Stn., Durham, NH. 124 p.

The results of several studies were summarized and presented to determine the influence of wildlife on the establishment of eastern white pine *(Pinus strobus* L.) in mixed forests. Ground disturbances caused by wildlife, primarily eastern gray squirrels (*Sciurus carolinensis* Gmelin), created a favorable seedbed for eastern white pine and protection from small-mammal seed consumers. A need for a greater understanding of the mixed-forest system was recognized, and ecological influences and interactions should be considered to make silvicultural practices relating to the

establishment and growth of eastern white pine on mixed-forest sites more effective and less expensive.

26 Alfaro, R.I. 1995. A sequential sampling system for the white pine weevil, *Pissodes strobi* (Coleoptera: Curculionidae). J. Entomol. Soc. B.C. 92:39–43.

A sequential sampling system was developed for the rapid assessment of white pine weevil (*Pissodes strobi* (Peck)) infestations in spruce (*Picea* spp.) stands. Stands were considered light infested if <10% of the trees had white pine weevil damage, and severe infested if >20% of the trees showed damage.

27 Alfaro, R.I.; Borden, J.H.; Fraser, R.G.; Yanchuk, A. 1994. An integrated pest management system for the white pine weevil. Pages 226–238 *in* R.I. Alfaro, G. Kiss, and R.G. Fraser, eds. The white pine weevil: biology, damage and management. Symposium proceedings, Richmond, British Columbia, 19–21 January 1994. FRDA Rep. No. 226. 311 p.

Available white pine weevil (*Pissodes strobi* (Peck)) control methods in Canada were reviewed and a possible integrated pest management system was formulated from this review. The following control methods were described: direct control, silvicultural control, genetic resistance, and hazard rating. Significant progress has been made refining these methods. The integrated pest management system combined silviculture-driven and resistance-driven tactics. The system relied on accurate hazard rating of plantation sites and required continuous monitoring of attack levels and the forecasting of productivity losses through the use of a decision support system.

28 Amishev, D.Y; Fox, T.R. 2006. The effect of weed control and fertilization on survival and growth of four pine species in the Virginia Piedmont. For. Ecol. Manag. 236:93–101.

Little was known earlier about the growth response of shortleaf (*Pinus echinata* Mill.), Virginia (*P. virginiana* Mill.), and eastern white pine (*P. strobus* L.) to intensive silvicultural treatments in this region. The growth response of these planted species, and loblolly pine (*P. taeda* L.), to weed control and fertilization was assessed in the Piedmont of Virginia. The site, with a deep, well-drained, and moderately permeable soil, was clearcut in 1999. A split-plot design was used with two sets of treatments, replicated three times. The four pine species were planted at a 1.5-m tree spacing. Four silvicultural treatments (no treatment, weed control, fertilizer, and weed control plus fertilizer) were applied. Weed control included a series of herbicide applications designed to eliminate hardwood vegetation. Fertilizer was added during the first five years to create large differences in soil nutrient availability. Soil and foliage samples were collected and analyzed after five years, and trees were assessed for survival from age two to five. Eastern white pine survival was lower and its height and diameter at breast height growth less than for the other pines, regardless of treatment. Survival of all pines was affected negatively when fertilizer was applied without controlling the competing hardwoods. Fertilization significantly increased extractable P, whereas herbicide decreased soil C and extractable K and Zn. The poor performance of eastern white pine was probably due to higher moisture and temperature stress.

29 Anderson, C.E.; Chapman, K.A.; White, M.A.; Cornett, M.W. 2002. Effects of browsing control on establishment and recruitment of eastern white pine (*Pinus strobus* L.) at Cathedral Grove, Lake Superior Highlands, Minnesota, USA. Nat. Areas J. 22:202–210.

The effects of browsing by white-tailed deer (*Odocoileus virginianus* (Zimmermann)) and snowshoe hare (*Lepus americanus* Erxleben) were examined on the establishment and recruitment of eastern white pine (*Pinus strobus* L.) in Minnesota. Three fenced exclosures (0.25 ha each) were erected in an eastern white pine stand that contained up to 10 000 eastern white pine seedlings per hectare under an open or partly open canopy that would encourage rapid growth of the pine. Three adjacent reference areas of equal size were designated as controls. Browsing was reduced significantly in the exclosures, and the reference areas also seemed to show lower levels of browsing than the surrounding areas. Eastern white pine stem density was greater in exclosure plots than in reference plots. The exclusion of browsers allowed for increased eastern white pine establishment and growth, but exclosures must be in place for probably five years for eastern white pine to recover from years of sustained deer browsing. A model was proposed for incorporating multiple factors to consider when restoring eastern white pine in the northern Lake States region.

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

A 125-year-old eastern white pine (*Pinus strobus* L.) stand in Minnesota was thinned to target residual basal areas of 18.4, 23.0, 27.5, and 32.1 m^2/ha. Permanent sample plots were set up in each treatment before thinning. Repeated measurements were taken during the next 43 years. The greatest total volume production and the greatest number of large-diameter trees occurred in the unit of highest residual density. Little or no eastern white pine regeneration occurred in this stand regardless of overstory density. By maintaining relatively high stand densities, large trees and high volume yields could be obtained.

31 Andrews, J.A.; Johnson, J.E.; Torbert, J.L.; Burger, J.A.; Kelting, D.L. 1998. Minesoil and site properties associated with early height growth of eastern white pine. J. Environ. Qual. 27:192–199.

The performance of eastern white pine (*Pinus strobus* L.) established on reclaimed mine lands was assessed as well as soil and site properties associated with early tree growth. Seventy-eight distinct eastern white pine plantations were selected, planted five to nine years previously across 14 reclaimed mines. In each plantation, one fixed area plot between 0.02 and 0.04 ha was established randomly. On each plot, all trees were sampled and a soil profile description was completed. Soil and foliar samples were collected and analyzed. The number of eastern white pine found ranged from 193 to 2868 trees per hectare. Eastern white pine was not the most abundant species in all plots. When all plots were averaged, 13 times more sourwood (*Oxydendrum arboreum* (L.) DC.) and 3 times more red maple (*Acer rubrum* L.) were present than eastern white pine. Rooting depth, electrical conductivity, surface soil P and Mn, and slope were the dominant independent soil/site variables. Height growth was related strongly to rooting depth and it was greater on steeper slopes, which is normally not the case in natural stands. Soil and site properties could be influenced when conducting reclamation work, as long as the minesoil properties that most influence tree growth are understood. This study supports earlier conclusions that rooting depth, electrical conductivity, and soil P were minesoil properties most closely associated with height growth of 10-year-old eastern white pines.

32 Arain, M.A.; Restrepo-Coupe, N. 2005. Net ecosystem production in a temperate pine plantation in southeastern Canada. Agric. For. Meteorol. 128:223–241.

The CO_2 and water vapor fluxes were investigated in a 65-year-old temperate eastern white pine (*Pinus strobus* L.) plantation in southern Ontario. Daily and seasonal dynamics of CO_2 were described, and the relationship between net ecosystem productivity and environmental variables explored. Planted and natural conifer forests were compared to improve understanding of their responses to environmental, physical, and physiological variables. A linear relationship was found between monthly carbon uptake and water loss. The differences in carbon uptake among plantations and between plantations and natural conifer forests were largely due to physical and physiological differences among stands.

33 Averill, R.D.; Wilson, L.F.; Fowler, R.F. 1982. Impact of the redheaded pine sawfly (Hymenoptera: Diprionidae) on young red pine plantations. Gt. Lakes Entomol. 15:65–91.

The impact of the redheaded pine sawfly (*Neodiprion lecontei* Fitch) was assessed in young red pine (*Pinus resinosa* Ait.) plantations. Data were recorded in three red pine plantations in Michigan that were infested with the redheaded pine sawfly during the 1968–1973 outbreak. The primary objectives of the study were (1) to identify the major environmental factors that influenced behavior and survival, (2) to develop a basic ecological model of redheaded pine sawfly impact on red pine, (3) to identify various land management options, and (4) to propose guidelines for managing this sawfly in red pine plantations. The ecological model was structured on the differences among three site class variations, and considered the major interrelations among the insect, the tree, and the environment. Redheaded pine sawflies preferred trees under moisture stress, and therefore damage was most severe in stands where there was competition from bracken fern or hardwoods and where soils were too moist, too shallow, or too compacted. Further, outbreaks were correlated to years of lower than average rainfall. Redheaded pine sawflies attacked the least productive trees in a stand, thus their effects on timber production were limited. Preventive redheaded pine sawfly management involved proper site selection for planting red pine.

34 Bailey, R.E.; Ahearn, P.J. 1981. A late- and postglacial pollen record from Chippewa Bog, Lapeer Co., MI: further examination of white pine and beech immigration into the central Great Lakes region. Pages 53–74 *in* R.C. Romans, ed. Geobotany conference II, Bowling Green State University, Bowling Green, Ohio, 1 March 1980. Plenum Press, New York, NY. 263 p.

Pollen studies of lakes and bog sediments provide a better understanding of vegetation development since the last glaciation in northeastern North America. Chippewa Bog in the eastern half of Michigan's Lower Peninsula was selected as a study site. In June 1977, 5-cm-diameter sediment cores were collected from near the center of the bog mat, and pollen types were determined. A total of 48 pollen types were encountered within 4 pollen assemblage zones that began about 10 500 years earlier. Jack (*Pinus banksiana* Lamb.) and red pine (*P. resinosa* Ait.) were not present in significant quantities until about 8700 years ago. Eastern white pine (*P. strobus* L.) was not a major component of the pine forest and not present in sufficient quantities until about 8700 years earlier. The source of Chippewa Bog local eastern white pine may have been from the east, whereas its migration into much of the central Great Lakes was probably from the south.

35 Baldwin, D.J.B.; Godchalk, H.G.; Perera, A.H.; Mooney, B.P. 1994. GRASP: A GIS-based ranking system for red and white pine forests in Ontario. Rep. No. 15. OMNR, OFRI, Forest Landscape Ecology Program, Sault Ste. Marie, ON. 73 p.

A GIS database of eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.) stands was compiled for the

Great Lakes–St. Lawrence forest of Ontario. The eastern white, red, and mixed-pine data included more than 6000 stands, all at least 50 years old and with a minimum of 10% canopy cover in a mixed forest. Many different stand attributes for each stand were contained in the database and include interior, isolation, disturbance, remoteness, soils, and biophysiographic conditions. A user-friendly self-contained software package, GRASP (GIS-based Ranking System for Pine), generated a ranking system for the pine areas from criteria set by the user.

36 Balmer, W.E.; Williston, H.L. 1983. Managing eastern white pine in the Southeast. Forestry Rep. R8-FR1. USDA For. Serv., Southern Region, Atlanta, GA. 11 p.
This report focused on eastern white pine (*Pinus strobus* L.) growing in the southern part of its natural range. Eastern white pine had a remarkable growth rate compared with other pine and hardwood species. Best growth occurred on imperfectly drained, alluvial soils along rivers and streams. Although growth was slower on well-drained soils, eastern white pine competed successfully with Virginia (*P. virginiana* Mill.) and pitch pine (*P. rigida* Mill.), and diameter growth rates surpassed all other associated species on all soils. Eastern white pine proved to do well under intensive management. After five growing seasons, underplanted eastern white pines were two thirds as tall as eastern white pines planted on a clearcut site.

37 Barret, J.P.; Alimi, R.J.; McCarthy, K.T. 1976. Growth of white pine in New Hampshire. J. For. 74:450–452.
Information on the growth characteristics of well-stocked, even-aged eastern white pine (*Pinus strobus* L.) stands in New Hampshire was presented to reassess the prospects for this timber species. Two data sets were studied: one from 196 plots measured around 1900, and one set from 85 plots measured between 1960 and 1964. Plots ranged from 0.02 to 0.08 ha and were in nearly pure eastern white pine stands that were undisturbed for at least the past 15 years. Diameter and height growth slowed with increasing age. Both data sets indicated that a high level of mean annual growth could be maintained even in stands that were approaching 90 years. Two major conclusions from the data sets were that growth rates were high, largely because of the high density of natural eastern white pine stands, and growth rates were sustained throughout a long period of time (90 years).

38 Barrett, J.P.; Goldsmith, L.J. 1973. Predicting growth of eastern white pine. Bull. 499. New Hampshire Agric. Exp. Stn., Durham, NH. 28 p.
This study was set up to provide information for foresters on even-aged, extensively managed eastern white pine (*Pinus strobus* L.) stands. A total of 65 semipermanent field plots in pure eastern white pine stands (eastern white pine makes up at least 80% of the basal area) were measured four times at three-year intervals and for each site; soil-site descriptions were recorded. Site index, cubic-foot volume, board-foot volume, cubic-foot growth, board-foot growth, and mortality could be predicted for eastern white pine in southern and central New Hampshire by using the tables, formulas, and graphs presented. The amount of available moisture as measured by drainage class was found to be the most important site factor influencing tree growth.

39 Barse, R.G.; Laidly, P.R. 1980. Wood specific gravity of plantation red pine little affected by spacing. Res. Note NC-251. USDA For. Serv., North Central For. Exp. Stn., St. Paul, MN. 2 p.
A 23-year-old red pine (*Pinus resinosa* Ait.) plantation planted on a good site in northwestern Wisconsin included four spacings of 1.5 × 1.5 m, 2.1 × 2.1 m, 2.7 × 2.7 m, and 3.4 × 3.4 m to determine the effects of spacing on wood specific gravity. Six trees were sampled from each tree spacing. The spatial distribution of trees had a considerable effect on stem diameter growth but had little effect on the specific gravity of wood.

40 Basham, J.T.; Morawski, Z.J.R. 1964. Cull studies: the defects and associated basidiomycete fungi in the heartwood of living trees in the forests of Ontario. Publication No. 1072. Department of Forestry, Ottawa. 69 p.
Mycological and pathological results of a cooperative study on heartwood defects of fungal origin in the principal commercial tree species of Ontario were presented. Surveys took place between 1947 and 1957 using 816 plots that were 0.05 ha. Almost 95% of the defects encountered in eastern white pine (*Pinus strobus* L.) were white pocket rot and incipient red rot, both caused by the fungus *Phellinus pini* (Brot. : Fr.) A. Ames. Defects in eastern white pine were generally not abundant in stands younger than 120 years but developed rapidly thereafter. Red pine (*P. resinosa* Ait.) was considered one of the least defective of the commercially important tree species in Ontario, with only 1% of the total merchantable volume defective. White pocket rot was the defect most commonly found in red pine.

41 Beaulieu, J.; Plourde, A.; Daoust, G.; Lamontagne, L. 1996. Genetic variation in juvenile growth of *Pinus strobus* in replicated Quebec provenance–progeny tests. For. Gen. 3:103–112.
Patterns of genetic variation among and within provenances were examined for growth traits in eastern white pine (*Pinus strobus* L.). Two hundred and sixty-six families

from 67 provenances in the natural range of eastern white pine were tested using a randomized complete block design with 20 blocks, with each family represented by a four-seedling row plot. After four years in a nursery, heights were measured and the trees were planted on three test sites in Quebec. After 6 years, the 10-year height was measured. Various differences among and within provenances were revealed. Selection at an early stage of the best families and breeding work would make it possible to genetically improve eastern white pine. A gain of 7.5% in 10-year height could be expected, but a longer term follow-up study was recommended to confirm whether this gain could be maintained until rotation age.

42 Beaulieu, J.; Simon, J.-P. 1994a. Genetic structure and variability in *Pinus strobus* in Quebec. Can. J. For. Res. 24:1726–1733.

The genetic diversity in 10 eastern white pine (*Pinus strobus* L.) populations from southern Quebec was determined from allozyme variants of 18 loci coding 12 enzyme systems by collecting seed from 30 sexually mature trees in each stand. The stands ranged from large populations to small sparsely located populations with an average age ranging from 90 to 110 years. Eastern white pine populations from the Ottawa River region and Anticosti Island had greater genetic diversity than populations from the St. Lawrence lowlands. Breeding, genetic conservation, or tree improvement programs in Quebec should derive their seed sources mainly from the Ottawa River region or Anticosti Island because of the higher level of genetic variability.

43 Beaulieu, J.; Simon, J.-P. 1994b. Inheritance and linkage relationships of allozymes in *Pinus strobus* L. Silvae Genet. 43:253–261.

Relatively few studies on isozyme variation had been conducted on eastern white pine (*Pinus strobus* L.). This study reported on the inheritance and linkage of 18 loci from 12 enzyme systems of eastern white pine from 10 natural populations in Quebec. The loci were analyzed by cellulose acetate electrophoresis using megagametophyte haploid tissue. Segregation ratios for pooled data showed that 14 of the 15 polymorphic loci conformed to Mendelian expectations. Chi-square statistics did not reject the hypothesis of independent segregation for any pair of loci.

44 Beaulieu, J.; Simon, J.-P. 1995. Mating system in natural populations of eastern white pine in Quebec. Can. J. For. Res. 25:1697–1703.

The mating systems of two natural populations of eastern white pine (*Pinus strobus* L.) in Quebec were studied. The populations contrasted in density (2000 trees per hectare and 250 trees per hectare) and age (110 years old and 55 years old). Cones were collected from 30 trees bearing mature cones in each population. Single- and multilocus outcrossing rate estimates were acquired from four polymorphic enzyme loci by means of open-pollinated progeny data. The study suggested the possible absence of self-fertilization but also implied the presence of a family structure favoring inbred mating.

45 Bebber, D.P.; Cole, W.G.; Thomas, S.C.; Balsillie, D.; Duinker, P. 2005. Effects of retention harvests on structure of old-growth *Pinus strobus* L. stands in Ontario. For. Ecol. Manag. 205:91–103.

The effects of a structural retention harvest were examined in old-growth eastern white pine (*Pinus strobus* L.) stands. During a 1992 harvest in Algoma Forest, Ontario, cavity-trees, snags, and coarse woody debris were conserved in an effort to maintain old-growth forest characteristics. Twelve logged and six unlogged stands were surveyed, and plots established in 2001. Stands consisted of a supercanopy of eastern white pine over a mixed conifer–hardwood canopy. Basal area, ground cover, regeneration, and woody debris were assessed. The outcomes demonstrated that structural retention harvesting could maintain or increase levels of habitat, but increased tree mortality and windthrow could also result.

46 Bebber, D.P.; Thomas, S.C.; Cole, W.G.; Balsillie, D. 2004. Diameter increment in mature eastern white pine *Pinus strobus* L. following partial harvest of old-growth stands in Ontario, Canada. Trees 18:29–34.

Increment cores were measured to determine how mature eastern white pine (*Pinus strobus* L.) respond to release from competition. Nine years after release, 12 harvested and 6 control old-growth eastern white pine stands were selected in central Ontario. At 89 points in the harvested and 55 points in the control stands, increment cores were taken from which ring widths were measured. The cores showed increased diameter growth of individual trees in thinned plots, which was first detectable three years after harvest and increased through at least eight years after harvest. The diameter growth response of old-growth eastern white pine might increase their wind firmness.

47 Becker, C.A.; Mroz, G.D.; Fuller, L.G. 1987. The effects of plant moisture stress on red pine (*Pinus resinosa*) seedling growth and establishment. Can. J. For. Res. 17:813–820.

The effects of moisture stress on survival and growth of 2+0 and 3+0 bare-root and 1+0 containerized red pine (*Pinus resinosa* Ait.) planting stock were assessed to evaluate which stock types were most resistant to top and root growth suppression by drought. A nested factorial

design with four replicates was set up to test five different watering levels yielding a total of 300 seedlings planted in pots. Moisture stress was measured weekly. Seedlings were measured after three months including shoot elongation, stem diameter growth, needle elongation, and bud development. Plant moisture stress reduced red pine seedling growth and survival significantly. Overall, the 2+0 stock performed better across the range of watering regimes tested.

48 Beckwith, A.F.; McNeice, W.S. 1978. Guides to growth in red pine plantations. Pages 141–164 *in* D.A. Cameron, comp. White and red pine symposium, Chalk River, ON, 20–22 September 1977. Symposium Proceedings O-P-6. Department of Evironment, Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. 178 p.

Growth and yield tables for red pine (*Pinus resinosa* Ait.) stands were developed from data on permanent sample plots located in red pine stands throughout Ontario. The same data were used to develop a practical marking guide that could be used in thinning prescriptions. The objective of the thinning guide was to produce stands from which an optimum number of large poles could be cut with a residual stand that provided for a full range of management options.

49 Beckwith, A.F.; Roebbelen, P.; Smith, V.G. 1983. Red pine plantation growth and yield tables. For. Res. Rep. No. 108. OMNR, Maple, ON. 70 p.

Growth and yield tables for red pine (*Pinus resinosa* Ait.) plantations were presented from data from over 30 years of remeasurements of 87 permanent sample plots in Ontario. Five tables were presented with a description for each table: present yield, normal yield of unthinned stands, projected yield for thinned and unthinned stands, individual tree volume, and site index. The tables could be applied to 20–60-year-old plantations with an initial spacing of 1.7 × 1.7 m to 2.3 × 2.3 m in Ontario site regions 5E and 6E.

50 Belli, K.L.; Ek, A.R. 1988. Growth and survival modeling for planted conifers in the Great Lakes Region. For. Sci. 34:458–473.

A general model framework for the early growth and survival of planted conifers was constructed. White spruce (*Picea glauca* (Moench) Voss) and red pine (*Pinus resinosa* Ait.) data were used for initial model development, and modeling efforts were restricted to the first five years after planting. Sixty-four publications on red pine and white spruce plantation experimental results were summarized in the database, which consisted of 527 records for red pine and 451 for white spruce. The database was used to examine the relationships between variables such as species, stock type, age class, site preparation category, lifting date, planting date, previous stand type, and reported average performance of planted trees. Two comparable growth estimation functions were derived from the database, which accommodated averages of either annual stem height increment or total cumulative stem height. A single average-survival function was derived as well. Because the framework was based on plantation averages, it should not be interpreted as providing precise predictions of performance for any particular site.

51 Bennett, K.P.; Desmarais, K. 2003. Managing white pine in a new millennium. Workshop proceedings, Caroline A. Fox Research Forest, Hillsborough, NH, 9–10 October 2003. 78 p.

This workshop and its proceedings of 16 short papers were designed to disseminate the latest information about eastern white pine (*Pinus strobus* L.) management, measurement, health, and regeneration in the northeastern United States. About 10% of the New England forests were classified as in the eastern white–red pine (*P. resinosa* Ait.) group, and the majority were in timber-size stands. Eastern white pine logs generally yielded a small percentage of high-grade lumber. Methods of inventory and managing eastern white pine stocking were discussed, and the importance of eastern white pine, particularly large eastern white pine, for wildlife habitat was described. The use of prescribed burning and other site preparation and tending methods were examined as well as various silvicultural approaches for improving the quality of eastern white pine.

52 Benzie, J.W. 1977. Red pine in the north central States. Gen. Tech. Rep. NC-33. USDA For. Serv., North Central For. Exp. Stn., St. Paul, MN. 22 p.

This handbook provided information for managers of red pine (*Pinus resinosa* Ait.) plantations in the Lake States with an emphasis on timber production. Management objectives that were discussed included plantation establishment, composition, and growth of red pine stands so that intermediate thinnings would provide useful products and the final harvest would yield high-quality sawtimber and veneer as well as wildlife habitat management, recreational uses, and watersheds. Stocking charts and growth and yield tables were also included.

53 Benzie, J.W.; Alm, A.A. 1977. Red pine seedling establishment after shelterwood-strip harvesting. Res. Note NC-224. USDA For. Serv., North Central For. Exp. Stn., St. Paul, MN. 3 p.

After a shelterwood-strip harvesting in a mature red pine (*Pinus resinosa* Ait.) stand in northeastern Minnesota,

3+0 red pine seedlings, red pine tubelings (10 weeks, 16 weeks, or 1 year old), and untreated red pine seed were planted. After six years, height and survival were determined. Highest survival was obtained with the one-year-old tubelings. Direct seeding had the lowest survival rate with only 3% survival. The 3+0 seedlings were taller than all others, with an average growth of 67 cm after six years. Shelterwood harvesting could be favorable for red pine seedling establishment and early growth, but how long the shelterwood-strips could be left standing before they seriously affected seedling development remained unknown.

54 Benzie, J.W.; Zasada, Z.A. 1972. Shelterwood-strip harvesting pattern with full-tree skidding to regenerate red pine. Res. Note NC-132. USDA For. Serv., North Central For. Exp. Stn., St. Paul, MN. 4 p.

A 100-year-old red pine (*Pinus resinosa* Ait.) stand in northern Minnesota was harvested, alternating 15.2-m-wide clearcut strips and 4.9-m-wide shelterwood strips of mature timber to test a more efficient way to harvest timber while maintaining an attractive forest environment. Removal of all trees in the strips combined with full-tree skidding provided effective site preparation for regeneration by tree planting. Some planting was required to obtain regeneration because the remaining seed trees were not able to provide sufficient seed in poor seed years. Strip cuts allowed for removal of trees in the final cut without damaging the adjacent residual trees.

55 Bergeron, Y.; Brisson, J. 1990. Fire regime in red pine stands at the northern limit of the species' range. Ecology 71:1352–1364.

Frequency, extent, and intensity of fires affecting red pine (*Pinus resinosa* Ait.) populations on islands and peninsulas of Lake Duparquet in northwestern Quebec at the northern limit of the species' range were studied to define the fire regime in red pine stands in this region. The fire regime appeared to be controlled by abiotic conditions. As well, high-frequency fires of variable intensity appeared to affect primarily xeric sites, and the past fire regime allowed for the self-maintenance of the red pine populations. The fire regime found in these stands was similar to those described for other areas in the range.

56 Bergeron, Y.; Gagnon, D. 1987. Age structure of red pine (*Pinus resinosa* Ait.) at its northern limit in Quebec. Can. J. For. Res. 17:129–137.

The age structure and fire history of northern red pine (*Pinus resinosa* Ait.) populations, which are restricted to lake landscapes in northwestern Quebec, were investigated to determine the mechanisms controlling the long-term maintenance of red pine at the northern limits of its distribution. Twenty-two red pine populations in the Lake Duparquet area were selected randomly. Diameter at breast height and heights were measured, fire scars were recorded, and increment cores were taken for each tree. The combined structure of the populations was balanced and uneven-aged, with two periods of increased recruitment (1805–1864 and 1925–1974). Two mechanisms responsible for red pine maintenance could be distinguished: self-regeneration of populations resistant to fires on xeric sites, and the transitory colonization of mesic sites by populations susceptible to lethal fires and established from distant seed sources. Red pine populations were probably restricted to sites protected by natural firebreaks provided by the local landscape.

57 Bergeron, Y.; Leduc, A.; Ting-Xian, L. 1997. Explaining the distribution of *Pinus* spp. in a Canadian boreal insular landscape. J. Veg. Sci. 8:37–44.

The distribution of jack (*Pinus banksiana* Lamb.), red (*P. resinosa* Ait.), and eastern white pine (*P. strobus* L.) was evaluated among xeric sites located on 117 islands in Lake Duparquet in the southern boreal forest of Quebec to determine the respective contributions of habitat, fire regime, and colonization–extinction processes. A random subsample of 49 islands was used for assessing tree composition and fire history with 81 quadrats, each 10×10 m, distributed in xeric portions of the selected islands. All pine (*Pinus* spp.) species were more frequent on large islands with large xeric areas, but their distribution appeared unstructured. Pine were possibly more abundant on islands with characteristics that promote lightning strikes and thus higher fire occurrence. Red pine showed a more aggregated distribution between the islands than other species. The distribution of eastern white pine was related mainly to the shortest distance to the lakeshore combined with altitude. Eastern white pine had a somewhat similar distribution as red pine, but it did not show as much clumping.

58 Berglund, J.V.; Leaf, A.L.; Leonard, R.E. 1976. Red pine foliage variation and field sampling intensity. Can. J. For. Res. 6:268–280.

Spatial variation, temporal variation, and treatment-induced variation were evaluated for their within-population effects on determining field sampling intensity or sample size. Because of temporal and spatial variation, past experience may be inadequate to determine sample size for foliage characteristics. Past experience can serve as a guide, and then allowable error and level of probability can be calculated to determine the constraints on current foliage sampling. Treatments tended to induce heterogeneity of variance of foliar measurements, increasing the number of samples required.

59 Berry, A.B. 1965. Effect of heavy thinning on the stem form of plantation-grown red pine. Publication No. 1126. Department of Forestry, Ottawa. 16 p.

A 13-year-old red pine (*Pinus resinosa* Ait.) plantation at Petawawa, Ontario, with 2.1×2.1 m spacing was thinned to 4.3×4.3 m spacing to determine the effects of thinning on stem growth. Measurements were taken every five years after treatment. At 19 years after thinning, diameter growth had increased, resulting in a change in stem form and increased taper. Form class, the ratio of diameter at half-height above breast height to diameter at breast height, remained relatively constant, but height growth was reduced for a short period following thinning.

60 Berry, A.B. 1971. Stem form and growth of plantation red pine 30 years after heavy thinning. Department of the Environment, Canadian Forestry Service, Petawawa For. Exp. Stn., Chalk River, ON. Information Report PS-X-24. 6 p.

Two red pine (*Pinus resinosa* Ait.) plantations at Petawawa, Ontario, were established with trees planted at 2.1×2.1 m spacing. One plantation was thinned to a spacing of 4.3×4.3 m at age 13, and one plantation was left unthinned. Thinning results were presented for up to age 42 and showed that additional growing space permitted the development of longer and wider crowns and larger diameters. The trees in the thinned stand also continued to increase in form class and had stem volumes more than twice the size of those in the untreated stands. Earlier production of sawlogs could be achieved by growing much larger individual stems through early thinning.

61 Berry, A.B. 1977. Metric yield tables based on site class and spacing for unthinned red pine plantations at the Petawawa Forest Experiment Station. Department of the Environment, Canadian Forestry Service, Petawawa For. Exp. Stn., Chalk River, ON. Information Report PS-X-65. 17 p.

Yield tables for high survival unthinned red pine (*Pinus resinosa* Ait.) plantations compiled and presented in this report were from data on 56 permanent sample plots in 31 red pine plantations located at Petawawa, Ontario. The tables presented in metric units include data from 20 to 50 years from planting by 5-year age classes for eight spacings and five site index classes. Site index curves were also presented.

62 Berry, A.B. 1982. Response of suppressed conifer seedlings to release from an aspen-pine overstorey. For. Chron. 58:91–92.

In this unreplicated study, the response of three conifers, eastern white pine (*Pinus strobus* L.), red pine (*P. resinosa* Ait.), and white spruce (*Picea glauca* (Moench) Voss), to release after 27 years of suppression under a mature aspen (*Populus* spp.)–pine stand was evaluated at Petawawa, Ontario. The conifers responded well to release even after such a prolonged period of suppression. The study suggested that dense sprouting of aspen suckers did not severely hinder the initial growth of conifers with well-developed root systems, and the aspen suckers might even be beneficial to eastern white pine because they provided protection from the white pine weevil (*Pissodes strobi* (Peck)). A release treatment later in stand development once aspen canopy closure starts to occur might be necessary because of diminished conifer height growth and whipping damage to pine leaders as they penetrated the hardwood canopy.

63 Berry, A.B. 1984. Volume and biomass yield tables for unthinned red pine plantations at the Petawawa National Forestry Institute. Department of Agriculture, Canadian Forestry Service, Petawawa National Forestry Institute, Chalk River, ON. Information Report PI-X-32. 27 p.

Yield tables for unthinned red pine (*Pinus resinosa* Ait.) plantations were presented from data on 31 plantations located at Petawawa, Ontario. Spacings included in the study ranged from 1.2×1.2 m to 4.3×4.3 m, and the principal soils were loamy or sandy tills and waterlaid sands. The tables presented data from 20 to 60 years from planting by 5-year age classes for eight spacings and five site index classes. Biomass data were included as well.

64 Bérubé, J.A. 1996. Use of triadimefon to control white pine blister rust. For. Chron. 72:637–638.

In a greenhouse experiment, the use of triadimefon was studied for two growing seasons on eastern white pine (*Pinus strobus* L.) seedlings as a means of controlling white pine blister rust (*Cronartium ribicola* J.C. Fischer). A total of 132 seedlings divided into 4 groups of 33 were sprayed two weeks before inoculation with a triadimefon mixture, and 132 seedlings were used as controls. During the second growing season, 70% of the untreated control group exhibited white pine blister rust symptoms, whereas only 4% of the treated seedlings showed symptoms of white pine blister rust, and only needle spots were found. The use of triadimefon in the field for the first five years (most lethal infections occur in the first five years) after planting might offer an effective means of reducing lethal white pine blister rust cankers on the stem.

65 Best, G.R; Monk, C.D. 1975. Cation flux in hardwood and white pine watersheds. Pages 847–861 *in* F.G. Howell, J.B. Gentry, and M.H. Smith, eds. Mineral cycling in southeastern ecosystems. Symposium proceedings, Augusta, Georgia, 1–3 May 1974. ERDA Symposium Series. 898 p.

The flux of dissolved cations (K, Na, Ca, Mg) was followed from input of ions in rainfall to output of ions from the forest watershed in stream discharge. The study took place in two communities: a mature hardwood forest and an eastern white pine (*Pinus strobus* L.) plantation, both in southwestern North Carolina. Nutrient concentrations were measured in precipitation input, throughfall, litterflow through soil percolation, and stream discharge. Nutrient flux was calculated from measurements of ion concentration and solution volumes. Amounts of water changed markedly from input to output, and leaching of cations from vegetation showed seasonal changes. The total leachate loss from vegetation was greatest for potassium and least for sodium; magnesium and calcium losses were intermediate. The cation load was similar to its original input level, giving evidence of the ability of the ecosystem to minimize external loss while maintaining a large internal flux.

66 Beverly, J.L.; Martell, D.L. 2003. Modeling *Pinus strobus* mortality following prescribed fire in Quetico Provincial Park, northwestern Ontario. Can. J. For. Res. 33:740–751.

A logistic regression model was presented for predicting eastern white pine (*Pinus strobus* L.) mortality after a prescribed surface fire as a function of tree, fire, and fuel characteristics. The model was based on a 10-month evaluation after a prescribed surface fire in Quetico Provincial Park, Ontario, which was ignited to reduce fire hazard. Data were collected from 176 trees and they included tree status, diameter, and height. Postfire mortality was relatively low—17% of eastern white pine trees or 10% of eastern white pine volume. Highest mortality was among trees <10 cm diameter at breast height (dbh); eastern white pine with a dbh of >20 cm were highly resistant to intense surface fires. The model could be applied in eastern white pine stands with a mixedwood understory in the Great Lakes–St. Lawrence forest region of Ontario.

67 Beverly, J.L.; Martell, D.L. 2004. Modeling prescribed surface-fire regimes for *Pinus strobus* conservation. Conserv. Biol. 18:1541–1552.

Natural and optimal eastern white pine (*Pinus strobus* L.) fire-management practices were compared using a simple stochastic simulation model. Many different fire regimes were modeled and tested for the maximum stand structural diversity they provided. Intermediate levels of fire disturbance resulted in the highest alpha diversity. The use of natural versus optimal fire-management practices would depend on conservation goals such as promoting natural ecosystem processes or ensuring the persistence of a particular species. The authors discussed the trade-offs between stochastic versus fixed-interval fire schedules. When stochastic simulations were used, maximum structural diversity occurred at a 40-year mean fire interval, whereas fires that were scheduled at fixed intervals showed a longer, 100-year return interval to maximize diversity.

68 Bevilacqua, E.; Puttock, D.; Blake, T.J.; Burgess, D. 2005. Long-term differential stem growth responses in mature eastern white pine following release from competition. Can. J. For. Res. 35:511–520.

The long-term growth response of eastern white pine (*Pinus strobus* L.) was examined after their release from a hardwood overstory. The study consisted of several eastern white pine–mixedwood stands in the Cartier Lake Silvicultural Area at Petawawa, Ontario. Partial harvesting was completed in fall 1971 creating released eastern white pine and control treatment areas. In 1995, 88 eastern white pine trees of three dominance classes (emergent, intermediate, and dominant) were harvested and sampled destructively. Growth and growth allocations were reconstructed for each tree characterizing the 23-year postrelease period using detailed stem analysis. Pines in all dominance classes showed significant increases in diameter, basal area, and volume increment after release compared with control trees. Midrotation eastern white pine with previous suppressed growth due to competition responded to release.

69 Beyeler, J. 1995. Regeneration following white pine shelterwood cuts in Shelburne Co., N.S. Res. Rep. No. 57. Cooperation Agreement for Forestry Development, Nova Scotia Department of Natural Resources, Truro, NS. 12 p.

Five eastern white pine (*Pinus strobus* L.) stands in Shelburne County, southwestern Nova Scotia, were partially harvested using a shelterwood system. Regeneration surveys were conducted from 1.5 through 7.5 years after treatment to determine the success of eastern white pine regeneration. An overview was given for each stand and it included stand description, photographs, and regeneration data. Shelterwood cuts were successful in the natural regeneration of eastern white pine, but the regeneration was overtopped by red maple (*Acer rubrum* L.) and balsam fir (*Abies balsamea* (L.) Mill.). These stands could be managed for quality sawtimber in future.

70 Bilgili, E. 2002. Stand development and fire behavior. For. Ecol. Manag. 179:333–339.

A fuel model based on stand fuel properties was developed to quantify and explain the effects of stand development and silvicultural techniques on fire behavior. The stands used for model development were red pine (*Pinus*

resinosa Ait.) and white spruce (*Picea glauca* (Moench) Voss) plantations. Rate of speed for a fire increased with the increase in crown fuels, especially when the crown base was low. All fire behavior properties were strongly related to fuel characteristics. Fire behavior in thinned stands was similar to unthinned stands, except for sharp changes in fuel loads. This study provided insight into fire behavior in other forest types and age classes. Trends in fire behavior properties were discussed regarding stand and fuel characteristics.

71 Binkley, D.; Valentine, D. 1991. Fifty-year biogeochemical effects of green ash, white pine and Norway spruce in a replicated experiment. For. Ecol. Manag. 40:13–25.

The effects of different tree species on soil chemistry and ecosystem biogeochemistry were studied in Connecticut. Fifty years ago, 120-m^2 plots were planted in a checkerboard replicated pattern to compare species response in an abandoned agricultural field with either green ash (*Fraxinus pennsylvanica* var. *subintegerrima* (Vahl) Fern.), eastern white pine (*Pinus strobus* L.), or Norway spruce (*Picea abies* (L.) Karst). Mineral soil samples were taken to a depth of 15 cm. Net nitrogen mineralization was assessed by the resin core method, and litterfall was collected and analyzed. The pH_{water} of the 0–5-cm soil layer was 4.6 under green ash, 4.2 under eastern white pine, and 3.8 under Norway spruce. This study demonstrated that the strength of the soil acids between species was the most important factor contributing to the differences in soil pH.

72 Black, B.A.; Abrams, M.D. 2005. Disturbance history and climate response in an old-growth hemlock–white pine forest, central Pennsylvania. J. Torrey Bot. Soc. 132:103–114.

The historical development, disturbance history, and climate response were investigated in relation to radial growth in an old-growth eastern hemlock (*Tsuga canadensis* (L.) Carrière) forest in Schall's Gap, central Pennsylvania. Twenty plots were set up, and species, diameter at breast height, and crown class were recorded for all trees >8 cm in diameter. Two to four trees from each plot were selected randomly and cored for radial-growth analysis. Some additional trees of exceptional age from outside the plots were also cored and analyzed. Eastern hemlock was dominant in all diameter and crown classes, whereas eastern white pine (*Pinus strobus* L.) had limited distribution, occurring only as dominant individuals with diameters between 40 and 70 cm. Eastern white pine formed an even-aged cohort developed during a narrow time interval between 1865 and 1870. No eastern white pine seedlings or saplings were present in the study area. Recent small and localized disturbances were insufficient to create any new eastern white pine regeneration.

73 Blankenship, B.A.; Arthur, M.A. 1999. Prescribed fire affects eastern white pine recruitment and survival on eastern Kentucky ridgetops. South. J. Appl. For. 23:144–150.

Successful fire prevention efforts in eastern Kentucky resulted in a decline of fire-tolerant species such as oak (*Quercus* spp.), yellow pine (*Pinus echinata* Mill.), and pitch pine (*P. rigida* Mill.) and led to an abundance of eastern white pine (*P. strobus* L.) regeneration. This study examined the effects of prescribed fire on understory eastern white pine in oak–pine ridgetop ecosystems. Three noncontiguous ridgetops on the Cumberland Plateau were selected, each divided into three treatments: one burned in March 1995, one burned in March 1996, and one left unburned as a control. Oaks dominated the overstories on the three ridges, with red maple (*Acer rubrum* L.) abundant in the midstory. A few large eastern white pines were found in the overstory. Eastern white pine was plentiful as regeneration and at times dense in the understory and midstory. Two growing seasons after the fires, 95–100% of the eastern white pine stems <2 cm diameter at breast height (dbh) had died and 72–90% of all eastern white pine stems had died. Significant mortality was measured in size classes up to 6 cm dbh. An abundance of postburn eastern white pine regeneration was found on each site. The age structure of eastern white pine was affected by the prescribed burn, but a single burn will have limited influence on the long-term species composition of these stands. To control eastern white pine competing with other fire-adapted species, a fire return interval of at least 10–20 years would be required.

74 Blodgett, J.T.; Herms, D.A.; Bonello, P. 2005. Effects of fertilization on red pine defense chemistry and resistance to *Sphaeropsis sapinea*. For. Ecol. Manag. 208:373–382.

The effects of fertilization on *Sphaeropsis sapinea* (Fr. : Fr.) Dyko & B. Sutton development and the chemical defense response in red pine (*Pinus resinosa* Ait.) were investigated. Twenty trenched and lined soil plots each containing one 13-year-old red pine were established at the Ohio Agricultural Research and Development Center, USA. Fertilizer was applied at 200 kg $N \bullet ha^{-1} \bullet year^{-1}$ using 18-5-4 N-P-K, which was applied to half of the trees starting in spring 1998. Branch tips wounded by *S. sapinea* were inoculated with the pathogen in May 2001 and assessed four weeks later. Fertilization decreased the resistance of red pine to *S. sapinea* and suggested that lignin and soluble phenolics might be involved in host defense.

75 Bockheim, J.G.; Leide, J.E. 1986. Litter and forest-floor dynamics in a *Pinus resinosa* plantation in Wisconsin. Plant Soil 96:393–406.

Litter and forest-floor dynamics in a 34-year-old red pine (*Pinus resinosa* Ait.) plantation with 2×2 m spacing in Wisconsin were determined using (1) leaf-litter bags, (2) litter-fall and forest-floor data and an exponential decay function, and (3) a preliminary nutrient mass balance equation. The half-life of decomposing red pine leaf litter was 2.6 years, whereas the half-life of dry matter in the forest floor was 4.7 years. Half-life of dry matter and nutrients in the forest floor ranged from 0.5 for K to 39 for Al. The release of macronutrients in decomposing leaf litter was K > Mg > P, S > N > Ca. A forest-floor nutrient balance sheet confirmed that the macronutrients N and Ca are accumulating most in the forest floor, but Mg, S, and K showed either net losses or no change.

76 Bockheim, J.G.; Leide, J.E.; Frelich, L.E. 1989. Red pine growth and chemical composition of foliage and forest floors across a precipitation-chemistry gradient in Wisconsin. Can. J. For. Res. 19:1543–1549.

One approach of investigating acidic deposition impacts on forest ecosystems, in the absence of long-term monitoring data, involves evaluating study areas along regional precipitation-chemistry gradients. The objective of this study was to assess recent growth patterns and the chemical composition of current foliage and forest floor in comparable red pine (*Pinus resinosa* Ait.) stands across pH, SO_4^{2-}, and NO_3^- gradients in Wisconsin. Three red pine plantations were selected within 17 km of each of five study sites, which were located across the gradient. Sampling and analyses were completed using standard methods. The within-site growth variation was greater than the among-site growth variation. Further, there were no significant correlations between the tree growth parameters and precipitation chemistry. Consequently, the historical increases in sulfur and nitrogen oxides, at least so far, have not had a measurable effect on red pine production in Wisconsin. This study illustrated the importance and difficulty of selecting a sufficient number of uniform stands across an environmental gradient to ensure that within-site variation was minimized.

77 Bonnor, G.M. 1964. A tree volume table for red pine by crown width and height. For. Chron. 40:339–346.

Because of the availability of better quality aerial photographs, a study was initiated to find the parameters that were measurable or interpretable on large-scale aerial photographs that would give the best prediction of individual tree volumes. Data from 594 red pines (*Pinus resinosa* Ait.) in 23 natural stands were collected at Petawawa, Ontario. Measurements taken included diameter at breast height (dbh), crown width, crown length, and canopy density. A multiple regression analysis showed that crown width and tree height exhibit a good correlation with dbh. On the basis of this relationship, a tree volume table was constructed and tested, and acceptable estimates were achieved using aerial photography.

78 Bormann, F.H. 1965. Changes in the growth pattern of white pine trees undergoing suppression. Ecology 46:269–277.

The phenotypic response of suppressed trees was studied in a 60-year-old, relatively undisturbed eastern white pine (*Pinus strobus* L.) stand on a silty loam soil in New Hampshire. Patterns of height and diameter growth were reconstructed by means of annual ring counts and measurements that were taken with a Baker vernier microscope that allowed for measurements of up to 0.02 mm. The length of internodes on 12 suppressed trees was also measured. The first evidence of suppression was a tree-wide decrease in the production of secondary xylem. Diameter growth decreased while trees were suppressed, whereas height growth was relatively unaffected.

79 Boucher, D.; Lavallée, R.; Mauffette, Y. 2001. Biological performance of the white pine weevil in relation to the anatomy of the resin canal system of four different host species. Can. J. For. Res. 31:2035–2041.

The structure of the vertical resin canal system of four host species, eastern white pine (*Pinus strobus* L.), and Norway (*Picea abies* (L.) Karst.), red (*P. rubens* Sarg.), and white spruce (*P. glauca* (Moench) Voss), were compared, and the relationship between these characteristics and the performance of white pine weevil (*Pissodes strobi* (Peck)) were examined at two locations in southern Quebec (Chaudière-Appalaches region and Outaouais region). These areas had been extensively planted with eastern white pine and white spruce, and weevil attacks were numerous. In the study area, 35 plantations were selected and terminal leaders were harvested to estimate the number of eggs per cavity. Newly attacked leaders were harvested in September to record adult emergence. Cross sections of lateral branches were used to examine resin canals. The anatomy of the resin canal system was principally related to adult mass. The density of inner resin canals was the most important variable related to weevil activity. Eastern white pine was very different from white spruce; it had a low density of very large inner resin canals, which seemed to be favorable for weevil body mass gain.

80 Boucher, D.; Mauffette, Y.; Lavallée, R. 2001. Biological performance of the white pine weevil in different host species and in two ecological regions of southern Quebec. Can. J. For. Res. 31:2026–2034.

The biological performance of the white pine weevil (*Pissodes strobi* (Peck)) on five host species, eastern

white (*Pinus strobus* L.) and jack pine (*P. banksiana* Lamb.), and Norway (*Picea abies* (L.) Karst.), white (*P. glauca* (Moench) Voss), and red spruce (*P. rubens* Sarg.), as well as the relationship between white pine weevil performance and leader dimensions was examined at two ecological regions of Quebec, the Outaouais and the Appalaches regions. A total of 40 plantations were studied. Leaders were harvested in June to estimate the number of eggs per cavity, and in July to follow adult emergence. White pine weevil performance did not differ among regions, but several differences were noted among host species. The number of eggs was greatest on jack pine, eastern white pine, and Norway spruce, compared with white spruce and red spruce. Adults emerging from eastern white pine were the heaviest, and the number of adults per leader was greatest on eastern white pine and Norway spruce. Leader dimensions were correlated with all variables of white pine weevil performance except eastern white pine survival.

81 Boucher, J.-F.; Bernier, P.Y.; Margolis, H.A.; Munson, A.D. 2007. Growth and physiological response of eastern white pine seedlings to partial cutting and site preparation. For. Ecol. Manag. 240:151–164.

This study used a large eastern white pine (*Pinus strobus* L.) field study at Petawawa, Ontario, to test the hypothesis that growth and photosynthetic rate of eastern white pine seedlings increased proportionally to the increase in light availability created by partial cutting. Three 110-year-old pine stands were included with four replicates of three thinning intensities: uncut control, partial cutting to a one-crown spacing between residual trees, and partial cutting to a two-crown spacing between residual trees. Split-plot site preparation treatments were applied using herbicide, scarification, a combination of treatments, or control, and subplots were selected randomly and underplanted with eastern white pine. Seedlings were measured for growth, and morphological and physiological measurements were taken. Maximum relative growth rate was reached at 50% photosynthetic photon flux density for both seedling height and diameter. The silvicultural treatments had no effect on light-saturated photosynthetic rate of current-year foliage or on midday shoot water potential. Soil scarification reduced the abundance of tree competition but stimulated the growth of shrub species. Crown spacing significantly increased both seedling total height and stem diameter. The partial cuts and the herbicide application significantly increased the total dry mass of seedlings. The use of a moderate overstory thinning treatment such as the one implemented in the one-crown spacing treatment was recommended as the best compromise among various biotic and abiotic factors for eastern white pine regeneration.

82 Boucher, J.-F.; Bernier, P.Y.; Munson, A.D. 2001. Radiation and soil temperature interactions on the growth and physiology of eastern white pine (*Pinus strobus* L.) seedlings. Plant Soil 236:165–174.

In an open-sided greenhouse, an experiment was set up to test the influence of soil temperature on the light response of eastern white pine (*Pinus strobus* L.) seedlings. Nine beds of silica sand were created with three light regimes (10, 40, and 80% of full light) and each bed was divided into three subplots with different soil temperatures (16, 21, and 26°C for midday temperatures). Each subplot contained 24 seedlings of which 16 were buffer seedlings. Seedling morphological and physiological variables were measured and analyzed. Significant interactions occurred between light and soil temperature effects on seedling growth and development. This study illustrated the importance of soil temperature on seedling growth and response to increased light availability.

83 Boucher, J.-F.; Munson, A.D.; Bernier, P.Y. 1995. Foliar absorption of dew influences shoot water potential and root growth in *Pinus strobus* seedlings. Tree Physiol. 15:819–823.

The authors tested the hypothesis that foliar absorption of dew increases shoot water potential and influences other water relations variables in eastern white pine (*Pinus strobus* L.). The study was set up in a greenhouse as a 2×3×3 factorial design using two-year-old eastern white pine seedlings with two watering treatments (normal and deficient), three artificial dew treatments (none, once, and three times per week), and three sampling periods (weeks 4, 8, and 10). Seedling growth and water relations were measured using standard procedures. Dew increased shoot water potential, stomatal conductance, and seedling root growth, especially for the seedlings grown under a deficient watering schedule. Because dew can be a frequent microclimatic event in some areas, this finding has practical implications for the water relations of eastern white pine growing under field conditions.

84 Boucher, J.-F.; Wetzel, S.; Munson, A.D. 1998. Leaf level response of planted eastern white pine (*Pinus strobus* L.) seven years after intensive silvicultural treatments. For. Ecol. Manag. 107:291–307.

The impact of intensive silviculture treatments on environmental conditions and leaf level morphology and physiology of seven-year-old planted eastern white pine (*Pinus strobus* L.) saplings was studied at Petawawa, Ontario. A total of 100 eastern white pine seedlings had been planted with 3+0 bare-root stock at 2×2 m spacing following a randomized complete block, split-plot factorial design. Treatments consisted of scarification, vegetation control, fertilization, and a combination of those treatments. The most marked

changes in leaf morphology and physiology of eastern white pine saplings were in response to vegetation control and scarification. Fertilization showed no positive impact on the saplings at this stage of development.

85 Bourdeau, P.F. 1963. Photosynthesis and respiration of *Pinus strobus* L. seedlings in relation to provenance and treatment. Ecology 44:710–716.

To determine whether different responses in photosynthesis and respiration would occur among different provenances of eastern white pine (*Pinus strobus* L.), seed from six provenances in the natural range of eastern white pine were germinated and maintained outdoors. Three years later, six seedlings from each provenance were placed in a heated greenhouse, and another set was kept in a cold frame. Photosynthesis and respiratory rates were measured through CO_2 exchange. Southern ecotypes of eastern white pine are more shade tolerant, but they are less efficient at cold temperatures. Seedlings kept outdoors showed higher rates of photosynthesis. Genetic variability in photosynthetic and respiratory response existed in eastern white pine, but its effects occurred only under specific combinations of treatment and environmental conditions.

86 Bowen, M.G. 1962. Plots one, two and forty-nine: a thinning experiment in white and red pine. Project P-118. Department of Forestry, Ottawa. 35 p.

The effects of three different thinning prescriptions on three 40-year-old red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.) stands at Petawawa, Ontario, were followed from the 1920s to 1959 in three permanent sample plots, PSP 1, 2, and 49. The following treatments were applied: PSP 1 had two heavy thinnings and a harvest cut (cutting 38% of total volume), PSP 49 was lightly thinned three times, and PSP 2 was left unthinned as a control. Nonreplicated results suggested that PSP 49 responded more than the two other PSPs. Annual increment and total yields were greater on PSP 49, where the light thinnings had been effective at reducing mortality and concentrating the growth on the quality stems. PSP 1 developed an understory of balsam fir. The control plot reached maximum basal area at age 60, the moderately cut plot was nearing maximum basal area at age 80, whereas the heavily thinned plot had a low basal area at age 80 (last year of measurement).

87 Boys, J.; Cherry, M.; Dayanandan, S. 2005. Microsatellite analysis reveals genetically distinct populations of red pine (*Pinus resinosa*, Pinaceae). Am. J. Bot. 92:833–841.

An analysis of 500 red pine (*Pinus resinosa* Ait.) trees was presented for 17 populations collected throughout their range. Five polymorphic microsatellite loci with an average of nine alleles per locus were identified. High inbreeding occurred in all the populations studied. The population differentiation was high with 28–35% of genetic variation partitioned among populations. Three northeastern populations were genetically distinct from the other populations. Results could be valuable for understanding the relationship between the plant genetic diversity in relation to geological history and refugial habitats during the Pleistocene era, but also valuable for designing genetically sound conservation and management programs for red pine.

88 Brace, L.G. 1968. Improvement cut in pine mixedwoods. Publication No. 1235. Department of Forestry and Rural Development, Ottawa. 12 p.

In 1939, an improvement cut was completed in 60-year-old eastern white pine (*Pinus strobus* L.)–mixedwood stands at Petawawa, Ontario. This improvement cut favored eastern white pine. It converted the stands from 38 to 76% softwood and removed 35% of the initial stand basal area. Some stands were left unthinned as controls. After 20 years, the average volume increase doubled in the treated stands compared with control stands. Pruning of eastern white pine crop trees caused an increase in lumber value of 14%.

89 Brace, L.G. 1972. Weevil control could raise value of white pine by 25%. Can. For. Ind. 92:42–45.

A total of 264 eastern white pine trees (*Pinus strobus* L.) were studied at Petawawa, Ontario, that ranged in age from 60 to 90 years with diameters of 15–51 cm, heights of 15–33 m, and a wide range of injuries caused by white pine weevil (*Pissodes strobi* (Peck)). The selected trees were felled and subjected to detailed stem analysis to determine stem volume and the degree and location of white pine weevil damage. White pine weevil damage was found responsible for cubic volume losses of 3–21% and 22–63% of board-foot volume losses for trees of 20 cm diameter at breast height. Total value losses from white pine weevil damage were about 25%. Various silvicultural options as well as direct white pine weevil control provide good opportunities for reducing losses.

90 Brace, L.G. 1978. An intermediate cutting in pine mixedwoods. Pages 131–138 *in* D.A. Cameron, comp. White and red pine symposium, Chalk River, ON, 20–22 September 1977. Symposiun Proceedings O-P-6. Department of the Environment, Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. 178 p.

An improvement cut was applied in two-storied pine (*Pinus* spp.) mixedwood stands at Petawawa, Ontario, and five-year results were presented. An average sawlog yield gain of 18.9 m^3/ha in 20 years was projected. Logging

damage resulted in 6% fatal damage to understory residual pine, 14% nonfatal, and 80% undamaged pine, a level that was considered acceptable. The reduction of amenity values in these stands as a result of the improvement cut was minimal and only 2% of a maximum theoretical reduction.

91 Brace, L.G.; Stewart, D.J. 1974. Careful thinning can preserve amenities and increase yield. Pulp and Paper Mag. Can. 75:36–42.

A commercial timber-harvesting operation was conducted at Petawawa, Ontario, to initiate shelterwood management of eastern white pine (*Pinus strobus* L.). The goal was to increase growth and yield of eastern white pine for sawlogs by releasing suppressed pines from a hardwood overstory. Logging damage resulting from the wheeled-skidder system was limited to 20% of the residual trees by careful planning and layout, training, and crew supervision. Sawlog volume gains expected from treating these two-storied mixedwood stands were about 45 and 64 m^3/ha for 20 and 30 years, respectively, following treatment. Such operations could still be profitable, and the forest owner would also realize a net return from future sawlog gains.

92 Braekke, F.H.; Kozlowski, T.T.; Skröppa, T. 1978. Effects of environmental factors on estimated daily radial growth of *Pinus resinosa* and *Betula papyrifera*. Plant Soil 49:491–504.

The relationships between estimated daily radial growth and environmental factors were investigated in red pine (*Pinus resinosa* Ait.) and white birch (*Betula papyifera* Marsh.) in northern Wisconsin. The stem radii of six red pines and four white birches were monitored with dendrographs during one growing season. Particular attention was given to lag responses of radial growth to changes in environmental factors. Precipitation was the single most significant factor. Radial growth of birch showed a greater physiological response to climate or energy flux than pine. This study emphasized the importance of water supply in regulating short-term changes in cambial growth.

93 Brand, D.G. 1990. Growth analysis of responses by planted white pine and white spruce to changes in soil temperature, fertility and brush competition. For. Ecol. Manag. 30:125–138.

The effects of scarification, fertilization, and brush control were examined on eastern white pine (*Pinus strobus* L.) and white spruce (*Picea glauca* (Moench) Voss) seedling growth and survival. Seedlings were measured in the first and second season after planting following a randomized block factorial design in a clearcut harvested area at Petawawa, Ontario. Scarification was the only treatment that stimulated height growth at this stage of plantation development. Growing conditions changed rapidly during the establishment period; so far, the trees appear able to adjust to the environmental stresses.

94 Brand, D.G. 1991. The establishment of boreal and sub-boreal conifer plantations: an integrated analysis of environmental conditions and seedling growth. For. Sci. 37:68–100.

An integrated analysis of environment and growth and a conventional growth analysis were applied to first- and second-year data from three conifer studies, one each in the Great Lakes–St. Lawrence, the boreal, and the sub-boreal forest regions. The study site in the Great Lakes–St. Lawrence area was near Petawawa, Ontario; the boreal near Foleyet, Ontario; and the sub-boreal near Summit Lake, British Columbia. A split-plot factorial experimental design with four replicates was used with three levels of scarification, two levels of fertilization, and competition control. Two conifer species were planted at each study site with eastern white pine (*Pinus strobus* L.) and white spruce (*Picea glauca* (Moench) Voss) planted at the Great Lakes–St. Lawrence site. Growth responses were related positively to increases in soil temperature and nutrient availability and to a decrease in plant competition.

95 Brand, D.G.; Janas, P.S. 1988. Growth and acclimation of planted white pine and white spruce seedlings in response to environmental conditions. Can. J. For. Res. 18:320–329.

The effects of scarification, fertilization, and brush control on the early development of eastern white pine (*Pinus strobus* L.) and white spruce (*Picea glauca* (Moench) Voss) were studied after planting 3+0 seedlings in a clearcut at Petawawa, Ontario, following a randomized block factorial design. The treatments consisted of scarification, fertilization, and brush control with herbicides. Trees were measured for four months after planting, then harvested and analyzed. Height and diameter growth and total biomass were measured. Soil temperature was the most important factor for the establishment of seedlings. With a colder soil temperature, brush control and scarification had no or a negative effect on growth, but with an increase in soil temperature, both treatments had a positive effect on growth. Also, nutritional treatments had the greatest influence on first-year growth of eastern white pine, whereas brush control was most important for white spruce.

96 Brand, D.G.; Kehoe, P.; Connors, M. 1986. Coniferous afforestation leads to soil acidification in central Ontario. Can. J. For. Res. 16:1389–1391.

Soils from 20 plots in conifer plantations established on abandoned farmland at Petawawa, Ontario, were resampled after 46 years (in 1984) to determine whether soils had

become more acidic. Soil samples from both periods were analyzed by a colorimetric method of pH determination using a Lovibond comparator. The latter samples were also assessed for pH with either a Fisher Accumet digital pH–ion meter or a Canlab portable digital pH meter. There was a significant average decrease of 0.86 pH units. In 1984, white spruce (*Picea glauca* (Moench) Voss) plots had become significantly more acidic than red pine (*Pinus resinosa* Ait.) plots. Average pH decrease under white spruce plantations was 1.28 versus 0.67 for red pine plantations. Considering the asymptotic nature of both stand biomass and forest-floor accumulation, minimal further decreases in soil pH were predicted for these sites.

97 Brand, D.G.; Magnussen, S. 1988. Asymmetric, two-sided competition in even-aged monocultures of red pine. Can. J. For. Res. 18:901–910.
The distribution of vigor among individuals in red pine (*Pinus resinosa* Ait.) plantations of various densities was examined to test hypotheses about the effects of increasing stand density. Data from three spacing trials at Petawawa, Ontario, were used to compute yields for individual trees in stands of differing densities at various points in time when these stands had the same mean stem volume. Competition was both asymmetric (small trees lose vigor more rapidly than large trees as density increases) and two-sided (not only do larger trees affect smaller trees, but to some degree, small trees also cause growth reduction in larger neighbors). Increased density resulted in increased size inequality.

98 Brillant, C.; Gendron, P.; Tétreault, S.; Castonguay, A.; Parent, F. 1977. Rentabilité des reboisements au Québec. I–Plantations de pin rouge et de pin gris. Mémoire Nº 36. Ministère des Terres et Forêts, Québec. 179 p. [Profitability of reforestation in Quebec. I. Plantations of red and jack pine; English abstract.]
An economic analysis of the growth potential of red (*Pinus resinosa* Ait.) and jack pine (*P. banksiana* Lamb.) in Quebec regarding variables such as species, thinning, and clearcutting was presented. The Faustmann's model was used in the analysis and it was demonstrated that the optimum rotation for both species might be between 52 and 55 years old. For red pine, the first thinning was profitable, whereas the second and third thinnings were not. For jack pine, all three thinning regimes were profitable.

99 Brissette, J.C. 1996. Effects of intensity and frequency of harvesting on abundance, stocking and composition of natural regeneration in the Acadian forest of eastern North America. Silva Fenn. 30:301–314.
Natural regeneration abundance, distribution, and species composition were examined after repeated partial harvesting. Eight silvicultural techniques were being evaluated in a long-term study in Maine in the Acadian forest. This paper focused on five of these silvicultural treatments, all of which involved partial harvesting including fixed and modified diameter-limit cutting, and the selection system with a 5-, 10-, and 20-year interval between harvests. Natural regeneration was abundant across a range of intensities and frequencies of partial harvests ranging from 25 000 to 80 000 trees per hectare. Coniferous species dominated regeneration in all treatments, and eastern white pine (*Pinus strobus* L.) was the dominant pine with red pine (*P. resinosa* Ait.) seldom present. Generally, the tree regeneration was sufficiently abundant and diverse after partial harvesting to sustain forest stands to meet a variety of forest management objectives.

100 Brosofske, K.D.; Chen, J.; Crow, T.R. 2001. Understory vegetation and site factors: implications for a managed Wisconsin landscape. For. Ecol. Manag. 146:75–87.
The understory vegetation diversity among seven major patch types was quantified and compared to assess whether or not and how diversity measurements related to site variables. Seventy-seven sites each containing one circular plot of 0.05 ha and representing seven patch types were surveyed in northern Wisconsin. Mature red pine (*Pinus resinosa* Ait.) and young mixed red and jack pine (*P. banksiana* Lamb.) were examples of the patch types studied. Little difference was noted in quantitative diversity measures among major patch types of the area. Canopy cover was observed to be the dominant site variable influencing diversity.

101 Brown, J.H. 2006. Growth intercept methods for predicting site index in white pine plantations in the glaciated areas of Ohio. North. J. Appl. For. 23:176–183.
Earlier studies demonstrated that site quality could be predicted using growth intercept methods involving measurements of cumulative length of 3–10 internodes beginning at or near breast height. Growth intercept methods were applied to estimate site quality in 21–53-year-old eastern white pine (*Pinus strobus* L.) stands planted on old-field sites in northern and western Ohio. A total of 159 plots in 93 separate stands were sampled, and only trees that had remained in a dominant or codominant position were selected for measurement. Simple correlation analyses were used to test growth intercept methods combined with soil and/or topographic factors. Multiple regression equations were developed for predicting heights in eastern white pine stands using three- and five-year growth intercepts beginning one year above breast height, and they provided estimates of site index as early as six years after stands reached breast height. Until recently, eastern white pine in Ohio had not been affected by white pine weevil (*Pissodes strobi* (Peck)), and therefore the effects of white pine weevil damage were not covered here.

102 Brown, J.H. 2007. Growth and site index of white pine in relation to soils and topography in the glaciated areas of Ohio. North. J. Appl. For. 24:98–103.

Eastern white pine (*Pinus strobus* L.) has a limited natural range in Ohio, but its growth is good on a variety of sites. This study aimed to develop soil-site equations containing only soil or topographic factors for estimating potential height growth and site index for planted eastern white pine. A total of 159 plots in 93 stands were selected to represent a range of soil and topographic conditions common in Ohio. Plots were small to minimize soil and topographic variation, but each plot contained three to five dominant or codominant trees whose age was determined from cores taken at breast height. Trees were measured for height, and soil profile descriptions were made from two soil pits per plot. Plots were divided into two groups (slope of 0–10% or slope >10%). From data on plots with 0–10% slopes, two multiple regression equations were developed for predicting heights: one containing slope and depth to mottling, and one that added clay content to the B_2 horizon. The equations were used to compute site indices for eastern white pine. The plots having slopes >10% showed significant correlation among average growth, depth of mottling, pH of the Ap soil horizon, and percentage of clay in the B_2 soil horizon. Less variation in height growth was seen on plots having >10% slopes. The 35-year site index ranged from 19 to 25 m where slopes were 0–10%, and from 22 to 25 m where slopes were >10%.

103 Brown, J.-L. 1994a. Essais de différentes intensités d'éclaircie dans des pinèdes d'âges multiples situées dans la forêt d'expérimentation du Ruisseau-de-l'Indien, circonscription de Pontiac, Québec. Mémoire de recherche forestière nº 110. Gouvernement du Québec, Ministère des Ressources naturelles. 249 p. [Testing of different thinning intensities in multi-aged eastern white pine stands in the Ruisseau- de-l'Indien experimental forest, riding of Pontiac, Quebec; English abstract.]

Eastern white pine (*Pinus strobus* L.) studies were presented for varying thinning intensities in multiple- and even-aged pine stands. Twelve experimental eastern white pine plots, three red pine (*P. resinosa* Ait.) plots, and one jack pine (*P. banksiana* Lamb.) plot were established in the Ruisseau-de-l'Indien experimental forest in Quebec. A better understanding of eastern white pine stand structure and dynamics was gained. The silvicultural thinning treatments were viewed as positive, and significant future gains in wood volume production were predicted.

104 Brown, J.-L. 1994b. White pine management in the Ottawa River area of Quebec. For. Chron. 70:437–442.

Eastern white pine (*Pinus strobus* L.) management activities west of the Ottawa River area in Quebec were presented including the historical eastern white pine harvesting and management that occurred before the new *Forest Act*, which was enacted in 1986, and how eastern white pine has been managed since the act came into effect. Eastern white pine management has moved from diameter-limit cutting and clearcutting to approaches that were better adapted to maintaining stand structure and improving regeneration success including greater use of the shelterwood method.

105 Bryson, T.; Storie, R.; Bowling, C. 1996. Status of older white pine plantations in northwestern Ontario. TR-95. OMNR, Northwest Science and Technology, Thunder Bay, ON. 24 p.

Eastern white pine (*Pinus strobus* L.) plantations set up before 1974 in northwestern Ontario were summarized in a database. Of these, 108 plantations were selected and field-assessed in 1993. The field surveys indicated that most of these plantations have not performed well. Of the 108 plantations visited, only 22 were classified as successful or somewhat successful. Generally, surviving eastern white pine trees were growing well, demonstrating good potential for eastern white pine timber production in this region. Many factors could have contributed to plantation failure, but probably interspecific competition was a major factor. Many of these plantations had not received any tending after their establishment.

106 Buchert, G.P. 1994. Genetics of white pine and implications for management and conservation. For. Chron. 70:427–434.

This paper provided an overview of eastern white pine *(Pinus strobus* L.) genetics, beginning with a background description of population genetic principles, the current understanding of the patterns of genetic variability in eastern white pine, and the biological mechanisms by which this variability was maintained. Furthermore, a discussion was presented on how this knowledge could be used to improve the management and conservation of eastern white pine. Many of Ontario's old-growth eastern white pine stands contain pristine gene pools and they should be managed carefully through the application of silvicultural treatments that are based on sound population genetic principles (for example, careful selection of seed trees before logging to minimize inbreeding, and avoiding high grading). This also applies to older natural stands in Ontario that have already had some management treatments.

107 Buchert, G.P.; Rajora, O.P.; Hood, J.V.; Dancik, B.P. 1997. Effects of harvesting on genetic diversity in old-growth eastern white pine in Ontario, Canada. Conserv. Biol. 11:747–758.

Genetic diversity measures at 54 isozyme loci coding for 16 enzymes in megagametophytes were compared

between preharvest and postharvest gene pools of two virgin, old-growth (~250 years old) eastern white pine (*Pinus strobus* L.) stands in central Ontario. Changes in genetic diversity between the stands suggested that genetic erosion was a result of harvesting. Old-growth stands should be regenerated carefully before harvesting to ensure that the gene pools of the original forests are maintained in the next generation.

108 Bunce, J.A.; Miller, L.N.; Chabot, B.F. 1977. Competitive exploitation of soil water by five eastern North American tree species. Bot. Gaz. 138:168–173.

Five species, pitch pine (*Pinus rigida* Mill.), red oak (*Quercus rubra* L.), eastern white pine (*P. strobus* L.), red ash (*Fraxinus pennsylvanica* Marsh.), and speckled alder (*Alnus incana* ssp. *rugosa* (Du Roi) J. Clausen), were assessed for their water status and rates of water loss during one growing season. Young trees were transplanted into a study site at Ithaca, New York, at a density of about two trees per square metre. Trees were transplanted, as well, into 15-cm-diameter pots with the soil from the field study site and grown under partial or full sunlight. When the soil dried, the more drought-adapted species reduced transpiration less than the species that were less drought tolerant. The soil water potential directly beneath non-transpiring plants was the same as elsewhere, indicating that the drought-adapted species transpired all the water conserved by the water-conserving species. The species with higher water use also gained more carbon during the summer. Therefore the presence of more drought-adapted species negatively influenced the survival and carbon acquisition of other species. Species composition of communities in xeric conditions was affected by the competitive exploitation of soil water.

109 Burgess, D.; Baldock, J.A.; Wetzel, S.; Brand, D.G. 1995. Scarification, fertilization and herbicide treatment effects on planted conifers and soil fertility. Plant Soil 168–169:513–522.

Scarification, fertilization, and brush control influences were examined on eastern white pine (*Pinus strobus* L.) and white spruce (*Picea glauca* (Moench) Voss) seedlings. Soil surface modification (blade scarification and mulching using a plastic sheet), fertilization, and herbicide treatment effects on soil nutrient and organic carbon content, tree growth, and survival and foliar nutrient status were assessed using a factorial design at Petawawa, Ontario. Plots had been planted with eastern white pine and white spruce. Seven years after outplanting, soil samples were taken to a 20-cm depth; foliar samples were collected in the fall; and light, soil moisture, and temperature were recorded throughout the growing season. The silvicultural treatments had a positive effect on seedling growth, and survival was 20% higher in scarified plots. Scarification did reduce soil carbon and nutrient contents two- to three-fold. Foliar nutrient, protein, starch, and lipid contents were little affected by treatments at this stage. Combined silvicultural treatments could increase early conifer growth by as much as 14 times, but longer term assessments are needed.

110 Burgess, D.; Pinto, F.; Wetzel, S. 2002. Some management implications from an eastern white pine regeneration experiment. Natural Resources Canada, Canadian Forest Service, Pacific Forestry Centre, Victoria, BC. Technology Transfer Note No. 28. 6 p.

A framework for eastern white pine (*Pinus strobus* L.) management under shelterwood conditions in Ontario was presented on the basis of an eastern white pine regeneration experiment set up at Petawawa, Ontario. The eastern white pine shelterwood system allowed for the harvest of poorer quality trees and those likely to be killed by natural disturbances. Eastern white pine regeneration grown in moderate shade was expected to experience less white pine weevil (*Pissodes strobi* (Peck)) damage and could thus be of higher quality when released. Regeneration requirements and seedling growth responses were discussed as well as implications for pine management.

111 Burgess, D.; Robinson, C. 1998. Canada's oldest permanent sample plots—thinning in white and red pine. For. Chron. 74:606–616.

Periodic measurements taken in a 71-year period from two permanent sample plots (PSPs) at Petawawa, Ontario, were used to examine the effects of thinning on the development of eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.). One PSP was thinned six times, whereas the other was left as an unthinned control plot. Measurements were taken just before and immediately after each thinning in the first PSP, and the other PSP was measured at corresponding times. Natural mortality in the control plot (129.7 m^3/ ha of sawlog volume) was 10 times the level in the thinned plot. Between the last two measurements, the periodic annual increment in the control plot declined markedly to <2 $m^3 \cdot ha^{-1} \cdot year^{-1}$, whereas it decreased only somewhat in the thinned plot, and its sawlog volume mean annual increment remained relatively stable at 5 $m^3 \cdot ha^{-1} \cdot year^{-1}$.

112 Burgess, D.; Robinson, C.; Wetzel, S. 2005. Eastern white pine response to release 30 years after partial harvesting in pine mixedwood forests. For. Ecol. Manag. 209:117–129.

A field study at Petawawa, Ontario, was set up in 1971 to investigate the growth, yield, and quality of eastern white pine (*Pinus strobus* L.). A randomized design with five

replicates was used to assess growth and stand development 30 years after treatment at three stand densities in partially harvested and uncut control plots. The growth of the immature released eastern white pine increased significantly at all three initial basal areas. The eastern white pine volume increment in control plots was about half as high as in treated plots. The increment in treated plots ranged between 6.1 and 8.3 $m^3 \bullet ha^{-1} \bullet year^{-1}$ and was highest in the plots with the medium stand density. This approach allowed for the effective use of the shorter-lived intolerant hardwoods for pulp, while increasing the growth and development of eastern white pine. This method could be applied to increase pine productivity and possibly increase the extent of eastern white pine in areas where pine is less common today than in earlier times.

113 Burgess, D.; Wetzel, S. 2000. Nutrient availability and regeneration response after partial cutting and site preparation in eastern white pine. For. Ecol. Manag. 138:249–261.

In three 110-year-old natural eastern white pine (*Pinus strobus* L.) stands at Petawawa, Ontario, a field experiment was set up to study the effects of thinning, site preparation, and underplanting. A randomized complete block, split-split plot design with four replicates was used. Three thinning and four site preparation treatments were applied, and eastern white pine seedlings were underplanted in subplots. Three years after treatment, the responses of natural and planted regeneration to the environmental changes (soil nutrient availability, light, soil moisture, and soil temperature) created by the different treatments were assessed. Eastern white pine seedling growth was greatest after overstory thinning to a two-crown spacing, together with scarification and brush control. Scarification after a good seed year increased eastern white pine regeneration numbers to the largest extent in uncut stands, suggesting that forest managers might be able to encourage advance regeneration of eastern white pine and thereby also help to sustain eastern white pine genetic diversity in pine stands.

114 Burgess, D.; Wetzel, S. 2002. Recruitment and early growth of eastern white pine (*Pinus strobus*) regeneration after partial cutting and site preparation. Forestry 75:419–423.

The effects of partial cutting and site preparation in natural eastern white pine (*Pinus strobus* L.) stands on eastern white pine regeneration and the underlying causes of differences in regeneration response were examined in three 110-year-old stands of eastern white and red pine (*P. resinosa* Ait.) at Petawawa, Ontario, 5 years after treatment. The experimental design was a randomized complete block, split-split plot design with four replicates. Partial cutting treatments consisted of uncut control, one-crown spacing between residual trees, and two-crown spacing between residual trees. Site preparation consisted of untreated control, blade scarification, brush control, or blade scarification and brush control combined. The number of naturally regenerating eastern white pine seedlings was greatest in the uncut scarified plots. But the most rapidly growing seedlings with highest nutrient status were in plots that received partial cutting and brush control. Partial cutting and site preparation applied periodically in high-value, productive, and long-lived eastern white pine stands could improve timber quality and enhance structure and diversity, and possibly result in multi-aged pine stands with some old-growth features.

115 Burgess, D.; Wetzel, S.; Baldock, J. 2000. White/red pine stand response to partial cutting and site preparation. J. Sustain. For. 10:221–227.

Thinning and site preparation treatments were assessed in three natural 110-year-old eastern white pine (*Pinus strobus* L.) stands at Petawawa, Ontario. A factorial design was used with four replicates. Thinning treatments consisted of thinning to one-crown spacing between residual trees, two-crown spacing between residual trees, and control. Site preparation consisted of blade scarification; brush control using herbicide, blade scarification, and brush control; or untreated controls. Eastern white pine seedlings were planted in subplots at a 2×2 m spacing. Scarification increased natural pine regeneration, both its number and distribution when timed with a good eastern white pine seed year. Planted eastern white pine showed a high survival rate in all treatments after two years. Longer term assessments will be needed to evaluate fully the effects of these silvicultural treatments.

116 Burgess, D.; Wetzel, S.; Pinto, F. 1999. Regenerating eastern white pine: A cooperative research approach. For. Chron. 75:423–425.

This paper described the background and partnerships involved in planning and setting up a cooperative field experiment. The study was set up in 1994 at Petawawa, Ontario, to examine thinning, underplanting, and site preparation treatments under a shelterwood system in mature, natural eastern white pine (*Pinus strobus* L.) stands as methods for establishing and promoting the early growth of pine regeneration. A randomized block design with four replicates was followed that included three thinning regimes (control, one-crown spacing, and two-crown spacing) and four site preparation treatments (control, scarification, brush control, and brush control combined with scarification). Research activities were evaluated and coordinated with field practices each year through the development of formal collaborative agreements, joint workshops, and field tours. The collaboration

with other scientists, foresters, and technicians increased the depth and scope of the study.

117 Burgess, D.M.; Methven, I.R. 1977. The historical interaction of fire, logging and pine: a case study at Chalk River, Ontario. Department of the Environment, Canadian Forestry Service, Petawawa For. Exp. Stn., Chalk River, ON. Information Report PS-X-66. 18 p.
The history and composition of two adjacent stands (jack, *Pinus banksiana* Lamb., and red pine, *P. resinosa* Ait., with scattered overstory eastern white pine, *P. strobus* L.) were explored at Petawawa, Ontario, to examine the interactions of fire, logging, topography, and the three pine species. The area was first logged for squared timber and sawlogs between 1837 and 1897. Several fires occurred in the area during the past 300 years with a fire interval of approximately 37 years. Regeneration underneath both stands was almost entirely eastern white pine. This suggested that on this dry and sandy site type with low understory competition, eastern white pine did not require fire for regeneration, and in the absence of fire, it would dominate these stands.

118 Buxbaum, C.A.Z.; Nowak, C.A.; White, E.H. 2001. Long-term soil nutrient dynamics and lateral nutrient movement in fertilized and unfertilized red pine plantations. Biogeochemistry 55:269–292.
A repeated-measures analysis was applied to test the hypothesis that soil fertility under potassium-limited red pine (*Pinus resinosa* Ait.) stands in Warrensburg, New York, is increasing toward a steady state, which was artificially induced more than five decades earlier. In 1992, soil potassium (K) was measured by horizon in 25 plots in red pine stands that had each been sampled at least twice previously. The new data were added to a 53-year-old database. At 16 of those plots, pure potassium salts were applied between 1942 and 1951 at elemental K rates varying from 56 to 336 kg/ha. The other nine plots were left as untreated controls. The rubidium–potassium reverse tracer method was used to examine the lateral movement of fertilizer K from treated plots to untreated plots. Soil K concentrations under both fertilized and unfertilized red pine increased significantly during the past 50 years. There was a gradual convergence of soil K under unfertilized plots toward concentrations in fertilized plots.

119 Calvert, W.W.; Brace, L.G. 1969. Pruning and sawing eastern white pine. Publication No. 1262. Department of Fisheries and Forestry, Ottawa. 22 p.
Twenty-seven years after thinning, a natural eastern white pine (*Pinus strobus* L.) stand at Petawawa, Ontario, was harvested at age 90. Selected crop trees had been pruned up to 5.5 m just after the last thinning. Trees were felled and examined to define stand characteristics, to compare lumber value of pruned and unpruned trees, and to evaluate the silvicultural operations in terms of utilization. The effect of taper sawing pruned logs was examined as well. Financial returns from second-growth eastern white pine could be increased considerably by pruning straight logs only and pruning fast-growing trees with branches of 2.5 cm or less. The average economic return on the pruning investment was 14.2%. The taper sawing did not affect quality.

120 Carleton, T.J. 2003. Old growth in the Great Lakes forest. Environ. Rev. 11:S115–S134.
Old growth in the Great Lakes forest was reviewed including its distribution, disturbance regimes, regeneration, and succession. The old-growth stage was identified by features linked to forest stand age including general stand characteristics, woody biomass volume, standing necromass (dead stems ≥10 cm diameter at breast height), coarse woody debris, and understory plant species diversity. Each feature was assessed along chronosequences of forests dominated by eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.). Less productive sites supported stands with a primary canopy that was mostly intact and was formed by pine trees with large, broad crowns. Standing woody biomass aggraded to 120–150 years and subsequently declined on all but the most productive sites. Snag volume tended to peak in the 90–125-year age range with a subsequent decline, and coarse woody debris accumulated in a pattern similar to that of aboveground woody biomass. Plant diversity was linked to the heterogeneity of substrata, much of which was attributed to woody necromass.

121 Carleton, T.J.; Arnup, R.W. 1993. Vegetation ecology of eastern white pine and red pine forests in Ontario. Rep. No. 11. OMNR, OFRI, Forest Landscape Ecology Program, Sault Ste. Marie, ON. 262 p.
Changes in understory species composition and floristic diversity in eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.) stands in Ontario were explored regarding differences in site conditions and stand age. A total of 170 natural fire-origin stands throughout the Canadian Shield in Ontario, ranging between 50 and 300 years and containing at least a 10% component of red pine or eastern white pine basal area, were surveyed during 1991 and 1992. Subplots based on 1- and 5-m^2 quadrats in 40 × 20 m fixed area plots were sampled to capture the variety of vegetation that occurred at different scales. Detailed site data were collected as well. Floristic composition was found to be most strongly related to site

features rather than to stand age. The stands were classified into four site-related groups (poor, shallow soils; deep, poor soils; shallow but rich soils, often on steep slopes; and deep rich soils on level topography), and trends in vegetation composition and diversity were then explored by constructing a chronosequence of stand age in each site group. Total stand basal area peaked at 140 years old. Poor sites showed a decline in basal area after 140 years suggesting that stand openings were gradually filled by regeneration, whereas richer sites did not show a decline in basal area after 140 years because hardwood species reoccupied the stand. Regeneration of eastern white pine was significantly higher in the poor site group.

122 Carleton, T.J.; Gordon, A.M. 1992. Understanding old-growth red and white pine dominated forests in Ontario. Rep. No. 2A. OMNR, OFRI, Forest Landscape Ecology Program, Sault Ste. Marie, ON. 83 p.

A variety of forest stands dominated by old-growth eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.) was sampled across a portion of the species' range in north central Ontario. Plots were established in 40 of these stands to survey the characteristics of old-growth red and white pine forests. Forest stand structure was determined, forest vegetation was sampled, and soil samples were analyzed. The stands showed great variety in upper canopy age (60–300 years), live basal area (23.3–92.7 m^2/ha), snag basal area (0.2–31.2 m^2/ha), and standing dead basal area (0.0–183.8 m^2/ha). A total of 35 species grew in the understory of stands with a uniform canopy and forest-floor environment, and 75 species were found in stands with nonuniform canopy and variable forest floors. Site-related effects largely explained the differences in composition among the sampled pine stands.

123 Carleton, T.J.; Maycock, P.F.; Arnup, R.; Gordon, A.M. 1996. *In situ* regeneration of *Pinus strobus* and *P. resinosa* in the Great Lakes forest communities of Canada. J. Veg. Sci. 7:431–444.

The evidence of in situ regeneration of eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.) was assessed by examining two existing databases. The first database was created after measuring diameters of 320 northern hardwood–conifer stands. The second database, the pine survey, had data from 170 stands of which at least 10% of the basal area was composed of eastern white and/or red pine. This database was a result of more intensive surveys with tree measurements, site quality, and other site features and vegetation surveys. The pine survey was stratified into five age classes: 50–80 year, 81–100 year, 101–120 year, 121–180 year, and 180+ year. The databases were used to determine dominancy of eastern white and red pine and the presence of pine regeneration. Eastern white pine seedlings and mature trees were more abundant than pine saplings, which were restricted to pine and oak forests. Seed production, dispersal, and seedling establishment seem less a barrier to successful pine regeneration than longer term seedling survival and growth.

124 Casselman, C.N.; Fox, T.R.; Burger, J.A. 2007. Thinning response of a white pine stand on a reclaimed surface mine in southwestern Virginia. North. J. Appl. For. 24:9–13.

Little was known about eastern white pine (*Pinus strobus* L.) response to thinning on surface mined lands, and therefore the productivity and growth responses following thinning were examined in a 26-year-old eastern white pine stand on a surface mine site in Wise County, Virginia. At age 17, the thinning was completed with three paired blocks containing 0.02-ha plots. One plot per block was thinned to a basal area of 20 m^2/ha. Each thinned plot had a paired control plot. Height and diameter of five randomly selected dominant and codominant trees were measured annually, and height and diameters of all live trees were measured nine years after thinning. Average height in the thinned stand at age 26 was 19 m, and the site index averaged 32 m at age 50. Diameter at breast height and height growth were greater in the thinned plots. A 7.6-cm difference in diameter between thinned and unthinned stands was projected for age 30, and 92% of the volume would be sawtimber in the thinned areas compared with only 66% in the unthinned areas. When all management costs were considered, these stands provided a favorable financial return, and therefore eastern white pine could be used to restore productive forest on reclaimed surface mines in the eastern United States.

125 Casselman, C.N.; Fox, T.R.; Burger, J.A.; Jones, A.T.; Galbraith, J.M. 2006. Effects of silvicultural treatments on survival and growth of trees planted on reclaimed mine lands in the Appalachians. For. Ecol. Manag. 223:403–414.

Additional information was needed on the growth of various tree species planted on mine soils, and their response to silvicultural treatments. One of the objectives was to examine the impact of silvicultural treatments on planted eastern white pine (*Pinus strobus* L.), hybrid poplar (*Populus trichocarpa* Torr. & A. Gray × *P. deltoides* Bartr. ex Marsh. ssp. *deltoides*), and a mixture of native hardwoods in Ohio, West Virginia, and Virginia on land surface mined for coal and subsequently reclaimed. A 3 × 3 factorial combination of a silvicultural treatment and tree species in a randomized complete block design with three replicates was set up at each study site. Silvicultural treatments consisted of weed control, weed control plus tillage, and weed control and tillage plus fertilization.

Trees were planted at 2.4 × 3.0 m spacing; eastern white pine were 2+0 bare-root seedlings. In each 0.25-ha treatment plot, a 20 × 20 m subplot was assessed for tree survival, height, and basal diameter growth. Eastern white pine had lowest survival, ranging from 27 to 58%, with best survival at the Virginia site. Eastern white pine height growth was not affected by silvicultural treatment. Tree survival and growth varied among the three sites, which was mostly due to differences in soil properties. Tillage should be applied on a site-specific basis. The interactions between site conditions, silvicultural treatments, and tree species were important for successfully establishing trees on mine soils.

126 Cayford, J.H. 1963. Reproduction and residual stand development following cutting in red pine–jack pine stands in Manitoba. Publication No. 1010. Department of Forestry, Ottawa. 19 p.

Red pine (*Pinus resinosa* Ait.) was once more abundant in Manitoba, but repeated fires and extensive logging nearly eliminated it. Methods of increasing red pine regeneration after cutting as well as the growth and mortality of residual trees were examined. In two red pine–jack pine (*P. banksiana* Lamb.) stands 50–70 years old in southeastern Manitoba, four 2-ha blocks were set up. In these blocks, 20-m-wide strips were clearcut alternating with 60-m-wide strips from which all jack pine trees and malformed red pine trees were removed. A residual basal area of 6.9 m^2/ha appeared optimal for early establishment of jack pine, and between 11.5 and 20.7 m^2/ha appeared optimal for red pine. Regeneration was closely related to seedfall and was greater on patches of mineral soil and on areas where litter thickness was reduced during logging. A two-cut shelterwood with ground preparation was suggested as a management method for pure and mixed red pine stands in Manitoba, especially in areas where thinning products cannot be readily marketed.

127 Cayford, J.H. 1964. Red pine seedfall in southeastern Manitoba. For. Chron. 40:78–85.

In a five-year period, red pine (*Pinus resinosa* Ait.) seed collections were made in a 60-year-old stand in Manitoba that originally supported a mixture of red and jack pine (*P. banksiana* Lamb.). It was partially cut, and contained two 20-m-wide clearcut strips. Twenty-four traps were located on each of the clearcut strips and 72 on the partially cut areas. During the five-year period, there was one heavy, one very light, and three moderate seed crops. Seed collection for the five years totaled 12.6 kg of seed (1 443 000 seeds)/ha on the partially cut area and 6.2 kg of seed (710 000 seeds)/ha on the clearcut strips. Seed dispersal was greatest in the fall, and most seed fell within a radius comparable to the height of the seed tree. Although seed quality differed between seed collections, the best quality of seed fell in the fall during periods of maximum seed dispersal.

128 Cayford, J.H.; Haig, R.A. 1964. Survival and growth of 1949–1962 red pine plantations in southeastern Manitoba. Publication No. 1093. Department of Forestry, Ottawa. 16 p.

Between 1927 and 1962, 1.7 million red pine (*Pinus resinosa* Ait.) trees were planted in southeastern Manitoba, and results of their early development until 1949 were published previously. This report described the development of red pine plantations since 1949 in southeastern Manitoba and is based on results from four studies established in different years. Experimental plantations were planted in the spring with 2+1 or 2+2 stock and measured one, two, three, and five years after planting. Provincial plantations, which contained experimental plots, were planted either in the spring or in the fall, with 2+2 stock, and measured annually afterward. Major factors of planting success were rainfall, site features, site preparation, planting method, season of planting, and biotic agents. Rainfall during the first planting season was the most important single factor affecting plantation success. Survival and growth were generally better on fresh than on dry sites. Hand planting was the most successful planting method and results of spring planting were better than fall planting.

129 Cayford, J.H.; Jarvis, J.M. 1963. Furrowing and sheltering to improve early survival of planted red pine on dry sites, southeastern Manitoba. Tree Plant. Notes 59:21–24.

The effectiveness of furrowing, sheltering, and furrowing plus sheltering on early survival of planted red pine (*Pinus resinosa* Ait.) was assessed on dry sites in the Sandilands Forest Reserve in southeastern Manitoba. Nine hundred red pine seedlings (2+2 stock) were planted for two consecutive years, and six treatments were applied: control, rock-shelter, paper-shelter, furrow, furrow plus rock-shelter, and furrow plus paper-shelter. Each treatment was applied to 150 seedlings, and furrows were 0.5–0.6 m wide and 5–10 cm deep. Overall, furrow and furrow plus shelter gave best results after one year, and all treatments showed better results than controls in the second year. Furrowing showed better survival rates than sheltering.

130 Cayford, J.H.; Jarvis, J.M. 1967. Fertilizing with ammonium nitrate improves red pine seed production. J. For. 65:402–403.

The effectiveness of fertilization with ammonium nitrate on red pine (*Pinus resinosa* Ait.) seed production in southeastern Manitoba was determined in a red pine stand 45–75 years old with diameters 10–38 cm. In May,

ammonium nitrate fertilizer was applied at the rate of 336 kg/ha. Two years later, selected trees were felled and cones were counted. The year of felling was considered a good seed year. Fertilization increased total cone production by 41% on average but had little or no effect on seed weight or seed soundness. Cone production of both fertilized and unfertilized trees increased with an increase in tree diameter.

131 Chambers, B. 1991. Understorey vegetation response to three silvicultural treatments in the white pine working group. COFTDU Tech. Rep. No. 15. OMNR, Central Ontario Forest Technology Development Unit, North Bay, ON. 52 p.

The posttreatment response of understory vegetation to three silvicultural treatments after uniform shelterwood harvest was examined in the eastern white pine (*Pinus strobus* L.) working group. The three treatments consisted of cut and leave, cut with mechanical site preparation, and cut with mechanical and chemical site preparation. A total of 130 temporary plots were established to compare vegetation responses to the three treatments. Sixty-five plots were measured before and after harvest. Eastern white pine seedlings establishing after harvest appeared to decline in numbers through time after mechanical treatment but appeared to increase in number after a mechanical and chemical treatment. This study stressed the need for the establishment of a Forest Ecosystem Classification system to assess the comparative effects of silvicultural treatment on vegetation and crop tree response.

132 Chapeskie, D.J.; Galley, D.F.; Mihell, J.R.; Quinn, N.W.; Struik, H.H. 1989. A silvicultural guide for the white pine and red pine working groups in Ontario. OMNR, Queen's Printer for Ontario, Toronto, ON. 88 p. + app.

The management of even-aged stands in the eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.) working groups was discussed throughout their entire life from renewal to the end of rotation. Two specific management objectives were identified: to maintain the genetic integrity of the resource, and to maintain or enhance the present volume of growing stock to provide high-value sawlogs and poles for the forest industry. Characteristics of the eastern white and red pine working groups in Ontario were described and they included their range and commercial importance, site characteristics, silvics of eastern white and red pine, and wildlife and environmental considerations. Management prescriptions were described and related to four site types: outwash plains, dumped till over bedrock, dumped till over molded till, and lacustrine deposits. The management descriptions included silvicultural systems, harvesting considerations, forest renewal, stand maintenance, conversion, and management intensity.

133 Clark, T.P.; Perera, A.H. 1995. An overview of ecology of red and white pine old-growth forests in Ontario. Rep. No. 18. OMNR, OFRI, Forest Landscape Ecology Program, Sault Ste. Marie, ON. 29 p.

Recent studies on the ecology of Ontario's old-growth eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.) forests were summarized. The studies focused on the following questions: What do old-growth forests look like?, How are ecological processes in old-growth forests different from those in younger forests?, and How do old-growth forests change? Characteristics of old eastern white and red pine forests, ecological functions and processes, and changes were all discussed at the landscape and stand level. Old-growth forests undergo their greatest changes in biomass, woody debris, and in diversity of certain plant species at about 140 years old. Site quality rather than stand age was probably the main factor in determining when these changes occur and how quickly they progress.

134 Clements, J.R. 1966. Development of a white pine underplantation in thinned and unthinned aspen. For. Chron. 42:244–250.

Part of a dense 12-year-old trembling aspen (*Populus tremuloides* Michx.) stand at Petawawa, Ontario, was thinned, reducing the stems from 6700 to 2000 per hectare, and both thinned and unthinned portions of the stand were underplanted with 2+2 eastern white pine (*Pinus strobus* L.) at a 0.9×1.5 m spacing. After 20 years, a dense understory, consisting mainly of red maple (*Acer rubrum* L.), had developed in the whole stand. Mortality of the planted eastern white pine was high in both treatments, caused mainly by the competition of the understory but also by white pine blister rust (*Cronartium ribicola* J.C. Fischer), white pine weevil (*Pissodes strobi* (Peck)) damage, and browsing. Once the eastern white pine seedlings reached a height of about 1.2–1.8 m, their growth increased. Underbrush should be controlled to reduce mortality and increase growth of the surviving eastern white pine.

135 Clinton, B.D.; Elliott, K.J.; Swank, W.T. 1997. Response of planted eastern white pine (*Pinus strobus* L.) to mechanical release, competition and drought in the southern Appalachians. South. J. Appl. For. 21:19–23.

The pine (*Pinus* spp.) component in the mixed oak (*Quercus* spp.)–pine forest type on xeric midslopes and ridges in southern Appalachian forest ecosystems was reduced by drought and associated southern pine beetle (*Dendroctonus frontalis* Zimmerman) infestations and the development of dense understories dominated by mountain

laurel (*Kalmia latifolia* L.). The effects of mechanical release, interspecific competition, and drought were assessed on height and radial-growth responses of eastern white pine (*Pinus strobus* L.). Four clearcut and burned sites were selected and planted with eastern white pine at a 6×6 m spacing. At age six, eastern white pine on two of the sites were released. At age 14, 16–20 eastern white pine stems were selected randomly on each site for diameter and height growth measurements. Competition and drought effects were determined on an individual tree basis. At age 14, two strata had developed: an overstory of eastern white pine and a clearly defined shrub layer dominated by mountain laurel. Height and radial-growth increment showed no significant response to release. Trees on all sites responded to a severe drought with a substantial decrease in annual radial increment. The drought possibly delayed or diminished the response of eastern white pine to mechanical release. The competitive influence of mountain laurel on eastern white pine growth was likely not as important as competition from other hardwood species.

136 Clinton, B.D.; Vose, J.M. 1999. Fine root respiration in mature eastern white pine (*Pinus strobus) in situ*: the importance of CO_2 in controlled environments. Tree Physiol. 19:475–479.

Root respiration of 39-year-old eastern white pine (*Pinus strobus* L.) trees in western North Carolina was measured in situ, and soil respiration rates were compared with root respiration at atmospheric CO_2 after normalizing for the effects of temperature and nitrogen. Overall, fine-root respiration rates measured at atmospheric CO_2 were higher than fine-root respiration measured at soil CO_2, with a peak in midsummer when fine-root respiration measured at atmospheric CO_2 was almost three times higher. Estimates of soil CO_2 flux and soil carbon budgets might be improved by better accounting for the rhizosphere microclimate during measurement of fine-root respiration.

137 Cloutier, D.; Rioux, D.; Beaulieu, J.; Schoen, D.J. 2003. Somatic stability of microsatellite loci in eastern white pine, *Pinus strobus* L. Heredity 90:247–252.

Tissue differentiated into gamete-bearing structures (megagametophytes) was examined, and the potential was determined for chimeric transmission of somatically occurring mutations at microsatellite loci. Adjacent shoots (ramets) were selected from 12 different genets for a total of 24 tree samples. Female cones were selected, and seed collected for genetic sampling. DNA samples were screened for variation at eight nuclear and four chloroplast microsatellite loci. Results suggested that microsatellites are stable genetic markers in eastern white pine (*Pinus strobus* L.) because no evidence of mutation was found during somatic growth and gamete formation. The estimated somatic mutation rate was substantially lower than that published for other plant species.

138 Cook, J.E. 2000. Disturbance history of two natural areas in Wisconsin: implications for management. Nat. Areas J. 20:24–35.

A characterization of the historical disturbance regimes in two natural areas in Wisconsin was completed using forest inventory data including age determinations. The first natural area was dominated by eastern white pine (*Pinus strobus* L.) and red oak (*Quercus rubra* L.) and the second by red oak and sugar maple (*Acer saccharum* Marsh.). Fire suppression reduced eastern white pine and red oak establishment in the second natural area but allowed red maple (*A. rubrum* L.) to increase dramatically. Prescribed fire in conjunction with the creation of canopy openings was recommended to maintain the red oak–eastern white pine canopy. Disturbances that create gaps >0.3 ha were needed to retain red oak in the canopy in the red oak–sugar maple stand.

139 Cooke, R.R.; Barrett, J.P. 1986. Growth estimates in natural white pine stands over two decades. Pages 46–50 *in* D.T. Funk, comp. Eastern white pine: today and tomorrow. Symposium proceedings, Durham, NH, 12–14 June 1985. Gen. Tech. Rep. WO-51. USDA For. Serv., Northeastern For. Exp. Stn., Durham, NH. 124 p.

Data collected during a 20-year period from 50 growth plots in natural stands in New Hampshire were used to examine growth rates and characteristics of natural eastern white pine (*Pinus strobus* L.) stands. Measurements included tree heights, diameters, and crown classes. Basal area per acre, basal area increment, and board- and cubic-foot volumes were calculated. Eastern white pine growth in New Hampshire was predictable and robust, and was sustained at high levels to stand ages of 80–100 years.

140 Cooley, J.H. 1970. Thinning and fertilizing red pine to increase growth and cone production. Res. Pap. NC-42. USDA For. Serv., North Central. For. Exp. Stn., St. Paul, MN. 8 p.

A 20-year-old red pine (*Pinus resinosa* Ait.) plantation and two natural red pine stands (53 and 55 years old) in Lower Michigan were studied to determine the effects of thinning and fertilizing on red pine growth and cone production. Three thinning treatments (leaving 4 trees per plot, leaving 16 trees per plot, and control) and three levels of fertilizing were applied to 0.04-ha plots arranged in a factorial, randomized block design. Mature cones were counted on four sample trees per plot for six years, and diameter at breast height was measured for the next five years. More cones were produced on thinned plots, but

fertilizer had no effects on cone production. In the natural stands there was an interaction between thinning and fertilization the first year after treatment, and heavy thinning had a greater effect on cone production than the light thinning. Thinning increased diameter growth more in the plantation than in the natural stands. Fertilization did not affect diameter growth in the natural stand but did increase diameter growth significantly after the second year in the plantation.

141 Coons, C.F. 1978. Red and white pine planting. Pages 103–110 *in* D.A. Cameron, comp. White and red pine symposium, Chalk River, ON, 20–22 September 1977. Symposium Proceedings O-P-6. Department of the Environment, Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. 178 p.
The planting of red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.) on abandoned submarginal agricultural fields in eastern Ontario was discussed. In the past, greater success was achieved in planting red pine than in planting eastern white pine in the eastern region. A much larger red pine planting program was conducted in Ontario since the turn of the century with nearly three times as many red pine planted. The presence of white pine weevil (*Pissodes strobi* (Peck)) and white pine blister rust (*Cronartium ribicola* J.C.Fischer) discouraged eastern white pine planting, but with better understanding of eastern white pine management, its comparatively high value and yield compared with many other tree species, and the existence of large acreages of suitable sites, planting of eastern white pine was expected to increase significantly between 1977 and 1982.

142 Corbett, C.M. 1994. White pine management and conservation in Algonquin Park. For. Chron. 70:435–436.
The uniform shelterwood system has been used since the early 1970s to manage eastern white pine (*Pinus strobus* L.) in Algonquin Park, Ontario. There are four harvesting stages applied approximately 20 years apart: (1) a preparatory cut at 60–80 years old to provide residual trees with a one-crown spacing, that is, the crown spacing between residual trees equals about the average crown diameter; (2) a seedling cut to facilitate natural or artificial regeneration; (3) a first removal thinning; and (4) final removal once the understory of eastern white pine has reached 6 m high. Red maple (*Acer rubrum* L.) and balsam fir (*Abies balsamea* (L.) Mill.) were recognized as major competitors that inhibit the regeneration and development of eastern white pine. Control of balsam fir was accomplished by straight blading, whereas control of red maple was more difficult. The use of the uniform shelterwood system and the maintenance of healthy scattered individual eastern white pine trees were successful in Algonquin Park for the conservation of eastern white pine.

143 Cornett, M.W.; Puettmann, K.J.; Reich, P.B. 1998. Canopy type, forest floor, predation, and competition influence conifer seedling emergence and early survival in two Minnesota conifer–deciduous forests. Can. J. For. Res. 28:196–205.
Two sites of the *Abies–Populus* forest type in Minnesota were examined to investigate ways in which early regeneration success of eastern white pine (*Pinus strobus* L.) and balsam fir (*Abies balsamea* (L.) Mill.) differ underneath deciduous and conifer canopy types in mixed conifer–deciduous forests. Germination experiments were conducted with eastern white pine and balsam fir seed. Experimental treatments included forest-floor removal, caging to exclude seed predators and herbivory, and weeding to study the effects of understory competition. Early regeneration of both species increased when seed predation and competition were reduced. Although eastern white pine was more tolerant of an intact forest floor, removal of the forest floor did not reduce its emergence or survival. Weeding showed no effects on emergence but tended to lower mortality rates.

144 Critchfield, W.B. 1986. Hybridization and classification of the white pines (*Pinus* section *strobus*). Taxon 35:647–659.
Much of the effort at hybridization came from attempts to increase resistance to white pine blister rust (*Cronartium ribicola* J.C. Fischer) in three economically important and highly rust-susceptible pines of North America: eastern white pine (*Pinus strobus* L.), western white pine (*P. monticola* Dougl. ex D. Don), and sugar pine (*P. lambertiana* Dougl.*)*. These species, together with several other North American and Eurasian species, form a morphologically coherent group of typical white pines with five-needled fascicles and elongate, thin-scaled cones that open and shed winged seeds at maturity. *Pinus strobus* and *P. monticola*, but not *P. lambertiana*, are typical of this group because of the ease with which they can be crossed with the other species of the group. On the contrary, no verified hybrids have been produced between the hard pines native to the Eastern and Western Hemispheres. Lack of agreement among the types of data that bear on the relationships of white pine suggested a need for new approaches to their classification.

145 Currie, W.S.; Aber, J.D.; Driscoll, C.T. 1999. Leaching of nutrient cations from the forest floor: effects of nitrogen saturation in two long-term manipulations. Can. J. For. Res. 29:609–620.
The effects of N saturation-induced changes were assessed by examining the cation–anion chemistry of soil solution leaching from the forest floor. The hypothesis that increased nitrate leaching caused increased concentrations of nutrient cations in soil solution was tested in a

67-year-old red pine (*Pinus resinosa* Ait.) plantation and in a predominantly 45–50-year-old oak (*Quercus* spp.) stand in Massachusetts. Nitrogen was applied for several years using backpack sprayers in six equal applications each year between May and late September. In each stand there was one low N addition (5 g $N \bullet m^{-2} \bullet year^{-1}$), one high N addition (15 g $N \bullet m^{-2} \bullet year^{-1}$), and one control (no N addition) per 0.09-ha plot. Throughfall and forest-floor samples (15 × 15 cm) were collected and analyzed. Concentrations of NO_3^- in forest-floor leachate increased with the rates of N addition, and correlated positively with cation concentrations, especially in the red pine stand.

146 Dahir, S.E.; Cummings Carlson, J.E. 2001. Incidence of white pine blister rust in a high-hazard region of Wisconsin. North. J. Appl. For. 18:81–86.

Sixty-one eastern white pine (*Pinus strobus* L.) stands in Wisconsin were examined for incidence of white pine blister rust (*Cronartium ribicola* J.C. Fischer) and to assess their current basal area and the relationship between site factors and the incidence of white pine blister rust. All stands were in areas where the risk of white pine blister rust was considered high. The mean incidence of infection was 7.2% for all sites but was 5.9% when the Bayfield Peninsula area was excluded where the mean incidence was 15.9%. Increased latitude, higher topographic position, northern aspect, lower total tree density, and absence of hardwood overstory were site factors that correlated with increased white pine blister rust. Slope was a significant factor. Where *Ribes* spp. is present in the general area, a recommendation was made to plant eastern white pine under an overstory of about 40–50% crown closure or to plant at high densities (2 × 2 m spacing) in open areas. In areas where trees are exposed to high winds that could spread spores to *Ribes* spp., pruning of lower branches was recommended or planting of densely foliated species that could act as a windbreaker.

147 Daoust, G.; Beaulieu, J. 2001. Genetics, breeding, improvement and conservation of *Pinus strobus* in Canada. Pages 3–11 *in* R.A. Sniezko, S. Samman, S.E. Schlarbaum, and H.B. Kriebel, eds. Breeding and genetic resources of five-needle pines: growth, adaptability, and pest resistance. Conference proceedings, IUFRO Working Party 2.02.15, Medford, OR, 23–27 July 2001. Publication No. RMRS-P-32. USDA For. Serv., Rocky Mountain Res. Stn., Fort Collins, CO. 259 p.

An overview was presented of studies from eastern Canada conducted in the past 50 years to improve knowledge of the genetics of eastern white pine (*Pinus strobus* L.). It described the efforts and accomplishments of several private and public sector organizations to establish breeding programs. One program was successful in developing rust-resistant interspecific hybrids. A series of genecological tests was established in 1988 examining juvenile growth. On average, a 14% genetic gain was expected for height growth 12 years after planting. Probably <2% of the old-growth eastern white pine forests will remain worldwide, which makes it an endangered ecosystem type. In Ontario, a conservation strategy for old-growth eastern white pine forest ecosystems was developed.

148 Davis, M.B. 1981. Quaternary history and the stability of forest communities. Pages 132–153 *in* D.C. West, H.H. Shugart, and D.B. Botkin, eds. Forest succession: concepts and application. Springer-Verlag, New York, NY. 517 p.

Evidence suggested that forest communities in temperate regions were chance combinations of species without an evolutionary history. Recent geological discoveries shortened the time scale of quaternary events that supported this view. The emphasis in studying plant communities could be placed more appropriately on changes in species composition and the mechanisms that permit rapid change rather than on the forces that act to maintain stability. An analysis of the historical movement of tree species demonstrated that eastern white pine (*Pinus strobus* L.) appeared first at a site in Virginia and then expanded rapidly northward and westward. Seven thousand years ago, dry climate prevented its expansion westward, but eastern white pine continued to expand northward, even north of its present natural range limit in Canada. It also grew earlier on sites 350 m above its modern elevation limits.

149 Day, M.W.; Rudolph, V.J. 1966. Early growth results of thinning plantation red pine by three methods. Mich. Agric. Exp. Stn. Q. Bull. 49:183–188.

Three methods of thinning red pine (*Pinus resinosa* Ait.) were evaluated: basal area, row thinning, and percentage of height. The study site was a red pine plantation in northern Michigan with a 1.8 × 1.8 m spacing and a site index of 20 at age 50. It was thinned at age 25. The study consisted of 16 plots with four replicates, and treatments were assigned randomly. Treatments consisted of leaving a residual basal area from 6.9 to 36.7 m^2/ha; removing every other, third, or fourth row; residual spacings of 17–30% of the height of the average dominant tree; and controls. Trees were measured before and three years after thinning. All plots responded positively to thinning. Basal area and merchantable volume growth were directly related to stand density after thinning. Competition began when the residual basal area was between 10.3 and 13.8 m^2/ha. The heaviest thinnings decreased the height growth, but trees showed the highest percentage of basal

area growth. Merchantable volume growth declined with the density of stocking after thinning, regardless of the thinning method.

150 Day, R.J.; Carter, J.V. 1990. Stand structure and successional development of the white and red pine communities in the Temagami forest. OMNR, Northeastern Region. Queen's Printer for Ontario, Toronto, ON. 38 p.
A study was set up at Temagami, Ontario, to gain additional information about its logging and fire history, principal forest communities by aerial survey, and the red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.) communities including their status and reproduction possibilities. Both the red and eastern white pine communities were of natural origin and even-aged, but they were very poorly stocked and gradually being replaced by tolerant species. The pines probably reproduced after wildfires between 1729 and 1865. The lack of hot wildfires since 1912 has led to losses of red and eastern white pine in the Temagami forest. Shelterwood and clearcutting systems were recommended to increase regeneration of red and eastern white pine, with prescribed burning being applied where feasible.

151 Day, R.J.; Carter, J.V. 1991. The ecology of the Temagami forest: based on a photointerpretive survey and the forest resources inventory of Temagami District. OMNR, Northeastern Region. Queen's Printer for Ontario, Toronto, ON. 88 p.
The ecology of the Temagami forest was described on the basis of a 2% photointerpretive survey of a 9-township study area (93.2 km^2), and a careful review and compilation of Forest Resources Inventory maps and data of a 30-township study area. Black spruce (*Picea mariana* (Mill.) BSP) (23.2%), white birch (*Betula papyrifera* Marsh.) (22.5%), jack pine (*Pinus banksiana* Lamb.) (14.0%), and poplar (*Populus* spp.) (11.1%) were the principal dominant species in the study area. Eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.) occupy fifth and sixth place (4.8% each). The large emergent eastern white and red pine trees were scattered throughout all the major communities in varying numbers per hectare. The average number of eastern white and red pine emergents per hectare in the Temagami forest was only 11.4. Fifty-eight percent of the stands sampled were completely lacking large emergent eastern white or red pine trees, and there were very few stands with more than 50 emergent pines per hectare.

152 DeBarr, G.L.; Barber, L.R.; Maxwell, A.H. 1982. Use of carbofuran for control of eastern white pine cone and seed insects. For. Ecol. Manag. 4:1–18.
The effectiveness of the insecticide carbofuran against eastern white pine (*Pinus strobus* L.) pests was tested in two seed orchards in North Carolina. Greater cone survival and the number of filled seed per cone were used as determinants of treatment success. A randomized complete block design was established and carbofuran was applied once a year to different eastern white pine clones at rates of 0, 4.5, 9.0, or 13.5 g active ingredient/cm of diameter at breast height. The pesticide protected the trees from four insect pests but was ineffective against the eastern white pine seed chalcid (*Megastigmus atedius* Walker). Increasing the pesticide application rate demonstrated no significant improvement in the carbofuran effectiveness. The different eastern white pine clones showed variable susceptibility to insect attacks.

153 DeBoo, R.F. 1978. Management of pine insects. Pages 165–175 *in* D.A. Cameron, comp. White and red pine symposium, Chalk River, ON, 20–22 September 1977. Symposium Proceedings O-P-6. Department of the Environment, Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. 178 p.
The current status of insect pests of red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.) occurring primarily in Ontario and Quebec was reviewed as well as options for their management, and the protection of pine (*Pinus* spp.) stands in the immediate future was discussed. Sawflies (the genera *Diprion* and *Neodiprion*), weevils (for example, the white pine weevil, *Pissodes strobi* (Peck)), and tip and shoot moths including the eastern pine shoot borer (*Eucosma gloriola* Heinrich) and *Rhyacionia* spp. were the major insects infesting established eastern white and red pine stands. Expensive and labor-intensive silvicultural practices must be used for pest management in pure stands of eastern white and red pine. Detecting infestations early and incorporating practical and effective treatments were also important. An abbreviated red and eastern white pine insect pest management calendar was presented, explaining when pest management measures were most effective. Several aspects of insect pest management such as use of pesticides and spray applications were expected to achieve prominence through the use of new materials and methods in the years ahead.

154 de Groot, P. 1985. Chemical control of insect pests of white pine. Proc. Entomol. Soc. Ont. 116(Suppl.):67–71.
The current chemical control methods were reviewed and presented for the economically important insect pests of eastern white pine (*Pinus strobus* L.). Control of white pine weevil (*Pissodes strobi* (Peck)) with chemicals remained difficult. The two factors critical to the success of a chemical control program (timing of the application and optimal coverage of the terminal buds and leader with insecticide) were difficult to achieve. Eastern pine shoot

borer (*Eucosma gloriola* Heinrich) and white pine cone beetle (*Conophthorus coniperda* (Schwarz)) were also difficult to control with chemicals. White grubs, mainly of the genus *Phyllophaga*, could be readily controlled with applications of chlordane to soil. Chlordane is no longer registered for use in Canada or the United States.

155 de la Cretaz, A.L.; Kelty, M.J. 2002. Development of tree regeneration in fern-dominated forest understories after reduction of deer browsing. Restor. Ecol. 10:416–426.

The effects of deer browsing and interspecific competition from hay-scented fern on tree regeneration were examined in red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.) plantations in central Massachusetts. Recovery patterns were evaluated for woody plant species in understories of varying fern density three years after a reduction in deer browsing due to hunting. Of particular interest was the ability of seedlings to outgrow the ferns, seedling growth rates, and seedling phenology. Fern cover continued to affect seedling stem density and species composition even after three years of reduced deer browsing. Stands with the highest density fern cover had significantly fewer seedlings of at least 30 cm high compared with stands with lower density. Partial elimination of fern cover should be sufficient to allow eastern white pine to develop. Height growth analysis showed that black birch (*Betula lenta* L.) and eastern white pine grew above the height of the fern canopy in three and six years, respectively. Two common tree species, white ash (*Fraxinus americana* L.) and red oak (*Quercus rubra* L.), grew beneath the dense fern cover for five years with height growth of <5 cm/year after the first year. At the end of the study, the ecosystem had not yet recovered from previous deer browsing.

156 Demeritt, M.E., Jr.; Garrett, P.W. 1996. Adaptation of eastern white pine provenances to planting sites. Res. Pap. NE-703. USDA For. Serv., Northeastern For. Exp. Stn., Radnor, PA. 7 p.

The phenotypic stability or adaptability of 29 eastern white pine (*Pinus strobus* L.) provenances in 12 plantations in the northeastern United States was explored. Plantations were established with 2+0 and 3+0 stock. Three planting designs were used, each a randomized complete block, and trees were measured for height at 10 years old, and for height and diameter at 16 years old. Height growth became more stable with increasing age. When diameter was used as a measure, provenance stability at age 16 was nearly identical to that using 16-year height growth.

157 Demeritt, M.E., Jr.; Kettlewood, H.C. 1976. Eastern white pine seed source variation in the northeastern United States: 16-year results. Pages 80–87 *in* Proceedings of the 12th Lake States forest tree improvement conference, Chalk River, ON, 18–22 August 1975. Gen. Tech. Rep. NC-26. USDA For. Serv., North Central For. Exp. Stn., St. Paul, MN.

An eastern white pine (*Pinus strobus* L.) provenance trial was set up in the northeastern United States to determine whether the movement of seed was possible throughout various geographic locations. The experimental design included three randomized complete blocks. Twelve eastern white pine provenance plantations in 10 various locations were established, and tree height and diameter growth were tracked for 16 years. Southern and central sources did not have the same growth advantage at age 16 as they did at age 10. Southern sources had higher early growth, but long-term results were needed before conclusions could be reached. Furthermore, performance varied between trees of the same county within a state. This indicated that only proven sources from a geographic region should be used for seedling production.

158 de Naurois, M.; Buongiorno, J. 1986. Economics of red pine plantation management in Wisconsin. North. J. Appl. For. 3:118–123.

The economics of red pine (*Pinus resinosa* Ait.) management in Wisconsin were estimated by simulating 88 management alternatives. Management alternatives differed in terms of product goal, initial density, intermediate thinning, length of rotation, and site quality. Pulpwood, or pulpwood and sawlogs, were considered product goals. Two computer models, TWIGS and REDPINE, were compared and REDPINE was chosen for its practicality. Economic returns from managing red pine for pulpwood as well as sawlogs were higher than managing for pulpwood alone. The most important factor influencing the economic return of a plantation was site quality. Sites with a lower site index were unlikely to be economical regardless of management regime. For sites with a higher site index, initial planting densities of 2.4 × 2.4 m followed by heavy thinnings at long intervals and shorter rotations were most economical. Rotations could be increased considerably and only slightly affect the economics.

159 Deresse, T.; Shepard, R.K.; Shaler; S.M. 2003. Microfibril angle variation in red pine (*Pinus resinosa* Ait.) and its relation to the strength and stiffness of early juvenile wood. For. Prod. J. 53:34–40.

Microfibril angle (MF-angle) of tracheids was studied in both dominant and codominant red pine (*Pinus resinosa* Ait.) through age 20 in a 57-year-old plantation and in a 42-year-old natural stand in eastern Maine. In both the plantation and natural stand, mean MF-angle decreased with age. In both stands, MF-angle decreased from earlywood

to latewood, and the difference between earlywood and latewood MF-angle increased with age. Flexural strength and stiffness of juvenile wood was negatively correlated with MF-angle. Both properties were positively correlated to specific gravity. Cultural practices that increase ring width early in stand development may increase MF-angle and reduce modulus of rupture and modulus of elasticity.

160 desBordes, W.K.; Thor, E. 1979. Estimates of heritabilities and gains from open pollinated progeny tests of eastern white pine. Pages 44–53 *in* Proceedings of the 1st north central tree improvement conference, Madison, WI, 21–23 August 1979. University of Wisconsin, Madison, WI.

Two 10-year-old progeny tests of eastern white pine (*Pinus strobus* L.) were evaluated to estimate their heritability and genetic gains. The studies were set up in two locations in Tennessee but they included 128 families from 13 stands located across Tennessee, Georgia, and North Carolina. The progeny tests contained 10-tree family row plots arranged in a randomized block design with 10 replicates. A combined location analysis was completed for eight characteristics on the basis of single tree measurements, and heritabilities were estimated using a variance components method. Progenies from Tennessee and Georgia grew fastest in both locations. Height, diameter, volume, and needle length were all strongly inherited traits. Selection of the best 40 families resulted in gains of 13% for height and 17% for diameter.

161 Desmarais, K.M.; Leak, W.B. 2005. Ten-year performance of eastern white pine under a crop tree release regime on an outwash site. North. J. Appl. For. 22:139–142.

The growth and value of a 38–40-year-old pure eastern white pine (*Pinus strobus* L.) stand in New Hampshire was examined following crop tree release, leaving a basal area of 15.9 m^2/ha. A total of 30 trees were monitored from 1991 to 2001. Basal area increased to 21.7 m^2/ha. Eleven of the 30 trees had real annual percentage change rates of 30% or more. All 11 trees were poletimber at the beginning and sawtimber at the end of the study. Under similar circumstances, more high-quality poletimber capable of vigorous growth should be retained to grow into sawtimber, and more sawtimber should be harvested during the first cutting.

162 Dibble, A.C.; Rees, C.A.; Sendak, P.E.; Brissette, J.C. 2004. Vegetation of forested uplands in the Massabesic Experimental Forest. Tech. Rep. NE-320. USDA For. Serv., Northeastern For. Exp. Stn., Newtown Square, PA. 71 p.

The Massabesic Experimental Forest in York County, Maine, was inventoried using a grid network of 399 permanent sample plots concentrated on the upland portions of the forest. About 500 species and subspecies of plants were identified. The most common species of overstory trees were eastern white pine (*Pinus strobus* L.), eastern hemlock (*Tsuga canadensis* (L.) Carrière), red oak (*Quercus rubra* L.), and red maple (*Acer rubrum* L.). The most common forest cover types were eastern white pine, pine (*Pinus* spp.)–oak (*Quercus* spp.), and pine–eastern hemlock. Large trees >46 cm were of particular interest, and they, on average, totaled 35 trees per hectare in the area sampled. Of the large trees measured, 66% were eastern white pine, 16% eastern hemlock, 11% red oak, 4% red maple, and 2% white oak (*Q. alba* L.). Tree mortality suggests that without natural disturbances or management activities to promote pine and oak, there will be a decrease in eastern white pine and red oak and an increase in eastern hemlock through time.

163 Dickmann, D.I. 1993. Management of red pine for multiple benefits using prescribed fire. North. J. Appl. For. 10:53–62.

This technical discussion of prescribed burning included effects on (1) overstory tree growth; (2) understory plants and pine regeneration; (3) soil properties; (4) soil organisms, diseases, and pests; (5) wildlife habitat; (6) environmental impacts; and (7) wildlife hazard reduction. Information in this report was based on a literature review as well as the author's own experience. Forest managers were encouraged to include prescribed underburning as a silvicultural option for this important forest species.

164 Dickmann, D.I.; Kozlowski, T.T. 1968. Mobilization by *Pinus resinosa* cones and shoots of C^{14}-photosynthate from needles of different ages. Am. J. Bot. 55:900–906.

The role of current-year and older needles of red pine (*Pinus resinosa* Ait.) as sources of photosynthate for development of cones and shoots was investigated. In 25–30-year-old red pine trees planted as a windbreak in central Wisconsin, current-year, 1-year-old, 2-year-old, and 3-year-old needles were exposed separately to $C^{14}O_2$ at various times during the growing season. One-year-old needles were the major source of current photosynthate for growth of both cones and shoot internodes of red pine. Two-year-old, three-year-old, and current-year needles were progressively less important. Growing reproductive tissues of red pine acted as sinks that would mobilize available carbohydrates. The preferential mobilization of carbohydrates was to reproductive tissues.

165 Dickmann, D.I.; Kozlowski, T.T. 1969a. Seasonal changes in the macro- and micro-nutrient composition of ovulate strobili and seeds of *Pinus resinosa*. Can. J. Bot. 47:1547–1554.

Seasonal changes in several macro- and micronutrients were investigated during the development of red pine (*Pinus resinosa* Ait.) strobili and seeds. First- and second-year strobili were collected at 2-week intervals during a growing season from a 25–30-year-old windbreak of red pine in central Wisconsin. Total N, K, Ca, Na, Al, Fe, B, Cu, and Zn in strobili and seeds were analyzed. The actual amount of all macronutrients increased steadily during the first growing season. The nutrient composition of strobili changed during the second growing season with concentrations of all macronutrients decreasing during most of the year. The concentration of the micronutrient elements Mn, Zn, Fe, Cu, and B in cone tissue decreased throughout most of the second growing season, whereas Na and Al increased throughout the second growing season. Seasonal patterns of macro- and micronutrients in the developing seeds varied from those of the strobili. The nutrient balance of the red pine strobili development period could be divided into three phases: nutrients move rapidly into the growing strobili, but as the strobili matured accumulation was reduced, and translocation of mobile nutrients out of senescing strobili occurred.

166 Dickmann, D.I.; Kozlowski, T.T. 1969b. Seasonal growth patterns of ovulate strobili of *Pinus resinosa* in central Wisconsin. Can. J. Bot. 47:839–848.

The seasonal growth patterns of strobili and seed were quantified and characterized, and some seasonal and daily water relations of strobili were investigated. First- and second-year strobili were collected at 2-week intervals from five to ten 25–30-year-old windbreak red pine (*Pinus resinosa* Ait.) trees in central Wisconsin. Total fresh and oven-dry weight of seeds per cone and average individual fresh and oven-dry seed weight were determined as well as patterns of diameter change of first-year and second-year cones. During the time when weight of second-year strobili was increasing rapidly, water content declined in the tissues. Maximum size of strobili was achieved approximately a month before maximum dry weight peaked in early August.

167 Dickmann, D.I.; Kozlowski, T.T. 1969c. Seasonal variations in reserve and structural components of *Pinus resinosa* cones. Am. J. Bot. 56:515–520.

Changes were assessed in reserve materials, lignin, hemicellulose, and cellulose of first- and second-year cones of red pine (*Pinus resinosa* Ait.). Five cones from each of 10 trees were collected at 2-week intervals during the 1966 growing season from 25–30-year-old windbreak red pine trees in central Wisconsin. Cones were subjected to chemical extraction of the respective fractions. Dry-weight accumulation by conelets during the first year was steady and gradual. Growth of second-year conelets was gradual in April and May, increased at a rapid rate in June and July, and was essentially completed by early August. The weights of lignin, hemicellulose, and cellulose all increased during the first growing season. The most dramatic changes in the composition of cones occurred during the latter part of the second growing season as cones matured. The cellulose content rose sharply in mid-June, at which time an abrupt decrease in extractable reserves was noted. The weight of the lignin fraction followed closely the overall dry-weight increase for second-year cones. Seasonal changes in hemicellulose were small. Major changes in the chemical composition of red pine cones occurred only during the last three months of their development.

168 Dickmann, D.I.; Kozlowski, T.T. 1970. Photosynthesis by rapidly expanding green strobili of *Pinus resinosa*. Life Sci. 9:549–552.

The photosynthetic capacity of green, second-year cones of red pine (*Pinus resinosa* Ait.) was investigated on 25–30-year-old windbreak trees. Data were collected during late June and early July when dry-weight increase by strobili was at a maximum and their demand for carbohydrates was greatest. Uptake and incorporation of $^{14}CO_2$ by green second-year cones showed that assimilation of ^{14}C by all strobili occurred. CO_2 exchange by green strobili was also examined and showed that photosynthetic uptake of CO_2 occurred in the light but was not sufficient to offset respiratory CO_2. Most of the carbohydrate incorporated into rapidly expanding cones was derived primarily from one-year-old needles, and photosynthesis by green strobili tissues could be considered only of local importance.

169 Dickson, A.; Leaf, A.L.; Hosner, J.F. 1960. Quality appraisal of white spruce and white pine seedling stock in nurseries. For. Chron. 36:10–13.

Several models for evaluating the quality of planting stock were assessed to develop an integrated seedling quality index. The selected combination was weight divided by a height–diameter quotient plus the root:shoot ratio. Total seedling weight, shoot weight and root weight on an oven-dry basis, root collar diameter, and height of 2+0 white spruce (*Picea glauca* (Moench) Voss) and eastern white pine (*Pinus strobus* L.) stock from four nurseries in the northeastern United States were used to develop the index.

170 Dixon, W.N.; Houseweart, M.W. 1983. Spring temporal and spatial activity patterns of adult white pine weevils (Coleoptera: Curculionidae) in Maine. Environ. Entomol. 12:43–49.

Activities of the white pine weevil (*Pissodes strobi* (Peck)) were observed during a 10-week period from April to

June in a 13-year-old eastern white pine (*Pinus strobus* L.) plantation in Maine with a 10% infestation rate. Monitored trees had an average height of 1.9 m, although the average height of the stand was 2.7 m. The shorter trees were chosen to minimize the disturbance of white pine weevils on the trees. White pine weevils emerged from overwintering in late April, peaked in mid-May, and none were found by early July. Greatest activity of adults occurred during late afternoon to early evening. White pine weevils occupied the leaders of the host trees the first two weeks of monitoring, but toward season's end were found more often on first-whorl lateral branches.

171 Dorworth, C.E. 1976. Reducing damage to red pine by *Gremmeniella abietina* in the Great Lakes–St. Lawrence forest region of Ontario. Department of the Environment, Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. Information Rep. O-X-252. 22 p.

The forest tree pathogen *Gremmeniella abietina* (Lagerb.) Morelet and the disease it causes were reviewed. The disease has been responsible for severe stem damage to red pine (*Pinus resinosa* Ait.) plantations in Ontario. Symptoms of *G. abietina* (Lagerb.) Morelet include tree mortality, lower branch mortality, foliar symptoms (previous year's foliage will turn either orange or yellow at the needle base), elongate cankers, and green pigment just beneath the bark in dead tissue. *Gremmeniella abietina* (Lagerb.) Morelet produces two types of reproductive structures, apothecia and pycnidia, usually on or just beneath the surface of dead stems and branches. Trees up to 0.9 m high were usually killed when they became infected. Trees >0.9 m usually survived, and trees >3.6 m often exhibited spectacular cankers. Control efforts should be directed toward the first decade of plantation development, the first five years being the most critical.

172 Dovčiak, M.; Frelich, L.E.; Reich, P.B. 2001. Discordance in spatial patterns of white pine (*Pinus strobus*) size-classes in a patchy near-boreal forest. J. Ecol. 89:280–291.

Changes in the spatial pattern of eastern white pine (*Pinus strobus* L.) were examined in a single stand and between tree size classes to test whether or not consecutive eastern white pine size classes have spatial patterns that are discordant. The study site in northeastern Minnesota was a mature aspen (*Populus* spp.) stand (mostly trembling aspen, *Populus tremuloides* Michx., and some largetooth aspen, *P. grandidentata* Michx.) with a low-density canopy of eastern white pine. A 90 × 80 m plot placed randomly in the stand contained 162 subplots each with a 1-m radius. Understory and overstory vegetation were sampled. Eastern white pine was classified into five size classes: one, 0.5–0.99 m tall; two, 1.0–1.99 m tall; three, 2.0–3.99 m tall; four, >3.99 m tall, <20 cm dbh; and five, ≥20 cm dbh. Abundance decreased progressively with age from size class two to size classes three, four, and five. Both stand-scale and neighborhood-scale spatial patterns of the individual size classes were nonrandom and differed from each other. Older size classes were distributed closer to seed trees than younger size classes. Recruitment into size-class two was restricted to small patches and could cause a regeneration bottleneck. Size-class spatial patterns differed in scale of clustering, degree of fine-scale overdispersion, lack of association of size classes, location of suitable neighborhoods in a stand, and the distribution of offspring size classes relative to seed trees.

173 Dovčiak, M.; Reich, P.B.; Frelich, L.E. 2003. Seed rain, safe sites, competing vegetation, and soil resources spatially structure white pine regeneration and recruitment. Can. J. For. Res. 33:1892–1904.

The study explored factors (seed rain, safe sites, competing vegetation, and soil organic matter) and combinations of factors that influence the dynamics of eastern white pine (*Pinus strobus* L.) regeneration and recruitment in aspen (*Populus* spp.) (mostly trembling aspen, *Populus tremuloides* Michx., and some largetooth aspen, *P. grandidentata* Michx.) mixedwood forests of the western Great Lakes region. Five study plots were set up where habitat characteristics were studied to identify the most significant predictors of eastern white pine germinant and seedling spatial patterns. Germinant and seedling densities were highest under dense overstory (>16 m^2/ha) and were unrelated to shrub cover. Sapling recruitment was greatest under low overstory density (<16 m^2/ha) and low shrub cover (<55%). Eastern white pine seed rain was equally important to suitable microhabitats in terms of eastern white pine regeneration. Recruitment was faster and more abundant in areas of low overstory density and low shrub cover, if soil was sufficiently deep.

174 Duchesne, L.C.; Herr, D.G.; Wetzel, S.; Thompson, I.D.; Reader, R. 2000. Effect of seed predation, shade and soil organic matter on the early establishment of eastern white pine and balsam fir seedlings. For. Chron. 76:759–763.

The difference in regenerative success of eastern white pine (*Pinus strobus* L.) and balsam fir (*Abies balsamea* (L.) Mill.) was examined in two studies. The first study was conducted under greenhouse conditions. Soil monoliths collected in an eastern white pine–jack pine (*P. banksiana* Lamb.) stand with an abundance of eastern white pine regeneration were used to compare the effects of different levels of organic material removal and shading on seed

germination between eastern white pine and balsam fir. Eastern white pine germination was significantly higher than balsam fir germination. Both species showed an increase in germination with increasing reduction of organic horizon and increasing shade level. The second study was conducted in an eastern white pine ecosystem with an abundance of balsam fir regeneration. Predation of eastern white pine and balsam fir seed was compared. Eastern white pine seed predation (70.4%) was significantly higher than balsam fir seed predation (5.0%). The fact that eastern white pine seed was preferred over balsam fir seed indicated that seed predation might be a critical factor in eastern white pine regeneration.

175 Duvall, M.D.; Grigal, D.F. 1999. Effects of timber harvesting on coarse woody debris in red pine forests across the Great Lakes States, U.S.A. Can. J. For. Res. 29:1926–1934.

Red pine (*Pinus resinosa* Ait.) forests in the Great Lakes States were compared for the effects of timber management on total amount and structural characteristics of coarse woody debris (CWD) with similar measures in unmanaged forests. Data were from 24 unmanaged red pine stands, all of which originated after fire, and from 75 managed red pine stands. CWD was inventoried on six sample plots in each stand. Chronosequences of CWD volume and biomass were developed by nonlinear least-squares regression, with age of inventoried stands as a surrogate for changes through time. There was less CWD in managed stands than in unmanaged stands (80% lower at stand initiation and 35% lower at age 90), and the amount of CWD approached a steady state much more rapidly in managed stands. The development of quantitative prescriptions for management of CWD in red pine forests across the Lake States region was premature, and a better understanding of both the causes of variation in CWD and the ecological consequences of such variation was needed. Analyzing effects of management was most appropriate and informative at the same stage of stand development. Although old growth was certainly rare and ecologically important, the effects of timber management on CWD were more drastic in young than in old forests.

176 Dyck, J.R. 1985. Fertilization improves red pine seed production. Department of Agriculture, Canadian Forestry Service, Northern Forestry Centre, Edmonton, AB. For. Manag. Note No. 31. 4 p.

This study aimed to determine whether fertilizer following thinning would improve cone and seed production. Eight pairs of trees, similar in crown and diameter shape, were selected in a 23-year-old red pine (*Pinus resinosa* Ait.) plantation in southeastern Manitoba, and one tree of each pair was treated with fertilizer. Cones were selected for three consecutive years. The first year was a bad seed year and results were not used. The second and third year were good seed years. Only cones maturing on the seventh whorl (from the top) were collected. Results showed that fertilization following thinning increased the number of cones significantly compared with the nonfertilized control trees. Fertilization also increased seed weight.

177 Eberhardt, J.C.; Brennan, E.; Kuser, J. 1988. The effect of fertilizer treatment on ozone response and growth of eastern white pine. J. Arboric. 14:153–155.

Eastern white pine (*Pinus strobus* L.) seedlings growing in pots were subjected to elevated levels of ambient ozone pollution and fertilized with four rates of fertilizer at a site in central New Jersey. Although eastern white pine was considered to be sensitive to ozone, the seedlings tested here did not develop any symptoms of ozone toxicity or any reductions in growth. The seedlings were fertilized three times with about two weeks between treatments. The manufacturer's recommended rate of 3.5g/l of Peters 20-20-20 fertilizer resulted in optimum growth and vigor of eastern white pine. It was concluded that eastern white pine was not particularly sensitive to ambient levels of ozone pollution.

178 Eckert, R.T.; Joly, R.J.; Neale, D.B. 1981. Genetics of isozyme variants and linkage relationships among allozyme loci in 35 eastern white pine clones. Can. J. For. Res. 11:573–579.

The variability and inheritance at 17 allozyme loci was assessed for 35 eastern white pine (*Pinus strobus* L.) clones. Open-pollinated seeds from each clone were collected from trees from seven sources in New Hampshire and two sources in Maine. The source trees were originally selected on the basis of their growth rate and form. The megagametophyte tissue was subjected to horizontal starch gel electrophoresis. Three different zones of polymorphic leucine aminopeptidase isozyme activity were identified in the 35 clones, and isozymes were under control of at least 17 loci. Most of the allozyme variation was controlled by five loci. The allozyme variation was comparable with that in loblolly (*P. taeda* L.) and pitch pine (*P. rigida* Mill.), but it was distributed differently.

179 Eggleston, K.L.; Crownover Sharp, R. 1985. Fertilizer trials on containerized red pine. Presented at Intermountain Nurserymen Association meeting held in Fort Collins, CO, 13–15 August 1985. 5 p.

The different effects of nitrate, ammonium, and urea forms of nitrogen fertilizers on containerized red pine (*Pinus resinosa* Ait.) were assessed in nurseries at four locations in Michigan, Wisconsin, and Minnesota. Fertilizer

treatment was the only variable. After 14 weeks, no particular fertilizer treatment was best at all locations, but all seedlings were affected by the fertilizer treatments. Height, stem caliper, shoots, and root dry weight all differed significantly between treatments, and treatments with both nitrate and ammonium produced larger seedlings at all locations. Responses to fertilizer were site specific.

180 Elliot, K.J.; Vose, J.M. 1993. Site preparation burning to improve southern Appalachian pine–hardwood stands: photosynthesis, water relations, and growth of planted *Pinus strobus* during establishment. Can. J. For. Res. 23:2278–2285.

This study was part of a long-term study initiated to examine the direct effects of changes in the microenvironment on the physiology and growth of eastern white pine (*Pinus strobus* L.) seedlings during establishment, and to examine the competitive effects of naturally regenerating vegetation on eastern white pine seedlings planted after prescribed fire. Two sites were selected in the southern Appalachians, and five 0.05-ha plots were set up per site. The sites were clearcut and burned in September, consuming all dry foliage, loose forest-floor litter, and fine woody material. The following spring, both sites were planted with two-year-old, bare-root eastern white pine seedlings at a 5 × 5 m spacing. A 2-m^2 circular plot was set up around six randomly chosen seedlings, creating a total of 60 subplots. Physiological performance and growth of seedlings were examined the first growing season after planting. Physiological measurements included net photosynthesis, transpiration, leaf conductance, and xylem water potential. Soil water, foliar N, seedling temperature, and light environment were recorded as well. The influences of competition on microenvironment conditions were examined by correlating competitor biomass with the percentage of light and foliar N. Significant relationships were found between microenvironment and seedling physiology, between seedling net photosynthesis and seedling diameter growth, and between competitor biomass and seedling physiology and growth. Both N and light were the dominant factors limiting net photosynthesis and diameter growth of seedlings.

181 Elliott, K.J.; Vose, J.M. 1994. Photosynthesis, water relations, and growth of planted *Pinus strobus* L. on burned sites in the southern Appalachians. Tree Physiol. 14:439–454.

Environmental variables, their interactions, and their effects on the physiology and growth of two-year-old planted eastern white pine (*Pinus strobus* L.) were studied on two clearcut and burned sites in the southern Appalachians. Net photosynthesis, leaf conductance, xylem water potential, and seedling growth were measured. Early in the growing season (May), net photosynthesis was related to vapor pressure deficit (42% of variation), midday water potential, crown temperature, and photosynthetically active radiation. Later in the growing season (July, August, September), as competing vegetation developed and started limiting the amount of light, seedling net photosynthesis was reduced. Light was the primary environmental factor limiting pine growth. Seedling diameter was related to needle nitrogen, average photosynthetic rate, and competitor biomass. There was no significant relationship between competitor biomass and needle water potentials or soil water content, indicating that competitors did not reduce available water. The models developed in this study emphasized the importance of multifactor (biotic and abiotic) influences on eastern white pine physiology and growth.

182 Elliott, K.J.; Vose, J.M. 1995. Evaluation of the competitive environment for white pine (*Pinus strobus* L.) seedlings planted on prescribed burn sites in the southern Appalachians. For. Sci. 41:513–530.

The competitive environment around planted eastern white pine (*Pinus strobus* L.) was studied, and the response of seedling growth to competition from naturally regenerating herbaceous and woody species was monitored for two years after prescribed burning. The ability of distance-independent and distance-dependent competition indices to predict resource availability was evaluated. Two sites in the southern Appalachians were selected, burned, and planted with two-year-old eastern white pine seedlings at a spacing of 5 × 5 m. Nitrogen was the most important resource limiting seedling growth in the first year. In year two, competition became more important and individual species had different effects on eastern white pine growth. Light was the most important resource limiting growth of the seedlings in the second year. Distance-independent measures of competition were not as well correlated with pine seedling growth as were distance-dependent measures. Competitor height and pine seedling diameter might be useful variables for evaluating early competitive effects.

183 Elliott, K.J.; Vose, J.M.; Clinton, B.D. 2002. Growth of eastern white pine (*Pinus strobus* L.) related to forest floor consumption by prescribed fire in the southern Appalachians. South. J. Appl. For. 26:18–25.

The survival and growth of eastern white pine (*Pinus strobus* L.) trees were evaluated eight years after planting on three fell-and-burn sites that differed in fire characteristics and carbon and nitrogen losses. Eastern white pine was planted as two-year-old, bare-root seedlings at 5 × 5 m spacing. Height and diameter at ground level were measured after planting and after the first, second, and

eighth growing seasons. Biomass and density of wood competitor species were not related to eastern white pine size or growth. Eastern white pine had higher relative growth rates on the site with the lowest N loss after fire. Eastern white pine increment and relative growth rate were related to the percentage of forest-floor litter mass and N loss. The loss of site N capital could have a significant negative effect on growth of planted eastern white pine in the longer term. A balance between reducing competition and retaining or improving site N would be an optimal fire treatment for these eastern white pine–hardwood sites.

184 Elliott, K.J.; White, A.S. 1993. Effects of competition from young northern hardwoods on red pine seedling growth, nutrient use efficiency, and leaf morphology. For. Ecol. Manag. 57:233–255.

The effects of competition from three northern hardwood species, pin cherry (*Prunus pensylvanica* L. f.), red maple (*Acer rubrum* L.), and striped maple (*A. pensylvanicum* L.), on planted red pine (*Pinus resinosa* Ait.) seedlings were assessed on two clearcut sites in western Maine. A replicated experimental design was used with the competitors at two densities (weeded and unweeded) and with or without fertilizer. This design included nine replicates of each treatment combination. Half the seedlings were harvested in the second growing season, the other half the following year. Biomass, annual production, and leaf area index were calculated for competitor species. Specific leaf area, leaf area ratio, and nitrogen use efficiency were calculated for red pine seedlings. Red pine responded to lower light and nutrient levels induced by competitors with a phenotypic response: higher specific leaf area, higher leaf area ratio, and greater nitrogen use efficiency. Fertilization decreased growth and nutrient use efficiency of the red pine seedlings, whereas competition decreased growth. The increase in nutrient use efficiency and altered leaf morphology with competition was insufficient to increase growth, but phenotypic adjustment might enable red pine seedlings to withstand competitive environments for longer periods.

185 Engstrom, F.B.; Mann, D.H. 1991. Fire ecology of red pine (*Pinus resinosa*) in northern Vermont, U.S.A. Can. J. For. Res. 21:882–889.

The mechanisms that maintain stands of red pine (*Pinus resinosa* Ait.) in a portion of its eastern range were studied specifically to document fire history and tree ages in a group of red pine stands in the uplands of northwestern Vermont. Six red pine stands were chosen for intensive study in plots ranging from 150 to 500 m^2 in each stand. Diameters were recorded, and germination dates and fire history of red pine were estimated. Red pine was dominant in the canopy but rare in seedling and sapling size classes. No fires were recorded in the past 65 years, and recorded fires before then were mainly light surface fires that neither killed canopy trees nor stimulated red pine recruitment. Fire scars recorded at least 17 fires in these stands between the early 1800s and 1922. The suppression program was started around 1920 by federal, state, and local governments, and no fires have been recorded since then. The mosaic of red pine of different ages in the study area suggested a history of small rather than large recruitment fires.

186 Erbilgin, N.; Raffa, K.F. 2002. Association of declining red pine stands with reduced populations of bark beetle predators, seasonal increases in root colonizing insects, and incidence of root pathogens. For. Ecol. Manag. 164:221–236.

A total of 17 healthy and declining red pine (*Pinus resinosa* Ait.) stands in Wisconsin were monitored throughout several growing seasons to quantify the populations of bark beetles (Coleoptera: Scolytidae), predators, and root and lower stem colonizing beetles, and the incidences of their associated fungi. Insects were trapped with lower stem flight traps and pitfall and funnel traps; a series of systematic root excavations was conducted randomly. A smaller population of bark beetle predators was noted in stands showing high tree mortality, but a larger population of lower stem-infesting bark beetles. Populations of root colonizing insects were higher in healthy stands early in the season, but higher in declining stands throughout much of the ovipositional period. A combination of low numbers of predators and reduced host tree resistance induced by root colonizing insects and pathogens might contribute to stand decline. The results support the view that forest decline was due to complex interactions among multiple biotic and abiotic stresses, and exhibited particular spatial and temporal patterns.

187 Erbilgin, N.; Raffa, K.F. 2003. Spatial analysis of forest gaps resulting from bark beetle colonization of red pines experiencing belowground herbivory and infection. For. Ecol. Manag. 177:145–153.

Tree growth rate, spatial analysis, and soil characteristics were investigated in red pine (*Pinus resinosa* Ait.) plantations in Wisconsin. The primary purpose was to determine whether the distance between healthy and diseased trees was associated with the epicenter of mortality, and to quantify the probability of tree death as a function of that proximity. Other objectives were to evaluate tree growth and soil factors associated with mortality. Seventeen sites were selected and each area was classified as declining, symptomatic control (consisted of portions of declining stands that were distant from the mortality zone and do not show symptoms of decline), or asymptomatic

control (stands that do not show any sign of mortality or stress). Red pine in close proximity to dead trees had reduced growth and a greater risk of mortality. An equation was developed to predict the likelihood of two trees being diseased in relation to their proximity. Total N was significantly higher in declining than in nondeclining stands. Three management applications were suggested to prevent the spread of fungal infection: mixed-block planting might decrease the chance of spread through root grafts, severing root grafts by mechanical or chemical means coupled with sanitation, and increased tree spacing.

188 Erickson, G.W. 1996. Growth and yield of a 59-year-old red pine plantation (plot 99) in Northern Minnesota. Res. Note NC-369. USDA For. Serv., North Central For. Exp. Stn., St. Paul, MN. 8 p.

Growth and yield data were presented from a 59-year-old red pine (*Pinus resinosa* Ait.) plantation on a well-drained soil in northern Minnesota containing 48 provenances from Ontario and the United States. The stand was measured for diameter at breast height and heights about every five years between 1950 and 1993 and thinned in 1951, 1956, 1983, and 1993. Residual basal area ranged from 18.6 to 21.6 m^2/ha after the first two thinnings, and to 32.1 m^2/ha after the third and fourth thinnings. In 1950 and 1955 combined, 71% of the trees were removed. Mean height growth by region showed no significant differences, but diameter growth responded quickly to thinning. The mean annual increment from 1950 to 1993 was 12.9 m^3/ha. Tree heights increased as soil depths increased across the plantation, independent of seed source.

189 Euskirchen, E.S.; Chen, J.; Bi, R. 2001. Effects of edges on plant communities in a managed landscape in northern Wisconsin. For. Ecol. Manag. 148:93–108.

Understory plant abundance, distribution, cover, and diversity were investigated near the clearcut edges of jack (*Pinus banksiana* Lamb.) and red pine (*P. resinosa* Ait.) plantations in northern Wisconsin. The clearcut edge effects were explored by running transects from the clear-cut through the area of edge influence. Species richness was higher in the jack pine than in the red pine stands. Depth-of-edge influence was calculated for vegetation species that showed a preference for one particular habitat (clearcut, edge, or interior). A depth-of-edge influence of 30 m should be considered a buffer zone when managing jack and red pine plantations near clearcuts to maintain species that require a forest interior environment. This estimate was based primarily on understory vegetation patterns and does not consider the edaphic or micro-climatic features of these ecosystems. Regression models were developed to predict diversity from topographic, structural, and stand composition variables.

190 Evert, F. 1973. New form-class equations improve volume estimates. Can. J. For. Res. 3:338–341.

Three form-class volume equations for red pine (*Pinus resinosa* Ait.) involving the upper stem diameter at 5.9 m and three standard volume equations based on diameter at breast height and height were tested for their accuracy. Sixty-four trees from three plots were felled and sectioned at Petawawa, Ontario, and 120 trees from six stands were selected and felled from elsewhere in Ontario and Quebec. All samples differed from each other in the size range of trees and their average taper. Volumes of the individual tree and volumes of the samples were estimated. All three new form-class equations met the required 10% accuracy in estimating tree volumes and the 5% accuracy in estimating stand volume. The three standard volume equations did not meet the accuracy for estimating tree volume or stand volume.

191 Ewers, F.W.; Aloni, R. 1987. Seasonal secondary growth in needle leaves of *Pinus strobus* and *Pinus brutia*. Am. J. Bot. 74:980–987.

One-year-old and two-year-old needles of eastern white pine (*Pinus strobus* L.) growing in Massachusetts, and Calabrian pine (*P. brutia* Ten.) growing in Israel were examined monthly or bimonthly throughout one year for a detailed seasonal analysis of leaf cambial activity. The aim was to determine the time of onset of secondary phloem production and peak phloem production in both developing and mature needles. The two species represent two very different climatic regions. *Pinus strobus* is from temperate Massachusetts and *P. brutia* is from Mediterranean Israel. Mature needles produced secondary phloem but no xylem, and the cambial zone for both species was two to three cell layers thick. Eastern white pine and Calabrian pine produced about two to four cell layers of secondary phloem in their current year needles and from four to six layers per year in their mature needles. The needle vascular cambium of eastern white pine was dormant in the winter months, whereas the needle vascular cambium of Calabrian pine was dormant in midsummer.

192 Fahey, T.J.;Yavitt, J.B. 2005. An *in situ* approach for measuring root-associated respiration and nitrate uptake of forest trees. Plant Soil 272:125–131.

A root in-growth method was used to quantify root-associated respiration and root nitrate uptake of mature woody plants in situ. Field measurements were conducted in a series of 0.4-ha plantations in New York including an eastern white pine (*Pinus strobus* L.) plantation. Eight root in-growth chambers were installed randomly at each site. Chambers were watered with a nutrient solution throughout the summer. Field measurements of CO_2 emissions were conducted four times using an infrared gas analyzer,

and nitrate uptake was quantified using ^{15}N. Chambers were returned to the laboratory, and roots were collected and analyzed using a soil respiration chamber. A significant difference was found in fine-root respiration among species. Most vigorous root in-growth was observed for red pine (*P. resinosa* Ait.) and sugar maple (*Acer rubrum* L.), two species with high NO_3 uptake rates. No statistically significant correlations were found for those two species between rates of root respiration, N concentration, and NO_3 uptake on a chamber-by-chamber basis.

193 Fajvan, M.A.; Seymour, R.S. 1993. Canopy stratification, age structure, and development of multicohort stands of eastern white pine, eastern hemlock, and red spruce. Can. J. For. Res. 23:1799–1809.
A statistical analysis of qualities such as diameter at breast height, height, and information obtained from core samples was used to construct a history of canopy stratification for five mature, mixed eastern white pine (*Pinus strobus* L.)–red spruce (*Picea rubens* Sarg.)–eastern hemlock (*Tsuga canadensis* (L.) Carrière) stands in eastern Maine. Clear patterns of dominance and eventual emergence of pine were observed. All stands in this study proved to be complex and highly stratified in height and canopy structure. The middle stratum held a majority of red spruce, and the lower strata contained a large proportion of eastern hemlock. Two apparent causes of canopy stratification were differences in growth rates and shade tolerances among species and the multicohort structure of the stands. The multicohort structure was attributed largely to partial disturbances such as spruce budworm (*Choristoneura fumiferana* (Clemens)) outbreaks and partial harvesting.

194 Fajvan, M.A; Seymour, R.S. 1999. Influence of white pine on structure and yields of mixed northern conifer forests. J. Sustain. For. 8:61–74.
The presence of eastern white pine (*Pinus strobus* L.) had a positive influence on yields within mixed-species, multicohort conifer stands in Maine. Five stands were assessed using a two-stage sampling method with each stage having a different intensity of sampling. Generally, total stand volumes were higher when eastern white pine was present, but red spruce (*Picea rubens* Sarg.) and eastern hemlock (*Tsuga canadensis* (L.) Carrière) volumes were lower in these mixed-species stands. Volumes were greatly affected by age structures, whether eastern white pine was present or not, with higher volumes in stands containing two or three cohorts. Management activities that promote eastern white pine in mixed-conifer stands provide the opportunity to combine the relatively rapid growth of eastern white pine with the sustained production of the more shade-tolerant eastern hemlock and red spruce.

195 Fayle, D.C.F.; Pierpoint, G. 1978. Interpreting performance of recently outplanted pine seedlings. Pages 113–121 *in* D.A. Cameron, comp. White and red pine symposium, Chalk River, ON, 20–22 September 1977. Symposium Proceedings O-P-6. Department of the Environment, Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. 178 p.
The development patterns of the shoot and root systems of red pine (*Pinus resinosa* Ait.) were discussed to diagnose and understand seedling performance problems after outplanting. Previously published studies were reviewed, and it was concluded that good initial root growth after planting was absolutely essential for good stem development.

196 Flannigan, M.D. 1993. Fire regime and the abundance of red pine. Int. J. Wildland Fire 3:241–247.
The relationship between fire regime and abundance of red pine (*Pinus resinosa* Ait.) was explored using three data sets: forest inventory data of 234 sites in the natural range of red pine, climatic data from 37 climate stations, and area burned by wildfire data of 28 years. A forward-stepwise regression was used to investigate the partitioning of the variance in the red pine volume data. The abundance of red pine was related closely to the fire regimes, but other factors such as competition and climate change were also playing a role in determining the range and abundance of red pine.

197 Flannigan, M.D.; Bergeron, Y. 1998. Possible role of disturbance in shaping the northern distribution of *Pinus resinosa*. J. Veg. Sci. 9:477–482.
Factors responsible for the distribution of red pine (*Pinus resinosa* Ait.) were investigated at its northern limit in northwestern Quebec. Research consisted of a germination experiment at two locations and a phenology experiment with trees from two island sites, all in the Lake Duparquet region of Quebec. Germination of red pine seed in large quantities occurred at both locations, and the phenology experiment showed that cones were produced at both sites. Seed germination and cone and seed production were probably not responsible for the northern limit of red pine. The fire regime was the most probable explanation for the distribution of red pine.

198 Flannigan, M.D.; Woodward, F.I. 1994. Red pine abundance: current climatic control and responses to future warming. Can. J. For. Res. 24:1166–1175.
A model was developed to describe the relationship between climatic variables and the abundance of red pine (*Pinus resinosa* Ait.). Climate, general circulation models (GCMs), and forest inventory data sets were used, and from available climatic variables obtained from 135 climatic stations across the range of red pine, a model was designed to fit

the present-day range and abundance of red pine. GCMs were used to explore the implications of a $2\times CO_2$ (greenhouse warming) environment on the range and abundance of red pine. Insufficient warmth during the growing season was the limiting factor for the northern limit of red pine, and competition and insufficient moisture for the southern and southwestern limits, respectively. In a $2\times CO_2$ environment, the northern limit of red pine was pushed northward 600 km, whereas the southern limit was moved north and east by almost 800 km; but higher potential maximum volumes of red pine were also predicted, suggesting a better growing environment.

199 Forboseh, P.F.; Brazee, R.J.; Pickens, J.B. 1996. A strategy for multiproduct stand management with uncertain future prices. For. Sci. 42:58–66.
An optimal harvesting strategy was to harvest when the current revenue was equal to or greater than the current reservation revenue. But the notion of reservation prices and the ensuing harvesting strategy are intuitively deficient and need modification to address multiple products. A simulation model based on red pine (*Pinus resinosa* Ait.) yields separated into pulp and sawtimber was used to illustrate this strategy. Accounting for multiple products could lead to dramatic changes in harvesting strategy and significant improvements in expected land values.

200 Fornes, R.H.; Berglund, J.V.; Leaf, A.L. 1970. A comparison of the growth and nutrition of *Picea abies* (L.) Karst. and *Pinus resinosa* Ait. on a K-deficient site subjected to K fertilization. Plant Soil 33:345–360.
On the oldest continuously studied forest fertilization trials in North America, at Pack Forest in New York State, a pronounced tree growth response was attained with only K fertilization. In 1951, a 19-year-old Norway spruce (*Picea abies* (L.) Karst.) stand and a 20-year-old red pine (*Pinus resinosa* Ait.) stand were fertilized with an even broadcast application of K (110 kg/ha and 90 kg/ha, respectively), leaving part of the stands untreated as controls. After 14 years for Norway spruce and 12 years for red pine, the growth response and nutrient uptake and distribution were examined by total tree analysis. Red pine produced more total weight on the site without treatment and also responded more strikingly to fertilization treatment than Norway spruce. Both species responded significantly to fertilization, with Norway spruce being a more nutrient demanding species than red pine.

201 Foster, D.R. 1988. Species and stand response to catastrophic wind in central New England, U.S.A. J. Ecol. 76:135–151.
One hundred and fifteen plots typical of transition hardwood–eastern white pine (*Pinus strobus* L.)–eastern hemlock (*Tsuga canadensis* (L.) Carrière) forests that experienced a 1938 hurricane were sampled in 1941 in Petersham, Massachusetts, and the data were examined for this study. The objective was to predict the susceptibility of species, forest types, and stratal position to wind damage as influenced by age, density, and height. Damage showed a positive linear relationship with stand age and height, and a negative relationship with density. Conifer forests appeared more susceptible to wind damage than hardwood forests. Even for a storm that could devastate large areas, a continuum of effect and consequence was noted that was controlled by site and vegetation factors. Eastern white pine, the most susceptible species, exhibited a similar damage curve in pure stands, mixed eastern white pine–red pine (*P. resinosa* Ait.) stands, and also in the hardwood stands, in which it ranged from rare to plentiful.

202 Foster, D.R. 1992. Land-use history (1730–1990) and vegetation dynamics in central New England, USA. J. Ecol. 80:753–771.
The early postsettlement vegetation in Petersham Township and Worcester County, Massachusetts, was described as well as the specific history and effects of land-use practices on the Prospect Hill tract of the Harvard Forest in Petersham. This historical analysis showed that at any landscale, land-use practices and the resulting vegetation patterns changed continuously. The changing quality and intensity of human activity resulted in the dynamic vegetation characteristics of this period. Long-term forest trends in the 20th century included a decrease in the importance of eastern white pine (*Pinus strobus* L.) due to logging and the 1938 hurricane, which greatly damaged eastern white pine stands.

203 Fowler, D.P.; Heimburger, C. 1969a. Geographic variation in eastern white pine, 7-year results in Ontario. Silvae Genet. 18:123–129.
Eastern white pine (*Pinus strobus* L.) seed from 12 provenances in the natural range of the species were sown and raised as 2+2 stock. The seedlings were planted in southern Ontario at Turkey Point and Ganaraska Forest using complete randomized blocks with four replicates at each location. Seedlings were measured at the time of transplanting and seven years after sowing. Two-year-old seedlings from southern provenances were larger than those from northern provenances, and root length was inversely related to top length. Seedlings at Turkey Point had more lammas shoots with significant differences among provenances. Total height at age seven was correlated with latitude, mean January temperature, and length of frost-free period at place of origin in the Turkey Point plantation. Trees planted at Ganaraska Forest did not show

these significant relationships. Seed of Pennsylvania origin was recommended for reforestation in southern Ontario due to its exceptional performance at both locations.

204 Fowler, D.P.; Heimburger, C.C. 1969b. Genetic improvement of red pine and eastern white pine. For. Chron. 45:414–420.

The current knowledge of genetics of red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.) was reviewed and presented. For each species, breeding programs were discussed, and suggestions were made to improve the existing breeding programs. As for red pine, improvements would be relatively small, but even a modest improvement might be economically justified in Ontario where the species had high value for reforestation. The emphasis for improving eastern white pine should be placed on breeding for resistance to white pine blister rust (*Cronartium ribicola* J.C. Fischer) and the white pine weevil (*Pissodes strobi* (Peck)).

205 Fowler, D.P.; Lester, D.T. 1970. Genetics of red pine Res. Pap. WO-8. USDA For. Serv., Washington, DC. 13 p.

Current literature was reviewed on the genetics of red pine (*Pinus resinosa* Ait.). This publication is one of a series of publications on the genetics of important forest tree species of North America. Red pine is a relatively uniform species, morphologically as well as genetically. Selection standards for red pine have not been developed. The approach recommended involves incorporating small amounts of genetic gain in large numbers of seedlings. Sexual (pollination) and asexual (rooting and grafting) reproduction were described. The need for progeny testing was explicit in discussions of any genetic improvement programs for red pine. Current projects on genetic improvement aimed to improve understanding of red pine genetics and produce commercial quantities of seed incorporating some genetic gain.

206 Fowler, D.P.; Morris, R.W. 1977. Genetic diversity in red pine: evidence for low genic heterozygosity. Can. J. For. Res. 7:343–347.

Genetic diversity in red pine (*Pinus resinosa* Ait.) was investigated using starch gel electrophoresis techniques to determine enzyme mobility differences among 297 megagametophytes from five widely separated geographical sources. Consistent and reproducible enzyme banding patterns were observed with no variation in band mobility. These results supported earlier studies showing a low degree of genetic variation in red pine. The most plausible explanation suggested that red pine was reduced, possibly during the Pleistocene, to a small refugial population that has yet to recover an equilibrium heterozygosity.

207 Fowler, R.F.; Wilson, L.F. 1975. Projected red pine yields from aldrin-treated and untreated stands damaged by white grubs and other agents. Gt. Lakes Entomol. 8:227–230.

An analysis of growth and yield projections of four red pine (*Pinus resinosa* Ait.) plantations in Hiawatha National Forest, Michigan, assessed the tolerable amount of white grub (larvae of the May beetle, *Phyllophaga* spp.) damage a stand could sustain before requiring an application of the pesticide aldrin. A randomized block design replicated five times on each site evaluated three aldrin treatments, and growth and yield projections on the basis of five-year-old trees. On three of four sites, control plots had greater financial returns than treated plots. When initial stocking was >2500 trees per hectare and the plantation was managed for sawtimber production, a stand could lose 50% or more of its trees before growth and yield losses from grubs were considered significant. White grubs can be beneficial in densely planted plantations by gradually lowering stocking, and in such cases chemical control of grubs was not recommended.

208 Fownes, J.H.; Harrington, R.A. 2004. Seedling response to gaps: separating effects of light and nitrogen. For. Ecol. Manag. 203:297–310.

The physiological and morphological plasticity of seedlings was investigated in response to light and nitrogen and their interaction. Dormant seedlings were collected from western Massachusetts and transplanted into pots in a greenhouse. The experiment was a split-plot design, with light (60 and 15% of full sunlight) as the main plot factor, and species and nutrient treatment (unamended soil from the field site and N addition equivalent to 150 kg N/ha) as subplot treatments. Six tree species including eastern white pine (*Pinus strobus* L.) were grown in forest gaps having different levels of light and soil nitrogen. The seedlings' growth patterns and photosynthetic capacity were assessed. Nitrogen was as important as light in determining seedling response to large gaps. Patterns of resource-use efficiencies were more regulated at the species level than within species. Seedling physiological responses to gaps were complicated by the differing effects of light and nitrogen on photosynthesis.

209 France, E.A.; Binkley, D.; Valentine, D. 1989. Soil chemistry changes after 27 years under four tree species in southern Ontario. Can. J. For. Res. 19:1648–1650.

The differences in soil chemistry after 27 years of stand development were examined for four species, eastern white pine (*Pinus strobus* L.), white spruce (*Picea glauca* (Moench) Voss), paper birch (*Betula papyrifera* Marsh.), and silver maple (*Acer saccharinum* L.), in replicated plantations north of Toronto, Ontario. Soils were classified

as Typic Eutroboralfs with a calcareous C horizon. Soil samples were taken from the top 15 cm of mineral soil as well as forest-floor samples. Biomass was greatest (3680 g/m^2) under eastern white pine and lowest under silver maple (240 g/m^2). Eastern white pine increased the soil's buffering capacity. Individual tree species had strong influences on some aspects of soil chemistry.

210 Francis, J.K. 1979. Species-site suitability of shortleaf, white, and Virginia pines. Pages 63–71 *in* Symposium for the management of pines of the Interior South. Tech. Publication SA-TP-2. USDA For. Serv., Southeastern Area State and Private Forestry, Atlanta, GA.

Environmental requirements were reviewed for three pine species of the interior southeastern United States, shortleaf (*Pinus echinata* Mill.), eastern white (*P. strobus* L.), and Virginia pine (*P. virginiana* Mill.). The requirements were compared among the species and they showed that eastern white pine was most successful in cooler mountainous areas, whereas Virginia pine performed better than eastern white or shortleaf pine on adverse sites. Eastern white pine grew farther north and at lower elevations. It also grew on practically all types of soil parent materials within its natural range. Eastern white pine showed better volume and height at 20 years on soils derived from limestone and dolomite than from shale.

211 Fraser, J.W. 1969. Influences of sweet-fern on germination, survival, and early growth of red pine. Can. J. Bot. 47:1681–1683.

The influences of sweet fern (*Comptonia peregrina* (L.) Coult.) on red pine (*Pinus resinosa* Ait.) germination, survival, and growth were tested in a laboratory with water extracts of sweet fern foliage and sweet fern roots for watering. Germination was not inhibited by the water extracts of sweet fern leaves or sweet fern roots. The variations in height growth were not related to any natural toxic effect of sweet fern. Both survival and height growth were probably more affected by the availability of moisture than by the presence of sweet fern.

212 Frederick, D.J.; Coffman, M.S. 1978. Red pine plantation biomass exceeds sugar maple on northern hardwood sites. J. For. 76:13–15.

Growth and biomass yields of red pine (*Pinus resinosa* Ait.) plantations were compared with those of unmanaged sugar maple (*Acer saccharum* Marsh.) stands in Michigan. Two red pine plantations (25 and 37 years old with an original spacing of 1.8 × 1.8 m) were assessed with two adjacent, natural, unmanaged sugar maple stands (one with two age classes, 43 and 67 years old, and one 58 years old) in Michigan. Each stand was sampled extensively for other purposes, and therefore only one 0.08-ha plot per stand was used for this study. Sample trees were cut to estimate dry weights. The younger red pine had a greater diameter, basal area, volume growth, and dry weight biomass than the sugar maple. Mean annual volume growth of red pine averaged five times that of sugar maple. Intensive management of red pine could increase volume and fiber production on some well-drained sites currently supporting second-growth maple.

213 Freeman, P.C.; Van Lear, D.H. 1977. Performance of eastern white pine and competing vegetation following two methods of stand conversion. South. J. Appl. For. 1:7–9.

Growth and survival of eastern white pine (*Pinus strobus* L.) seedlings planted underneath a hardwood overstory were compared for two growing seasons with seedlings planted in a clearcut with or without herbicide in the Piedmont of South Carolina. The hardwood stand was composed primarily of upland oaks (*Quercus* spp.) and hickories (*Carya* spp.) with scattered yellow-poplar (*Liriodendron tulipifera* L.) and shortleaf pine (*P. echinata* Mill.) and it had a basal area of 29 m^2/ha. Seedlings were planted using a 2 × 2 split-plot, randomized complete block design with three replicates. Seedling diameters were greater in the clearcut, and diameter growth in the clearcut was greatest after herbicide spraying. Overall seedling survival rate after the second growing season was low at 49%, which was attributed partly to the quality of the stock and partly to dry weather. Height growth and survival were not influenced by any treatment combination. Planted eastern white pine seedlings grew beneath a residual hardwood overstory without significant loss in height growth or survival, although some diameter growth was sacrificed.

214 Frelich, L.E. 1992. The relationship of natural disturbances to white pine stand development. Pages 27–37 *in* R.A. Stine and M.J. Baughman, eds. White pine symposium proceedings: history, ecology, policy and management, Duluth, MN, 16–18 September 1992. University of Minnesota, Extension Service Distribution Center, St. Paul, MN. 202 p.

Interactions between life-history characteristics of eastern white pine (*Pinus strobus* L.) and natural disturbances were examined to characterize eastern white pine's niche within the forest landscape. The most favorable disturbance regime for eastern white pine was probably a fire cycle of 150–300 years and intervening light surface fires every 20–40 years. Eastern white pine was successful in the presettlement times because surface fires every 20–40 years gradually eliminated hardwoods on dry sites and created multi-aged pine forests. On moist sites, succession to shade-tolerant hardwoods probably occurred. Severe windstorms occurring

several times each century gradually reduced the pine component and advanced succession toward hardwoods.

215 Frelich, L.E.; Machado, J.-L.; Reich, P.B. 2003. Fine-scale environmental variation and structure of understorey plant communities in two old-growth pine forests. J. Ecol. 91:283–293.

Two old-growth red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.) forests in Minnesota were studied to investigate nitrogen and light influences on the structure of understory plant communities. Soil nitrogen mineralization, soil depth, and light levels were measured. Trees were mapped, and the percentage of cover of herbs and small shrubs estimated. Nitrogen and light had a moderate influence on the understory plant community structure. Much of the spatial distribution of species groups remained unexplained. Although plant species did arrange themselves along N and light gradients, the gradients were probably too narrow to allow the degree of differentiation seen at the landscape level.

216 Funk, D.T. 1971. Eastern white pine seed source trials: ten-year results from three Midwestern plantations. Res. Pap. NC-113. USDA For. Serv., North Central For. Exp. Stn., St. Paul, MN. 4 p.

In an effort to improve eastern white pine (*Pinus strobus* L.), a provenance study was set up on three sites, one each in southern Indiana, southeastern Illinois, and northeastern Iowa. Trees from 16 sources throughout the natural range of eastern white pine were planted and remeasured 10 years later. Trees from southern Appalachian seed sources growing in southeastern Illinois and southern Indiana were taller and had fewer branches for their size than trees from other sources. Therefore selecting eastern white pine of southern Appalachian seed origin probably offers good opportunities for obtaining both higher volume production and reduced branching.

217 Funk, D.T. 1979. Genetic variation in volume growth of eastern white pine. For. Sci. 25:2–6.

Plantations of eastern white pine (*Pinus strobus* L.) were set up to assess growth and development as affected by genetic variation among 16 provenances collected from throughout the natural range of eastern white pine. The 2+0 pine seedlings were planted at a 2.1 × 2.1 m spacing in experimental sites in Iowa and Ohio. Both sites were tended with herbicide to control grass and weed competition during the first few years postplanting. The studies were assessed most recently at either 16 or 17 years old. The relative performance of eastern white pine had remained fairly consistent during the past several years. Geographic origin testing was considered a worthwhile approach in forest genetic research. Local eastern white pine seed did not always perform best, and such results have already affected the development of seed procurement policies.

218 Gagné, W.C.; Martin, J.L. 1968. The insect ecology of red pine plantations in central Ontario: V. The Coccinellidae (Coleoptera). Can. Entomol. 100:835–846.

The factors involved in changing the species composition of coccinellid populations were investigated as two red pine (*Pinus resinosa* Ait.) plantations aged in the Algoma District, Ontario. In conjunction with field observations, life histories of coccinellids were observed by rearing them at a constant temperature of 21°C and under 12 hours of fluorescent lighting per day until they deposited eggs. The 13 species of coccinellidae found in the stands could be divided into two major ecological groups that corresponded to the two plantation age classes. One group inhabited young plantations up to 16 years old, whereas the second group inhabited older stands. As the trees grew older, species diversity decreased and the stands became less favorable for coccinellidae generally. Species of coccinellidae that occurred in young red pine plantations were replaced largely by a different species complex.

219 Garcia Bailo, B.; Castelli Emison, M.R.; Blake Coleman, W.; Burk, C.J. 2004. Thirty-six years of change in an eastern hemlock–white pine stand in western Massachusetts. Rhodora 106:273–286.

The patterns of vegetation change were studied in an eastern hemlock (*Tsuga canadensis* (L.) Carrière)–eastern white pine (*Pinus strobus* L.) stand in western Massachusetts from 1963 to 1999. Major mortality of all canopy species was noted, but eastern hemlock remained the dominant species. Extensive drought was believed to be responsible for low recruitment into the canopy and numerous tree deaths between 1963 and 1975. Five years after rainfall amounts returned to normal levels, tree seedlings were well established. Tree deaths during the latter period coincided with defoliation resulting from heavy infestations by gypsy moths (*Lymantria dispar* (Linnaeus)) and windthrow during severe ice storms. Because the hemlock woolly adelgid (*Adelges tsugae* Annand) was not discovered until after the 1998 sampling, this study could serve as a baseline for assessing the effects of these insects on regional forests.

220 Garrett, P.W. 1973. Geographic variation in resistance to white pine weevil (*Pissodes strobi*) (Coleoptera: Curculionidae) by eastern white pine (*Pinus strobus*). Can. Entomol. 105:347–350.

Seedlings from 12 seed sources of eastern white pine (*Pinus strobus* L.) were planted in southern Ontario to determine differences in white pine weevil (*Pissodes strobi* (Peck)) damage per provenance. Use of chemicals to control white pine weevil populations was shown earlier

to be impractical and uneconomical. The planting design consisted of four randomized blocks containing 81-tree (9×9) plots at 1.8×1.8 m spacing. At age 13, significant differences were identified among provenances, but all sources were heavily attacked. No correlation was made between provenance latitude and attack success, or between attack and mean provenance height. The possibility of locating a provenance resistant to white pine weevil damage was considered improbable.

221 Garrett, P.W. 1986. Role of tree improvement in providing pest-resistant eastern white pine (*Pinus strobus* L.). Pages 75–88 *in* D.T. Funk, comp. Eastern white pine: today and tomorrow. Symposium proceedings, Durham, NH, 12–14 June 1985. Gen. Tech. Rep. WO-51. USDA For. Serv., Northeastern For. Exp. Stn., Durham, NH. 124 p.

A literature review was presented covering the three major problems of eastern white pine, *Pinus strobus* L. (white pine blister rust, *Cronartium ribicola* J.C. Fischer; white pine weevil, *Pissodes strobi* (Peck); and atmospheric pollutants), and the opportunities for pest resistance in eastern white pine through selection and/or breeding were discussed. Suggestions for developing resistance in eastern white pine included genetic improvement within the species, hybridization between eastern white pine and other resistant five-needle pines, and the possible introduction of nonnative white pines in the northeast.

222 Garrett, P.W.; Schreiner, E.J.; Kettlewood, H. 1973. Geographic variation of eastern white pine in the northeast. Res. Pap. NE-274. USDA For. Serv., Northeastern For. Exp. Stn., Upper Darby, PA. 14 p.

Geographic variation of eastern white pine (*Pinus strobus* L.) was investigated involving 32 provenances planted in 12 locations throughout the northeastern United States. After 10 years, the plantations were assessed for survival, height, branch number and angle, damage and form, secondary flushing, and presence of cones. Southern Appalachian and southern Ontario seed sources should be favored at least as far north as central Pennsylvania. From central Pennsylvania to southern Maine, growth of local and southern Appalachian sources was about the same. Farther north, above latitude 45°00′ N, use of local seed sources was recommended. Needle length was greatest in the southern provenances. Branching habit and damage were not important factors, but cone production was greater and earlier in the central and northern provenances.

223 Genys, J.B. 1987. Provenance variation among different populations of *Pinus strobus* from Canada and the United States. Can. J. For. Res. 17:228–235.

The survival, heights, and diameters were assessed for 117 eastern white pine (*Pinus strobus* L.) provenances from Canada and the United States. Particular emphasis was on the relationships between seed source and latitude, longitude, or altitude. Seedlings were raised in a nursery for two years and then outplanted in two Maryland plantations, one each on the Piedmont Plateau and the Coastal Plain. The plantations each contained four randomized blocks with each block containing four trees of each seed source. Heights were measured at age 10, and heights, diameters, and survival measured at age 16. Heights and diameters correlated directly with altitude and indirectly with latitude. In both locations, seedlings from northern provenances generally had the lowest survival and slowest growth. The seedlings with the best performance in Maryland were nonnative provenances from Tennessee, Kentucky, North Carolina, and Norfolk County, Ontario.

224 Genys, J.B. 1991. Genetic diversity in *Pinus strobus*: results of range-wide provenance studies in Maryland, 1965–1990. Pages 100–104 *in* P.W. Garrett, ed. Proceedings of a symposium on white pine provenances and breeding. IUFRO Working Party S2.02-15. XIX World Congress, Montréal, Quebec, 5–11 August 1990. Gen. Tech. Rep. NE-155. USDA For. Serv., Northeastern For. Exp. Stn., Radnor, PA. 105 p.

A 25-year-old study was evaluated to assess differences among many eastern white pine (*Pinus strobus* L.) seed sources. A total of 119 provenances from the United States and Canada were compared with a focus on three Maryland plantations. These plantations were established in three physiographically distinct regions. Each plantation consisted of four randomized blocks, and each block had four trees of each seed source. Many characteristics were compared among seed sources such as germination, seed coats, cotyledons, seed weights, terminal bud formation, leaf length, foliage color, survival, height, diameter, susceptibility to ozone and sulfur dioxide, vulnerability to white pine blister rust (*Cronartium ribicola* J.C. Fischer), susceptibility to white pine weevil (*Pissodes strobi* (Peck)), and cambial electrical conductivity. Differences in characteristics were assessed mainly in terms of the latitude of the seed sources. Eastern white pine seed sources were highly variable. Some provenances produced seedlings that were superior for wood and fiber, whereas others produced seedlings of greater resistance to damaging pollutants, disease, and insect pests.

225 Gerlach, J.P.; Reich, P.B.; Puettmann, K.; Baker, T. 1997. Species, diversity, and density affect tree seedling mortality from *Armillaria* root rot. Can. J. For. Res. 27:1509–1512.

Mortality from armillaria root rot caused by the fungus *Armillaria* spp. is a major concern of forest management, and this study was initiated to determine how the proportion of conifers in a plot influenced seedling mortality from

Armillaria spp. Two sites were clearcut in Minnesota and, with an incomplete factorial design of species mixtures and densities, replanted with six conifers including eastern white pine (*Pinus strobus* L.) and four hardwoods. Conifers were more susceptible to armillaria infection, and plots with a greater abundance of conifers tended to have higher infection and mortality rates. Greater species diversity or functional group diversity (mixtures of hardwoods with conifers) probably would reduce the levels of infection and mortality. Implications for management were still unclear as site and stand level factors were likely to affect the relative impact of species composition and diversity on disease.

226 Ghent, A.W.; Franson, S.E. 1986. Changes in mortality and size-class spatial distribution patterns in pre-closure and post-closure conifer plantations. For. Sci. 32:559–575.

Changes in spatial, tree-distribution patterns were investigated in plantations of red pine (*Pinus resinosa* Ait.) and white spruce (*Picea glauca* (Moench) Voss). Tree mortality and the distribution of living trees were followed for trees of different vigor classes. Frequencies of joins between trees of the same vigor class exceeded statistical expectations in a preclosure white spruce plantation and in both preclosure and postclosure red pine plantations in Ontario. Members of a preclosure vigor class tended to occur in clumps with members from the same vigor class. Lattice plantings of 17- and 18-year-old postclosure red pine showed consistently significant deficits of joins between members of the most vigorous (largest diameter) class of living trees, indicating a natural trend to regular distributions of the largest trees without the intervention of thinning.

227 Gillespie, A.R.; Hocker, H.W., Jr. 1986a. Thinning response of immature white pine. North. J. Appl. For. 3:148–150.

The response of immature eastern white pine (*Pinus strobus* L.) to thinning was tested in six, second-growth eastern white pine stands ranging from 24 to 57 years old in southern New Hampshire. Treatments assessed included thinning to B-line stocking, thinning to approximately 198 crop trees per hectare, and control. The plots were remeasured every two years for eight years. There were no significant differences in net basal area growth after eight years, but the thinned plots had a significantly greater diameter increment. Immature eastern white pine trees responded well to thinning and various thinning methods to meet different management objectives.

228 Gillespie, A.R.; Hocker, H.W., Jr. 1986b. The influence of competition on individual white pine thinning response. Can. J. For. Res. 16:1355–1359.

A model was developed to predict eastern white pine (*Pinus strobus* L.) diameter growth after thinning, and it included competition, initial diameter, and crown class as independent variables. Ninety trees were selected from two pole-sized stands in New Hampshire, both of which had been thinned in 1976. One stand was thinned to B-line stocking and the other stand was thinned to release approximately 200 trees per hectare. Growth response was measured at two-year intervals after thinning for eight years. Model coefficients indicated a decrease in eight-year diameter growth with increasing crown suppression, crown competition, or tree size class. The variables selected were age, percentage of live crown, and prethinning growth. Altering a tree's environment by thinning alters growth in proportion to the change in competition. Competition from neighboring trees was a key factor in growth response.

229 Gilmore, A.R.; Jokela, J.J. 1978. Relationship of wood specific gravity, height, and diameter of white pine to geographic source of seed. For. Res. Rep. No. 78-1. University of Illinois, Agric. Exp. Stn., Urbana, IL.

Seed was collected from 16 provenances of eastern white pine (*Pinus strobus* L.) from throughout its natural range for a study that began in 1955. At age 16, the plantation was thinned, and tree heights and diameter at breast height (dbh) were measured. A one-inch cross section from the stump end of the butt log was taken to determine wood specific gravity. Wood specific gravity was determined from oven-dry weights and green volume. The sample volume was calculated using the water displacement principle. Significant differences in wood specific gravity (0.315–0.358) were noted between provenances, but no correlation was found between wood specific gravity and geographic location, or tree volume (height and dbh). Forty-two percent of the variation in wood specific gravity was explained by dbh alone.

230 Gilmore, D.W.; O'Brien, T.C.; Hoganson, H.M. 2005. Thinning red pine plantations and the Langsaeter hypothesis: a northern Minnesota case study. North. J. Appl. For. 22:19–26.

This study examines the Langsaeter hypothesis that the total production by volume of a red pine (*Pinus resinosa* Ait.) stand of a given age and composition on a given site is constant and optimum throughout a wide range of stocking densities. Ten-year postthinning stem measurements were taken from four red pine plantation plots with three different, nonreplicated thinning treatments: geometric strip thinning, crown thinning, and a thinning from below whereby the high-quality larger diameter trees were retained. The stand was 46 years old at the time of measurement. The response to thinning was attributable mainly to the reduction in basal area relative to the other thinning treatments versus the specific thinning

prescriptions themselves. There was no strong evidence to support Langsaeter's hypothesis.

231 Gilmore, D.W.; Palik, B.J., comps., eds. 2006. A revised managers handbook for red pine in the North Central Region. Gen. Tech. Rep. NC-264. USDA For. Serv., North Central Res. Stn., St. Paul, MN. 55 p.

A comprehensive overview was developed to describe various approaches to red pine (*Pinus resinosa* Ait.) management to address many current red pine management issues. Changes in management objectives such as managing red pine at the landscape level and managing multi-aged stands have created new challenges not addressed in previously published management guides. This guide focuses mainly on three management goals: production management, extensive management, and reserve management. A decision key was developed to guide the landowner to applicable management practices including conserving red pine genetics and the establishment and management of stands for ecological complexity.

232 Godman, R.M. 1962. Red pine cone production stimulated by heavy thinning. Tech. Note No. 628. USDA For. Serv., Lake States For. Exp. Stn., St. Paul, MN. 2 p.

A thinning experiment was set up in a red pine (*Pinus resinosa* Ait.) plantation in Michigan, leaving residual densities of 13.8, 18.4, 23.0, 27.5, 32.1, and 36.7 m^2/ha. In the fall of a poor seed year, cones were counted when the twice-thinned plantation was 51 years old. The percentage of trees bearing cones was inversely proportional to the residual basal area. At the higher stand densities, the few trees with cones tended to be the dominant trees in the stand, and generally had small crown openings to the south or west. Maximum yield per hectare should occur at a residual density of about 18.6 m^2/ha.

233 Goebel, N.B.; Cool, B.M. 1968. Releasing white pines after 20 years of suppression in the upper Piedmont of South Carolina. For. Farmer 27:9, 22.

Surviving trees of an eastern white pine (*Pinus strobus* L.) underplanting in a hardwood stand in South Carolina were released after 20 years of severe suppression. The released eastern white pine had an average height of 1.2 m at the time of release. Nine years after release, height growth had doubled and the survival rate was 20% higher for the released trees. The tallest eastern white pine at the time of release showed the greatest height gain after release.

234 Gould, E.M., Jr. 1986. Where have all the forests gone? Long time passing. Pages 22–25 *in* D.T. Funk, comp. Eastern white pine: today and tomorrow. Symposium proceedings, Durham, NH, 12–14 June 1985. Gen. Tech. Rep. WO-51. USDA For. Serv., Northeastern For. Exp. Stn., Durham, NH. 124 p.

The history of eastern white pine (*Pinus strobus* L.), specifically in New England, began 15 000 years ago when the ice left the area of New England. Eastern white pine was probably more plentiful 5000–8000 years ago. The species was very important to the American colonists for a variety of uses. Recorded forest regulations from the time of the colonists provide a valuable commentary on the interaction between pine trees and people. Unforeseen events played a central role in the shaping of New England's forests. In the future, management plans must be designed to be flexible and capable of coping with radical and unexpected changes

235 Gower, S.T.; Son, Y. 1992. Differences in soil and leaf litterfall nitrogen dynamics for five forest plantations. Soil Sci. Soc. Am. J. 56:1959–1966.

The influences of five species including eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.) with different leaf life spans on leaf litterfall and soil N dynamics were examined using a randomized block design with four replicates. In Wisconsin on loess soils, five species, red oak (*Quercus rubra* L.), European larch (*Larix decidua* Mill.), eastern white pine, red pine, and Norway spruce (*Picea abies* (L.) Karst.), were planted, and all species within a block were planted on the same soil series. After 28 years, soil samples were taken and analyzed. Nitrogen mineralization was assessed by the buried-bag incubation method, and litterfall was collected for two years for which annual N content per plot was calculated. Leaf litterfall N content did not differ significantly among the five species. Annual net N mineralization and nitrification rates did differ significantly among the five species, demonstrating that tree species could modify soil N mineralization rates in a relatively short time period.

236 Graber, R.E. 1965. Germination of eastern white pine seed as influenced by stratification. Res. Pap. NE-36. USDA For. Serv., Northeastern For. Exp. Stn., Upper Darby, PA. 9 p.

The influence of stratification temperature and length of stratification period on the completeness and speed of germination in eastern white pine (*Pinus strobus* L.) seed was examined for the first time using a statistical approach. Seed was collected from three sources in southwestern Maine and stratified at 2.2, 4.4, and 10.0°C, for 10, 30, 60, and 90 days. All treatments were replicated three times with one control for each seed source. A second study included stratification of seed from one source at 4.4°C for 1, 5, 20, and 45 days. The length of the stratification period was the major factor influencing germination. Almost complete germination occurred after

30 days or more of stratification regardless of stratification temperature or seed source. The most rapid germination was by seed stratified for 90 days.

237 Graber, R.E. 1968. Planting site, shade, and local seed source: their effects on the emergence and survival of eastern white pine seedlings. Res. Pap. NE-94. USDA For. Serv., Northeastern For. Exp. Stn., Upper Darby, PA. 12 p.

Eastern white pine (*Pinus strobus* L.) seeds were collected in southwestern Maine and direct-seeded on two sites, one with a moist Sutton loam soil and the other with a droughty Windsor loamy sand. At each site, two light intensity treatments, 85 and 40% of full sunlight, were tested. Seedling survival was about equal between sites and shade treatments, but seedling losses due to each of the two major causes of mortality (failure to establish and damping-off) were strongly influenced by the site and shade treatment. Nearly all losses due to damping-off occurred on the moist site, whereas most mortality due to failure to establish occurred on the dry site.

238 Graber, R.E. 1970. Natural seed fall in white pine (*Pinus strobus* L.) stands of varying density. Res. Pap. NE-119. USDA For. Serv., Northeastern For. Exp. Stn., Upper Darby, PA. 6 p.

Seedfall was assessed during a good seed year and a bad seed year in mature eastern white pine (*Pinus strobus* L.) stands in southwestern Maine in three stand densities: 42.9, 27.5, and 18.4 m^2/ha of basal area. Total seedfall in the intermediate-density stand was significantly higher (50%) than the seedfall in the low- and high-density stands. Seedfall peaked in late September, and time of seedfall was not related to stand density. Amount of pine seed in the intermediate stand was 4.4 million seeds per hectare in a good seed year and 1.0 million seeds per hectare in a bad seed year.

239 Graber, R.E. 1988. Stem quality of white pine established by seeding in furrows and by planting. North. J. Appl. For. 5:128–129.

The quality of eastern white pine (*Pinus strobus* L.) established by direct seeding was compared with the quality of planted seedlings. Eastern white pine was direct-seeded in furrows on a site in New England with a Gloucester sandy loam soil. Four years later, several seedlings were handlifted and planted at 1.8 × 1.8 m spacing to compare the quality of eastern white pine established by seeding with the quality of eastern white pine in a plantation. The density of the seeded pines was almost three times higher than the planted pines, but their diameter was smaller. Differences in mean tree height were minimal. Planted trees showed more injuries caused by white pine weevil (*Pissodes strobi* (Peck)), which significantly influenced stem quality. This study supported earlier work illustrating that frequency and severity of white pine weevil damage could be reduced to low levels when eastern white pine was grown in high-density stands.

240 Grafton, W.N.; Carvell, K.L. 1970. Growth response of white pine seedlings to release after heavy single-tree selection cuttings. Castanea 35:136–144.

The response of understory eastern white pine (*Pinus strobus* L.) seedlings following single-tree selection cutting was examined in mixed oak (*Quercus* spp.) and eastern white pine stands in southeastern West Virginia. Thirteen 0.4-ha circular plots were set up in partially harvested areas, and the height of all eastern white pine seedlings 65 cm or taller was measured the year before and the year of release and in four consecutive years after release. The number of buds set the year before, the year of, and the year after release was recorded as well. Understory eastern white pine seedlings responded rapidly to release after single-tree selection cutting, and height growth the first year after release was controlled primarily by conditions prevailing before cutting. Height increment in the year of release was found to be the best indicator of future growth response. The number of lateral buds was a measure of seedling vigor and expected to be related to height increment.

241 Green, J.C. 1992. Ecological features of white pine stands for wildlife. Pages 44–53 *in* R.A. Stine and M.J. Baughman, eds. White pine symposium proceedings: history, ecology, policy and management, Duluth, MN, 16–18 September 1992. University of Minnesota, Extension Service Distribution Center, St. Paul, MN. 202 p.

The ecological features of eastern white pine (*Pinus strobus* L.) stands that are important for birds, which were used as a surrogate for wildlife, were examined through a literature review. A compilation of information on habitat specialists and avian communities in relation to eastern white pine was presented for eastern white pine as a species and as a community. The complexity of the vegetation in old-growth stands that have many layers and a variety of tree and understory species made these older eastern white pine forests important for wildlife. Diversity in eastern white pine forests should be maintained, both for eastern white pine itself and for all the benefits it imparts to wildlife.

242 Grigal, D.F.; Arneman, H.F. 1970. Quantitative relationships among vegetation and soil classifications from northeastern Minnesota. Can. J. Bot. 48:555–566.

Forty upland forest stands including eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.) stands in Minnesota were sampled to determine relationships between vegetation

and soils. Vegetation was sampled at 10 randomly located points in each stand, and a soil pit was dug near the center of each stand. Soil samples were analyzed, and the 40 stands were classified into groups based on three criteria: vegetation, soils, and environment. Classification based on basal area of overstory was very similar to the cover type classification but neither was related closely to the soil or environmental classifications. Classification based on species frequency excluding single-stand species was relatively closely related to other classifications such as soil and environmental classifications. Probably the single best criterion of classification for forest stands in northeastern Minnesota was frequency of all species.

243 Gross, H.L. 1985a. Impact of pests on the white pine resource of Ontario. Proc. Entomol. Soc. Ont. 116(Suppl.):33–37.

The importance of intensively managing eastern white pine (*Pinus strobus* L.) including adequate pest management was emphasized as vital to growing satisfactory eastern white pine. Insect pests and diseases of eastern white pine were described and discussed. White pine weevil (*Pissodes strobi* (Peck)) was the most important insect pest of eastern white pine and caused major volume losses. White pine blister rust (*Cronartium ribicola* J.C. Fischer) was the most important disease of eastern white pine and caused stem and branch cankers that eventually killed the stem or branch. Annual losses caused by decay were estimated at approximately 22 100 m^3 of gross merchantable volume in Ontario.

244 Gross, H.L. 1985b. White pine blister rust: a discussion of the disease and hazard zones for Ontario. Proc. Entomol. Soc. Ont. 116(Suppl.):73–79.

Literature on white pine blister rust (*Cronartium ribicola* J.C. Fischer) was reviewed, and methods of hazard zoning developed in the Lake States were applied to Ontario. Four hazard zones were identified (low, intermediate, high, and severe) from previous surveys of eastern white pine (*Pinus strobus* L.) plantations. Pruning the highly susceptible lower branches from eastern white pine was recommended to control the disease. Vegetational and topographic features were correlated with infection hazard.

245 Grossman, G.H.; Potter-Witter, K. 1991. Economics of red pine management for utility pole timber. North. J. Appl. For. 8:22–25.

A range of management options were compared using simulation modeling that included utility pole production as well as sawtimber and pulpwood production to examine their effects on increasing landowner revenue. Stands with a density >2200 trees per hectare or stands thinned to a basal area of 25.3 m^2/ha were considered suitable for production. Management alternatives were simulated for common Lake States practices in high site index red pine (*Pinus resinosa* Ait.) plantations with thinning strategies consisting of light and heavy thinnings. If landowners estimated 30% of the stands to be poles at age 45, the soil expectation values (4% discount rate) would increase by $47/ha on site index 60 and $247/ha on site index 75. If real price increases in sawtimber and poles were expected, returns could increase by $608/ha on site index 60 and $890/ha on site index 75. If the market existed, landowners who managed to increase the percentage of poles from red pine plantations would have increased revenues.

246 Gunter, J.E.; Rudolph, V.J. 1968. Economics of red pine release on the Fife Lake State Forest. Mich. Agric. Exp. Stn. Q. Bull. 50:507–519.

The economic aspects of releasing underplanted red pine (*Pinus resinosa* Ait.) from competing oak (*Quercus* spp.) were examined on the Fife Lake State Forest in Michigan's Lower Peninsula. All oaks >30 cm at stump were cut at age 40–80 when the pines were approaching 40 years old. Two treatments were evaluated: full release and intensive management, and no release and extensive management. The results demonstrated that releasing red pine plantations from low-quality overstory hardwoods was economically favorable. The full release, intensive management method was recommended for managing red pine for maximum production.

247 Guyette, R.P.; Dey, D.C. 1995. Age, size and regeneration of old growth white pine at Dividing Lake Nature Reserve, Algonquin Park, Ontario. For. Res. Rep. No. 131. OMNR, OFRI, Sault Ste. Marie, ON. 11 p.

Although much attention focused on protecting some old-growth eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.) ecosystems in Ontario, little information existed on their structure or function or about the natural disturbance processes that formed them. Increment cores were taken and diameter at breast height measured 1.4 m aboveground for 28 dominant pine trees; their slope and aspect were also noted. Germination dates were estimated and the mode of regeneration determined. Trees varied by at least 200 years, and 20% of sampled trees were older than 400 years. Advanced regeneration was the most common mode of regeneration. The development of this multi-aged pine forest resulted from relatively frequent minor disturbances from surface fires and windthrow, and infrequent major disturbances caused by more intense forest fires.

248 Haberland, F.P.; Wilde, S.A. 1961. Influence of thinning of red pine plantation on soil. Ecology 42:584–586.

The changes in physical, chemical, and microbiological properties of soil were assessed after heavy thinning of

a dense red pine (*Pinus resinosa* Ait.) plantation. In a 15-year-old red pine plantation in central Wisconsin on a nonpodzolic outwash sand of Plainfield series, plots were set up in a fully stocked, and in a thinned part (to 50% of the basal area) of the plantation, and on adjacent cleared land. Soil moisture, percolation of water, movement of soluble nutrient salts, and chemical composition of the soil and forest litter were determined. A heavy thinning created more light, water, and nutrients for released trees. But the soil suffered an appreciable loss of organic matter. It was considered more important to avoid a deterioration of the stand and site quality than to achieve an immediate increase in diameter growth.

249 Haider, W. 1994. The aesthetics of white pine and red pine forests. For. Chron. 70:402–410.

Stand aesthetics values and perception of old-growth forests in northeastern Ontario were studied using the Scenic Beauty Estimation method, which relates psychometric analysis to quantitative forest stand characteristics and has been widely applied elsewhere in landscape research. There was a high agreement for scenic beauty in this study between environmental groups and other public groups but less agreement between either of these and resource managers. Linking people's aesthetic evaluations to physical stand characteristics might provide valuable insights for forest management alternatives.

250 Haig, R.A.; Cayford, J.H. 1960. Factors affecting survival and growth of red pine plantations in southeastern Manitoba. Tech. Note No. 93. Department of Northern Affairs and National Resources, Forestry Branch, Ottawa. 17 p.

In southeastern Manitoba, red pine (*Pinus resinosa* Ait.) was first planted in 1927 on areas that originally supported jack pine (*P. banksiana* Lamb.). Forty-one red pine plantations between 12 and 27 years old were assessed for growth and survival, and limited observations were made of the most important factors affecting growth and survival. Forty-two percent of the planted area was satisfactorily stocked. The main factors influencing red pine development were drought, plantation density (increasing density showed an increase in height and diameter), occurrence of jack pine (increasing amount of jack pine was responsible for increasing survival but decreasing growth), and soil conditions (in relation to drought). Drought in the year of planting was considered to be the main cause of low survival rates. Despite a low survival rate and slow growth, health and form of the surviving trees was excellent. Red pine was recommended for planting in southeastern Manitoba on moderate fresh to fresh sites with a maximum spacing of 1.8 × 1.8 m.

251 Hallet, R.A.; Hornbeck, J.W. 1997. Foliar and soil nutrient relationships in red oak and white pine forests. Can. J. For. Res. 27:1233–1244.

Foliar levels and soil nutrients were assessed in five pure stands of eastern white pine (*Pinus strobus* L.) and red oak (*Quercus rubra* L.) growing on sandy soils in northern New England and New York. Soils were classified on the basis of complete soil-pit descriptions, and a stand survey was completed for each plot by recording species, diameter, and height for all trees with a diameter at breast height of >10 cm. Foliar Ca in red oak was more than three times the amount in eastern white pine foliage, and red oak foliage also had more Mg, K, and N. Some nutrients were at low levels because of acid precipitation and past land use, and nutrient limitations might have had a negative impact on growth. But in this particular study, trees showed higher than average growth rates. Low concentrations of extractable elements in the A and B horizons on all sites emphasized the importance of the forest floor in supplying nutrients for tree growth.

252 Hamelin, R.C.; Bourassa, M.; Rail, J.; Dusabenyagasani, M.; Jacobi, V.; Laflamme, G. 2000. PCR detection of *Gremmeniella abietina*, the casual agent of Scleroderris canker of pine. Mycol. Res. 104:527–532.

An efficient and reliable detection method was developed for the detection and differentiation of the North American and European race of *Gremmeniella abietina* var. *abietina* Petrini et al. the causal agent of scleroderris canker of pine, directly from infected tissues. A polymerase chain reaction (PCR) approach was used to increase sensitivity of detection, which allowed for the detection of *G. abietina* var. *abietina* in needles of inoculated symptomatic and asymptomatic seedlings. A total of 56 red pine (*Pinus resinosa* Ait.) fascicles and 48 jack pine (*P. banksiana* Lamb.) fascicles were collected from various locations within the distribution range of scleroderris canker in Quebec and were tested for the presence of *G. abietina* var. *abietina.* From each fascicle, one needle was tested using the PCR approach and another needle was used in fungus isolation and culture procedures. The method showed successful detection and race identification of the North American and European races of *G. abietina* var. *abietina* directly from infected tissues without having to culture the fungus.

253 Hannah, P.R. 1988. The shelterwood method in northeastern forest types: a literature review. North. J. Appl. For. 5:70–77.

Studies on the shelterwood method between the early 1800s and 1988 were reviewed, particularly in the northeastern forests, and they suggested that eastern white pine

(*Pinus strobus* L.) could be regenerated effectively with a two- or three-cut shelterwood method. The approach needed to achieve the following conditions: (1) conduct first cut at or after good seedfall and reduce canopy cover to about 50%; (2) obtain good mineral soil exposure for seedling establishment; (3) control competing hardwood by cutting or using herbicides; and (4) remove overstory when pines are about 1.5 m tall or less to minimize seedling damage, or remove overstory in two or more cuts and grow regeneration 4.6–6.1 m tall under partial shade to minimize white pine weevil (*Pissodes strobi* (Peck)) damage.

254 Harman, D.M. 1975. Movement of individually marked white pine weevils, *Pissodes strobi*. Environ. Entomol. 4:120–124.

A total of 104 marked white pine weevils (*Pissodes strobi* (Peck)) were released in a 12-year-old eastern white pine (*Pinus strobus* L.) stand in Maryland, and their individual movements were recorded between May 10 and June 14, 1972. Of the recovered white pine weevils, 57% changed trees only once and none changed trees more than four times. Movement direction was significantly correlated with the direction of tree rows. Twenty-four percent of the white pine weevils were never found and might have left the area entirely or died. Disruptive effects of capturing and marking should also be considered. But springtime dispersal activity of white pine weevil adults was characterized by a sizeable percentage of the population being mobile, few movements, and moving relatively short distances.

255 Hartman, J.P.; Buckley, D.S.; Sharik, T.L. 2005. Differential success of oak and red maple regeneration in oak and pine stands on intermediate-quality sites in northern Lower Michigan. For. Ecol. Manag. 216:77–90.

The success of natural red oak (*Quercus rubra* L.) and red maple (*Acer rubrum* L.) regeneration in oak (*Quercus* spp.) and pine (*Pinus* spp.) cover types in Michigan was compared after canopy and understory treatments. Three natural oak stands (88–100 years old) and three red pine (*Pinus resinosa* Ait.) plantations (59–75 years old) were studied. Each stand was subdivided into 0.44-ha plots that received one of four canopy treatments at random: clearcut, 25% canopy cover, 75% canopy cover, and control. Overstory plots were subdivided into 0.02-ha understory plots that received four treatments at random: shrub layer removal, herb layer removal, control, and litter removal in small (1-m^2) plots. Plots were sampled 10 years after treatment. Most oak seedlings were found in the 25% canopy cover treatment in both pine and oak stands, but oak regeneration <2.5 cm diameter at breast height was significantly less abundant in pine than in oak stands. However, it was generally free to grow in the pine stands. The majority of oak regeneration was found in subplots where red maple was mechanically removed. Restoring red pine on sites of intermediate quality where red maple was a competitor would increase the abundance of red pine and provide a better understory environment for the regeneration of oak.

256 He, H.S.; Mladenoff, D.J.; Gustafson, E.J. 2002. Study of landscape change under forest harvesting and climate warming-induced fire disturbance. For. Ecol. Manag. 155:57–270.

A spatially explicit landscape model, LANDIS, was used to predict changes in forest composition in a variety of ecoregions in northern Wisconsin given different simulated climate warming and fire disturbances. Indivdual trajectories of species abundances were compared under different conditions. Because of climate warming, shifts in species composition were seen as well as an overall decrease in forest cover. Red pine (*Pinus resinosa* Ait.) abundance increased from 8 to 20% under current circumstances but decreased to 0% under warming conditions. Eastern white pine (*P. strobus* L.) maintained its abundance of 20% under current conditions but declined to 3% under warming conditions. At the ecosystem or landscape level, species abundance and distribution information generalized from the model simulation could provide overall estimates of landscape pattern changes.

257 Heckman, S.T. 1992. White pine management on the Menominee and its evolutionary process. Pages 157–167 *in* R.A. Stine and M.J. Baughman, eds. White pine symposium proceedings: history, ecology, policy and management, Duluth, MN, 16–18 September 1992. University of Minnesota, Extension Service Distribution Center, St. Paul, MN. 202 p.

A declining number of eastern white pine (*Pinus strobus* L.) in the Menominee Forest, Wisconsin, and the absence of natural regeneration in the majority of sawtimber stands led to intensive investigation of the silvicultural requirements of eastern white pine and its regeneration in particular. A method for naturally regenerating eastern white pine was developed from on-site, seedfall, seed viability, germination, and seedling establishment investigation, combined with research outside the Menominee Forest. The method emphasized scarification of seedbed, manipulation of the overstory canopy, and control of understory competition. Scarification was usually delayed until several years after the regeneration cut to allow for drying and initial decomposition of logging residue. Scarification and herbicide treatment were to take place in late summer of an expected good seed year.

258 Heckman, S.T.; Pecore, M.J.; Sloan, K.R. 1986. Natural white pine regeneration: site requirements. Pages 57–61 *in* D.T. Funk, comp. Eastern white pine: today and tomorrow. Symposium proceedings, Durham, NH, 12–14 June 1985. Gen. Tech. Rep. WO-51. USDA For. Serv., Northeastern For. Exp. Stn., Durham, NH. 124 p.
A series of field trial areas was set up in the Menominee Indian Reservation in north central Wisconsin to systematically evaluate the cumulative impact of site, crown density, scarification, and brush control on the various stages of eastern white pine (*Pinus strobus* L.) seedling establishment and early growth. Scarification combined with a sufficient reduction in canopy density had a substantial impact on first-year survival. After the first year, hardwood and brush competition was found to be the dominant factor affecting establishment and survival.

259 Heeney, C.J. 1978. Silvicultural requirements of white and red pine management. Pages 53–59 *in* D.A. Cameron, comp. White and red pine symposium, Chalk River, ON, 20–22 September 1977. Symposium Proceedings O-P-6. Department of the Environment, Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. 178 p.
An overview of silvicultural requirements of eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.) in Ontario suggested that eastern white and red pine should be managed according to an even-aged management system rather than an uneven-aged system. Basic pine sites were described including deep, sandy outwash plains; shallow, sandy sites on low, granitic ridges; and glacial tills. The most appropriate silvicultural systems were discussed including clearcutting, strip cutting, and uniform shelterwood. Finally, ministry records were reviewed to assess eastern white and red pine regeneration. Generally, eastern white pine regeneration was found to be insufficient in Ontario.

260 Heinselman, M.L. 1981. Fire intensity and frequency as factors in distribution and structure of northern ecosystems. Pages 7–57 *in* H.A. Mooney, T.M. Bonnicksen, N.L. Christensen, J.E. Lotan, W.A. Reiners, eds. Fire regimes and ecosystem properties. Conference proceedings, Honolulu, HI, 11–15 December 1978. Gen. Tech. Rep. WO-26. USDA For. Serv., Washington, DC.
An understanding of the role of fire is necessary to understand the dynamics of most forest ecosystems in northern North America. A fire regime in most red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.) stands of infrequent moderate surface fires had an average return interval of 36 years with about 160-year intervals between severe fires. Two classes of pine forests from the standpoint of fire regimes were the classic pure red and eastern white pine groves with little understory development and almost no mixture of shade-tolerant conifers or hardwoods, and eastern white pine forests (with little red pine) with significant stand components of shade-tolerant conifers or hardwoods. The first class was in more fire-prone physiographic situations, whereas the second class seemed to be better protected by its physiographic location. In presettlement time, vegetation of many northern ecosystems was structured by fire in composition, vertical stratification, and horizontal arrangement of plant communities. In the far north, fire had maintained the structure and pattern of the forest mosaic. In other areas, the forest mosaic was modified greatly by logging, human-caused fires, and fire suppression.

261 Henning, S.J.; Dickmann, D.I. 1996. Vegetative responses to prescribed burning in a mature red pine stand. North. J. Appl. For. 13:140–146.
The effects of low-intensity prescribed spring surface fires in northern Lower Michigan were investigated in a widely spaced mature red pine (*Pinus resinosa* Ait.) plantation growing on a high-quality sandy loam soil. The plantation was divided into blocks, and plots were set up within each block and randomly assigned a spring burning treatment with a fire frequency of 2, 5, or 10 years or an unburned control. The red pine overstory was affected minimally by all fires. No detectable differences in total percentage cover or richness of ground flora species occurred among treatments, but they did differ by block. Species richness of the woody understory declined as the burning interval decreased and the number of burns increased. Managers of red pine ecosystems should consider surface fires with intervals depending on management goals to establish natural regeneration.

262 Herr, D.G.; Duchesne, L.C. 1996. Effects of organic horizon removal, ash, watering regime, and shading on red pine seedling emergence. Can. J. For. Res. 26:422–427.
The effects of postfire soil organic horizon thickness, ash, shade regime, and water regime were examined on red pine (*Pinus resinosa* Ait.) seedling emergence. A total of 225 soil monoliths were collected from the forest floor of the Frontier Lake experimental site at Petawawa in the Great Lakes–St. Lawrence forest region. The organic horizon was measured, and then 100, 75, 25, or 0% of the organic horizon was removed from each monolith. Removed organic horizons were combined and burned. A split treatment was created for each monolith either with or without ash. Monoliths were then seeded with red pine seed in a greenhouse with a randomized complete block design with different watering regimes assigned randomly. Watering treatments consisted of 25, 50, 75,

or 100% of the average rainfall for June. Shade regimes consisted of 25, 50, 75, or 100% of photosynthetically active radiation. No red pine seedlings emerged on the control monoliths or control water regime. Overall, red pine emergence was highest under high water regimes, increased shade regimes, and increased organic horizon removal. Ash consistently reduced red pine seedling emergence. These results were derived from greenhouse experiments, but they should help in determining the postfire seedbed conditions required for optimal red pine seedling emergence.

263 Hibbs, D.E. 1982. White pine in the transition hardwood forest. Can. J. Bot. 60:2046–2053.

In some older hardwood stands in New England, eastern white pine (*Pinus strobus* L.) trees were the tallest trees. Because it was not clear how eastern white pine, with an initial slow growth rate and only moderate shade tolerance, could outgrow the hardwoods, the author reconstructed the development of the successful eastern white pines. Stands were sampled, and codominant and dominant eastern white pine were felled and sectioned into 1.2-m units, aging each section by counting annual rings. Several possibilities were found for the successful regeneration of eastern white pine in hardwood stands: (1) group reproduction in dense hardwood stands, (2) single pine regeneration if hardwood competition was low, (3) advanced regeneration from previous stands, and (4) in mature forests, regeneration in canopy gaps.

264 Hibbs, D.E. 1983. Forty years of forest succession in central New England. Ecology 64:1394–1401.

A 40-year study of succession was conducted in New England with permanent sample plots after canopy removal by a 1938 hurricane. Eleven permanent sample plots were examined, 10 of which had supported unmanaged, mature (50+ years) eastern white pine (*Pinus strobus* L.) originating on abandoned farmland with considerable hardwood regeneration. After 40 years, eastern white pine was found in a third of the codominant canopy positions but not in dominant ones. Red maple (*Acer rubrum* L.) was most abundant, accounting for almost a third of all stems but only 9.6% of the basal area. Eastern white pine accounted for 23.3% of the stems and 34.3% of the basal area. Generally, three stages in canopy position and structure were identified. Natural mortality due to limits to longevity and species-specific patterns in the rates of height growth were possibly the driving forces behind this period of succession.

265 Hibbs, D.E.; Bentley, W.R. 1987. White pine management: volume and value growth. North. J. Appl. For. 4:197–201.

A simulation model for thinned and unthinned eastern white pine (*Pinus strobus* L.) stands was developed to estimate the volume and financial yields, which were sensitive to site quality and responsive to the effects of thinning. Two phases were distinguished: phase one modeled the early growth of normally stocked, unmanaged stands; phase two began with the first thinning and continued with a 10-year thinning cycle. The model gave either an economical balance between the time required to increase basal area and cost of carrying, or a balance between decreasing rates of volume and final harvesting (that is, opportunity cost of carrying timber). Precommercial thinning was not recommended, and first thinnings were suggested as average tree size reached commercial minimums at age 45–60, and a final harvest at 60–75 years.

266 Hills, G.A.; Pierpoint, G. 1960. Forest site evaluation in Ontario. Res. Rep. No. 42. Ontario Department of Lands and Forests, Toronto, ON. 64 p.

A classification system was developed for sites in Ontario to evaluate their potential productivity for a variety of crops, and it included an assessment of factors that affect the choice and success of treatments. The system consisted of two parts with the first part outlining the classification of sites into types. The second part evaluated these types and illustrated how the system could be used when managing a forest area. In part two, present and potential production of eastern white pine (*Pinus strobus* L.) on a reference area was used as an example. Because future forest production depends on both physiographic features and characteristics of the present forest, the units were evaluated using both the living and nonliving site components.

267 Hocker, H.W., Jr. 1961. Germination of eastern white pine seed and early establishment of white pine seedlings on prepared sites. Tech. Bull. No. 103. New Hampshire Agric. Exp. Stn., Durham, NH. 15 p.

The effectiveness of site preparation in the germination and early establishment of eastern white pine (*Pinus strobus* L.) seed loss to birds and rodents, and microclimatic differences resulting from treatment were studied in two clearcut, 155- and 65-year-old eastern white pine stands. In the first stand, four treatments were assigned randomly to four 2 × 2 m plots: spraying, slash burning, scarification, and control. Four subplots were set up in each plot for direct seeding, of which two were caged. In the second stand, three plots 1 × 1 m were established with three treatments: slash burning, scarification, and control, and three types of direct seeding: caged, unprotected, and one with treated seed. After one year, treated seedbeds enhanced the germination and survival of eastern white pine seedlings more than untreated seedbeds, and best results were attained on the scarified seedbeds with treated seed.

268 Hodges, C.S. 1986. Diseases of eastern white pine. Pages 93–98 *in* D.T. Funk, comp. Eastern white pine: today and tomorrow. Symposium proceedings, Durham, NH, 12–14 June 1985. Gen. Tech. Rep. WO-51. USDA For. Serv., Northeastern For. Exp. Stn., Durham, NH. 124 p.

Some of the more important diseases of eastern white pine (*Pinus strobus* L.) were described and means for their prevention or control discussed. White pine blister rust (*Cronartium ribicola* J.C. Fischer) caused severe losses in eastern white pine stands, and *Ribes* spp. eradication was recommended. Removing lower branches was also an effective means of control. White pine root decline caused by *Verticicladiella procera* was a relatively new problem in eastern white pine but could cause losses in Christmas tree plantations of up to 20%. Little was known about the disease, but avoiding planting on heavy, poorly drained soils, removing infected trees, and not replanting infested areas with eastern white pine were recommended. Basal canker of eastern white pine is similar to white pine root decline, but the progress of basal canker is slower. Chewing wounds created by ants provided openings for the basal canker-causing fungus, allowing it to invade the tree. Losses from the disease could be decreased by direct control of ants. Eastern white pine was also found to be very sensitive to several air pollutants, such as ozone, sulfur dioxide, nitrogen oxides, and fluoride.

269 Hoff, R.; Bingham, R.T.; McDonald, G.I. 1980. Relative blister rust resistance of white pines. Eur. J. For. Pathol. 10:307–316.

The mechanisms of resistance to white pine blister rust (*Cronartium ribicola* J.C. Fischer) that had been observed in resistant crosses of western white pine (*Pinus monticola* Dougl. ex D. Don) were compared with mechanisms in the more resistant Eurasian pines along with levels of resistance in various North American pines. A total of 17 pine species were examined. The resistance mechanisms observed were prevention of needle injury, reduced frequency of needle injuries, premature shedding of infected needles, fungicidal reaction in the short shoot, reactions that eliminate established bark infections, and the ability of a seedling to remain alive when infected. Eastern white pine (*P. strobus* L.) was most susceptible to white pine blister rust, and the most frequent mechanism of resistance was a mechanism that prevented the fungus from infecting the needles, which was found in 70% of the Eurasian pines and in 15% of the North American pines.

270 Holla, T.A.; Knowles, P. 1988. Age structure analysis of a virgin white pine, *Pinus strobus*, population. Can. Field-Nat. 102:221–226.

The age and structure characteristics of a mature, undisturbed eastern white pine (*Pinus strobus* L.) stand were investigated using life table analysis. On the southern shore of Sandford Lake, northwestern Ontario, a 34.5-ha area was sampled using the point-centered quarter method coupled with the transect method. Diameter and increment cores of eastern white pine were taken. The age of some seedlings and saplings was estimated by counting the bud scale scars or branch whorls. Destructive harvest of some small trees allowed for ring counts to verify ages. Trees that could not be aged by cores were aged using least-squares regression curves of age versus diameter. Apart from the large number of trees in the lower age group and size class, there was generally a similar number of eastern white pine in each age class, which suggested population stability. Stability was typical of shade-tolerant climax species. The age-distribution patterns also indicated continual recruitment and fire disturbance. The results showed high mortality for eastern white pine in the first 10 years. Trees that survived this initial vulnerable period then gained a high probability of longevity.

271 Honer, T.G.; Ker, M.F.; Alemdag, I.S. 1983. Metric timber tables for the commercial tree species of central and eastern Canada. Department of the Environment, Canadian Forestry Service, Maritimes Forest Research Centre, Fredericton, NB. Information Report M-X-140. 139 p.

Metric yield tables were presented for 21 major commercial species of central and eastern Canada, which included both eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.). Four types of tables provided estimates for total volumes; merchantable volumes; ratios of merchantable volumes to total volumes for various stump heights, top diameters, and merchantable lengths; and diameters inside and outside bark for stump height, breast height, and sections of the lower bole. Volume equations were standardized and based on existing form-class volume tables as well as some additional measurements from various research and management studies.

272 Hornbeck, J.W.; Smith, R.B.; Federer, C.A. 1988. Growth trends in 10 species of trees in New England, 1950–1980. Can. J. For. Res. 18:1337–1340.

Red spruce (*Picea rubens* Sarg.) and balsam fir (*Abies balsamea* (L.) Mill.) showed a decrease in growth since the 1960s. To find out whether other species showed similar trends, the growth trends of 10 species including eastern white pine (*Pinus strobus* L.) were determined by examining over 5000 increment cores from several thousand plots randomly located in New England. Red spruce and balsam fir were the only species showing negative growth curves, confirming previous studies. The mean growth rate of eastern white pine was the greatest but might have indicated that the sampled eastern

white pine was considerably younger than most of the other species.

273 Horton, K.W. 1962. Regenerating white pine with seed trees and ground scarification. Tech. Note No. 118. Department of Forestry, Ottawa. 19 p.

A combination of potential treatments was tested for regenerating eastern white pine (*Pinus strobus* L.) in western Quebec. Lightly stocked eastern white pine stands about 160 years old were scarified and thinned leaving about 32 trees per hectare. The sites ranged from very dry to moist, and a total of 0.5% of the stands were sampled on four, parallel, randomly established lines of neighboring 4-m^2 plots. Full-crowned eastern white pine seed trees were marked to be left as residuals. Plots were set up and sampling of the understory was done for five consecutive years. Adequate stocking and density of eastern white pine regeneration was achieved with about 11 000 seedlings per hectare on the scarified sites. Treatments were timed just before a heavy seedfall, and seed trees were not needed in this particular study because sufficient seed remained from the branches left behind on-site. Nevertheless, 5–10 good seed trees should be left to ensure a future seed supply. Scarification was especially beneficial on fresh sites for the preparation of suitable pine seedbeds.

274 Horton, K.W. 1966. Profitability of pruning white pine. For. Chron. 42:294–305.

The silvicultural efficiency and economic limits of pruning second-growth eastern white pine (*Pinus strobus* L.) were examined with a particular interest in 60–90-year-old pruning stands. Selected trees were pruned up to 5.2 or 10.4 m in 80-year-old eastern white and red pine (*P. resinosa* Ait.) stands. It was profitable to prune larger, maturing eastern white pine up to age 80, and pruning costs decreased appreciably with increasing stand age. The larger, dominant trees at time of pruning provided the greater clear-board yield, hence profit, and 40 years between pruning and harvesting was advocated.

275 Horton, K.W.; Bedell, G.H.D. 1960. White and red pine: ecology, silviculture and management. Bulletin 124. Department of Northern Affairs and National Resources, Forestry Branch, Ottawa. 185 p.

The ecology, silviculture, and management of eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.) were reviewed. The authors included all subjects from the literature that influenced eastern white and red pine management. The emphasis was on pine management in Canada, particularly in the Great Lakes–St. Lawrence forest region, but the technical coverage pertained to pine throughout its natural range. This publication was both a monograph of the eastern white and red pine forest type and a comparative study of the two species.

276 Horton, K.W.; Brown, W.G.E. 1960. Ecology of white and red pine in the Great Lakes–St. Lawrence Forest Region. Tech. Note No. 88. Department of Northern Affairs and National Resources, Forestry Branch, Ottawa. 22 p.

This report summarized the current knowledge of the ecology of eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.) in the Great Lakes–St. Lawrence forest region. Eastern white and red pine development on a range of sites and stand history conditions in the region were surveyed, and the pertinent literature was reviewed. Comparative site relationships were described in detail, discussing such topics as climate, light, soil nutrients, soil structure, distribution relationships, and pine associates. Pine are normally present on relatively dry climatic and soil conditions. Occurrence of pine on a local physiographic level was also discussed, considering natural succession, fire and cutting effects, productivity, and regeneration capacity.

277 Houseweart, M.W.; Knight, F.B. 1986. Entomological problems in growing white pine. Pages 89–92 *in* D.T. Funk, comp. Eastern white pine: today and tomorrow. Symposium proceedings, Durham, NH, 12–14 September 1985. Gen. Tech. Rep. WO-51. USDA For. Serv., Northeastern For. Exp. Stn., Durham, NH. 124 p.

Three insect pest problems of eastern white pine (*Pinus strobus* L.) were discussed: the seedling debarking weevil (*Hylobius congener* Dalla Torre, Schenkling and Marshall), the introduced pine sawfly (*Diprion similis* (Hartig)), and the white pine weevil (*Pissodes strobi* (Peck)). The seedling debarking weevil can heavily damage or kill seedlings of different conifer species. The introduced pine sawfly was a major problem for eastern white pine in the Lake States where there seemed to be a lack of natural enemies to control the insect population. The white pine weevil was considered to be the major impediment to the management of eastern white pine. It was responsible for great volume and quality losses, up to 40%, and regardless of numerous research studies, it remained a major problem.

278 Houston, D.B.; Stairs, G.R. 1973. Genetic control of sulfur dioxide and ozone tolerance in eastern white pine. For. Sci. 19:267–271.

An estimate of the upper limit of genetic control for tolerance of eastern white pine (*Pinus strobus* L.) to sulfur dioxide and ozone was obtained using clonal repeatability analyses. Five tolerant and five sensitive clones were fumigated for six hours with a mixture of 2.5 parts

per hundred million (pphm) sulfur dioxide and 5 pphm ozone. Needle elongation and two indices of direct needle damage were used to assess the response. The repeatability estimates obtained showed that the tolerance sensitivity reaction to combined sulfur dioxide and ozone was under strong genetic control in eastern white pine. Field selection of parent trees that are tolerant or sensitive to these pollutants can be done with a high degree of success. New breeding studies would be required to confirm the nature of the tolerance under conditions of sexual reproduction.

279 Houston, D.R. 1969. Basal canker of white pine. For. Sci. 15:66–83.

Two thousand hectares of young, planted eastern white pine (*Pinus strobus* L.), 8–10 years old, in north central New York were affected by a basal canker disease of which the causes were unknown. To determine the origin of the disease, its development was studied by taking pictures at permanently established points at six-month intervals, and in two 0.08-ha plots. An assessment of every sample tree was made annually. Cankers were located on the main stems from the root collar up to 30 cm, and on many cankers fruiting bodies were present. Cankers probably developed from interactions among many different factors such as former land use, environmental influences, and biotic agents.

280 Howard, T.E. 1986. The lore and lure of eastern white pine. Pages 10–15 *in* D.T. Funk, comp. Eastern white pine: today and tomorrow. Symposium proceedings, Durham, NH, 12–14 September 1985. Gen. Tech. Rep. WO-51. USDA For. Serv., Northeastern For. Exp. Stn., Durham, NH. 124 p.

The demand outlook for eastern white pine (*Pinus strobus* L.) suggested an upward trend in its use for manufactured products, primarily for furniture, using the higher grades of eastern white pine lumber. Other end products were expected to be in increasing demand, but low-grade lumber and fiber could be competing with abundant substitute materials. Aggressive marketing and improved technology would be needed to use the abundant low-quality eastern white pine supply. Managing the forest and mills to produce a larger component of the higher wood grades appeared most promising.

281 Hoyle, M.C.; Mader, D.L. 1964. Relationships of foliar nutrients to growth of red pine in western Massachusetts. For. Sci. 10:337–347.

The use of foliar analysis was explored for identifying limiting nutrients in red pine (*Pinus resinosa* Ait.) plantations. Eighteen 0.04-ha plots were set up in western Massachusetts in 24–37-year-old red pine plantations with a 1.8×1.8 m spacing. In each plot, sample trees were selected for growth measurement and collection of foliage samples. Nutrient contents of needles were calculated in percentage of oven-dry weight, in total amounts in the foliage from the sampled branch, and as ratios. Mineral contents of the dominant and codominant trees differed from those in the intermediate crown class. Foliar analysis from a wide range of stands could successfully identify limiting growth factors. Total nutrient content was slightly more effective than percentage values; nutrient ratios were of questionable value. Height growth correlated strongly with calcium levels and basal area growth with potassium. Volume growth was related primarily to soil moisture.

282 Hubbes, M.; Lin, D. 1985. Proteins, isozymes and resistance to white pine blister rust. Proc. Entomol. Soc. Ont. 116(Suppl.):81–89.

Protein and isoenzyme patterns were examined for correlations between the varieties or clones of eastern white pine (*Pinus strobus* L.) and their susceptibility or resistance to white pine blister rust (*Cronartium ribicola* J.C. Fischer). Current year needles of resistant, susceptible, and immune clones, varieties, and species of eastern white pine were analyzed by polyacrylamide electrophoresis. The protein patterns showed no obvious differences among resistant, susceptible, and immune clones. Comparisons using clones of *P. strobus* ×*griffithii* and their isozyme patterns involving only peroxidase showed a difference between very susceptible and resistant clones.

283 Humble, L.M.; Humphreys, N.; Van Sickle, G.A. 1994. Distribution and hosts of the white pine weevil, *Pissodes strobi* (Peck), in Canada. Pages 68–75 *in* R.I. Alfaro, G. Kiss, and R.G. Fraser, eds. The white pine weevil: biology, damage and management. Symposium proceedings, Richmond, British Columbia, 19–21 January 1994. FRDA Rep. No. 226. 311 p.

The distribution of the white pine weevil (*Pissodes strobi* (Peck)) across Canada was presented as well as a summary of the hosts used by the pest. The distribution maps were based on collection records accumulated since 1948 by the Canadian Forest Service's Forest Insect and Disease Survey. Pine (*Pinus* spp.) was the primary host for white pine weevil in eastern Canada, whereas spruce (*Picea* spp.) was the primary host in western Canada and Newfoundland. Records of white pine weevil damage on pine and spruce in forest stands were summarized by region. Data from this study was to be used to develop a risk/hazard rating for white pine weevil in the various subzones.

284 Hunt, F.M.; Mader, D.L. 1970. Low density management—a means to increase timber yields while using less soil moisture. Mass. Agric. Exp. Stn. Bull. 588. 24 p.

Large areas of dense plantations were planted for the watershed protection of municipal watersheds. This

study in central Massachusetts investigated three levels of stand density to determine how eastern white pine (*Pinus strobus* L.) growth was affected as well as the soil moisture depletion rate. Two plantations planted in 1940 at a 1.5 × 1.5 m spacing with 3+0 seedlings were thinned in 1962 and 1967. After the second thinning, there were 247, 692, and 1680 trees per hectare, respectively, in the low-density, thinned, and control plots. On 13 selected crop trees per plot, aluminum dendrometer bands were fitted at breast height to measure diameter growth. Soil moisture measurements were taken with a neutron probe. Increased diameter growth of crop trees resulted from the thinning treatments. During late season droughts, the heavily thinned plots had more available soil moisture and therefore they were able to grow later in the season. This work demonstrated the use of heavy thinning to promote crop tree growth while reducing water losses through transpiration.

285 Innes, J.C.; Ducey, M.J.; Gove, J.H.; Leak, W.B.; Barrett, J.P. 2005. Size–density metrics, leaf area, and productivity in eastern white pine. Can. J. For. Res. 35:2469–2478.

Data from 12 even-aged, second-growth eastern white pine (*Pinus strobus* L.) stands in southern New Hampshire were used to compare size–density metrics with stand productivity. Leaf area index and measures of crown morphology were measured along with diameters, height, height to base of live crown, foliar retention, and annual needle fall. Models with and without site index and stand age were used to predict total stand accretion, leaf area index, and growth efficiency. A strong positive linear relationship occurred between leaf area index and periodic volume accretion, which seemed consistent across the range of site types, ages, and management histories of the study sites. Of the site indices tested, only stand density index was a significant predictor of accretion. Size–density metrics combined with other stand attributes were correlated with biological measures of stand growth. The authors were surprised that a strong relationship between leaf area index and volume was found despite the small sample size.

286 Irland, L.C. 1986. White pine: the case for optimism. Pages 1–6 *in* D.T. Funk, comp. Eastern white pine: today and tomorrow. Symposium proceedings, Durham, NH, 12–14 June 1985. Gen. Tech. Rep. WO-51. USDA For. Serv., Northeastern For. Exp. Stn., Durham, NH. 124 p.

The economic environment in the northeastern United States including changes in eastern white pine (*Pinus strobus* L.) stumpage costs and lumber markets provided an increased incentive for growing and marketing higher grade eastern white pine logs. Resource data showed vigorous increases in volume growth of eastern white pine, but much of this wood was of poor quality and underused, and it might not be economically logged. Recent surveys showed extensive and increasing overstocking of eastern white pine. The potential productivity of eastern white pine in pure and mixed stands offered many opportunities for viable investments to improve eastern white pine quality and value.

287 Jackson, S.M.; Pinto, F.; Malcolm, J.R.; Wilson, E.R. 2000. A comparison of pre-European settlement (1857) and current (1981–1995) forest composition in central Ontario. Can. J. For. Res. 30:605–612.

Knowledge of forest composition before European settlement is recognized as important for application in the conservation and restoration of forest resources. A 278-km transect was studied, which ran westerly from about 35 km northwest of Sudbury to an area near Sault Ste. Marie, Ontario. Ontario land survey notes recorded in 1857 were compared with Forest Resource Inventory data completed from 1981 to 1995. Large-scale changes in forest composition have occurred in these central Ontario forests during the past 140 years. Forest composition shifted most in the eastern part with a large reduction in conifers and increases in the percentages of aspen (*Populus* spp.) and white birch (*Betula papyrifera* Marsh.). Harvesting during the past 50 years was considered a major factor affecting forest composition because it had preferentially removed species such as spruce (*Picea* spp.) and pine (*Pinus* spp.).

288 Jacobson, G.L., Jr. 1992. A 7000-year history of white pine. Pages 19–26 *in* R.A Stine and M.J. Baughman, eds. White pine symposium proceedings: history, ecology, policy and management, Duluth, MN, 16–18 September 1992. University of Minnesota, Extension Service Distribution Center, St. Paul, MN. 202 p.

The postglacial changes in distribution and abundance of eastern white pine (*Pinus strobus* L.) were reviewed including the 7000-year history of eastern white pine in Minnesota and the response of eastern white pine to past climate changes. During the last 12 000 years, the distribution and abundance of eastern white pine in North America varied greatly. When eastern white pine first reached Minnesota from both the south and north, it did not move westward but instead moved eastward because of a more favorable climate. Eastern white pine was most abundant when climates were warmer and drier. Climate change studies predicted a rising mean summer temperature, and it was expected that this might favor eastern white pine in the future.

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

Postglacial changes in the distribution and abundance of eastern white pine (*Pinus strobus* L.) during the past 12 000 years in eastern North America were investigated to show past responses of eastern white pine to climatic change and also some possible effects of climatic change on future responses. Data from numerous paleoecological investigations completed during past decades were examined. This data is available in the public domain in the North American Pollen Database. The earliest documented postglacial fossil record of eastern white pine dates to about 13 000 years ago in the Shenandoah Valley of Virginia. Eastern white pine spread northward after colonizing areas of Virginia and western Maryland to the north and west, reaching northern New England 10 000 years ago; the central Great Lakes region 9000 years ago; and Minnesota and western Ontario about 7000 years ago. Natural disturbances such as fire as influenced by climate rather than climate itself probably control the abundance of many species in temperate regions. Climatic warming to some extent might well favor the establishment of eastern white pine and be tolerated by existing eastern white pine trees. Climatic effects on white pine blister rust (*Cronartium ribicola* J.C. Fischer) and white pine weevil (*Pissodes strobi* (Peck)) must also be considered because these pests have provided serious challenges in recent decades.

290 Johnsen, K.H.; Feret, P.P.; Seiler, J.R. 1988a. Comparison of greenhouse and environmentally controlled growthroom root growth potential testing of 2+0 eastern white pine seedlings. New For. 2:139–143.

Seasonal patterns of root growth potential, the ability of a new seedling to grow new roots, were tested simultaneously in a greenhouse and growthroom environment for two consecutive years using 2+0 eastern white pine (*Pinus strobus* L.) seedling stock from a Virginia nursery. A complete randomized block design was used and analysis of variance was completed to compare the two testing environments. Analyses showed no significant differences between seedlings from the two different testing environments for either year.

291 Johnsen, K.H.; Feret, P.P.; Seiler, J.R. 1988b. Root growth potential and shoot activity of northern and southern provenances of 1–0 eastern white pine seedlings grown in a Virginia nursery. Can. J. For. Res. 18:610–614.

The relative importance of genetic control of root growth potential was examined using one-year-old (1+0) eastern white pine (*Pinus strobus* L.) seedlings grown in a Virginia nursery from seed of two northern and one southern provenance. (**Note**: The symbol for transplant was standardized to + throughout the bibliography to indicate the time the seedling was in the sowing bed and in the transplant bed.) On 10 occasions between October and April, seedlings were handlifted for root growth potential testing. Significant differences in root growth potential were shown between the northern and southern provenances. Heritability estimates indicated that root growth potential was under minimal genetic control in 1+0 eastern white pine seedlings. Large differences in shoot activity did not result in large root growth potential differences. Morphological attributes were not very useful for predicting root growth potential in 1+0 eastern white pine bare-root seedlings.

292 Johnsen, K.H.; Feret, P.P.; Seiler, J.R. 1989. Root growth potential and bud dormancy of 2+0 eastern white pine grown in a Virginia nursery. Can. J. For. Res. 19:1598–1602.

Seasonal patterns of root growth potential and bud dormancy for 2+0 eastern white pine (*Pinus strobus* L.) were examined throughout two lifting seasons in a Virginia nursery to test for correlations between seasonal changes in root growth potential and bud dormancy. Seedlings were handlifted on 10 and 11 occasions, respectively, and each time, seedlings were selected randomly from three blocks, and root growth potential testing was conducted. Root growth potential patterns were different during the two years. In the first year, a relationship between dormancy release index and root growth potential existed, whereas in the second year there was no relationship. The relationship between dormancy release index and chilling hours was very strong in both years, and a temperature range of 0–7°C was highly correlated to dormancy release.

293 Johnsen, K.H.; McConnell, S.P.; Regelbrugge, J.C.; Seiler, J.R. 1988. Hydraulic conductance of roots present at the time of lifting and newly regenerated roots of 2+0 eastern white pine seedlings. Tree Plant. Notes 39:5–8.

Eastern white pine (*Pinus strobus* L.) 2+0 seedlings were handlifted from four locations in Virginia to determine the relative difference in hydraulic conductivity of roots present at the time of lifting (January 1987) compared with newly generated roots. The surface areas of the taproot, old lateral roots, and newly generated roots were measured, and hydraulic conductances per seedling were calculated. Although the roots present at the time of lifting could conduct water, the percentage of the root system composed of newly regenerated roots as well as the temperature of the water used in the testing system significantly affected the rate of hydraulic conductance.

294 Johnson, J.E.; Lindow, S.G.; Rogers, R. 1998. Light, soil, and seedling characteristics associated with varying levels of competition in a red pine plantation. New For. 15:23–36.

A five-year-old plantation planted with 3+0 red pine (*Pinus resinosa* Ait.) stock was studied to investigate the relationship between tree class, soil conditions, and performance of seedlings growing under differing levels of natural competition. During the fifth growing season, tree growth, moisture status, and nutrition were monitored, and soil samples were taken and analyzed. Seedlings were placed into low, moderate, or high competition classes: low—woody competition less than half the height of the tree; moderate—woody competition greater than half the height of the tree in only one or two quadrants of the plot; and high—woody competition greater than half the height of the crop tree in three or four of the quadrants of the plot, or the tree is overtopped. Red pine seedlings growing under low competition had an absolute volume growth increase of 795% over the seedlings growing under the heaviest competition. Trees growing under low competition had longer and heavier needles but generally lower nutrient concentrations. Site preparation and subsequent release treatments that increased sunlight to young seedlings would have the greatest effect on their growth.

295 Jones, A.C. 1992. The problem with white pine. Pages 64–72 *in* R.A. Stine and M.J. Baughman, eds. White pine symposium proceedings: history, ecology, policy and management, Duluth, MN, 16–18 September 1992. University of Minnesota, Extension Service Distribution Center, St. Paul, MN. 202 p.

Some problems of managing eastern white pine (*Pinus strobus* L.) were discussed including disease, insect, and animal damage, and difficulties in successfully regenerating it. White pine blister rust (*Cronartium ribicola* J.C. Fischer) was recognized as the most important disease of eastern white pine, and white pine weevil (*Pissodes strobi* (Peck)) was recognized as the most important insect pest. Both problems were discussed and some management practices suggested. Some animals such as white-tailed deer (*Odocoileus virginianus* (Zimmermann)) feed on eastern white pine, and their damage can be substantial. Because fire was no longer a regular disturbance, eastern white pine needed artificial disturbances to regenerate. These problems should all be considered when managing eastern white pine.

296 Jones, S.L.; Naylor, B.J. 1993. A comparison of small mammal communities in old pine forests and other common forest types in Sault Ste. Marie District. Rep. No. 12. OMNR, OFRI, Forest Landscape Ecology Program, Sault Ste. Marie, ON. 20 p.

Small mammal communities in old eastern white pine (*Pinus strobus* L.) forests and other forest types in central Ontario were described and compared to determine whether old eastern white pine forests were a unique habitat for certain small mammals, and whether timber harvesting affected small mammal communities. Cut and uncut sites of old-growth eastern white pine, sugar maple (*Acer saccharum* Marsh.), boreal mixedwood, and black spruce (*Picea mariana* (Mill.) BSP) stands were assessed. Four parallel transects were set up in each plot. Each transect had 15 sample stations and each held three traps. In 11 620 trap nights, a total of 1260 mammals were caught. Trapped animals were identified by species, sex, and breeding condition. Two-way ANOVA and Tukey's multiple comparisons were made to test for differences. Old-growth eastern white pine had somewhat higher richness and abundance of small mammals, although values were comparable to those of other upland forest types. Old-growth pine was probably not a unique habitat for small mammals, and harvesting was not a factor.

297 Jordan, G.J.; Ducey. M.J. 2007. Predicting crown radius in eastern white pine (*Pinus strobus* L.) stands in New Hampshire. North. J. Appl. For. 24:61–64.

Region- and stand-type-specific crown radius prediction equations were developed for eastern white pine (*Pinus strobus* L.) to test alternative equation forms and also to evaluate how data sources and model forms affected the relative performance of new and previously published crown size equations. A total of 449 forest-grown trees on 60 growth and yield plots in single-cohort stands dominated by eastern white pine located through southern and central New Hampshire were used for data collection. Diameter at breast height, height, height to base of live crown, and four crown radii were measured. Several models were tested with several predictive variables. A model using diameter at breast height, basal area, and live crown ratio resulted in the best predictions.

298 Joyce, D.G.; Lu, P.; Sinclair, R.W. 2002. Genetic variation in height growth among populations of eastern white pine (*Pinus strobus* L.) in Ontario. Silvae Genet. 51:136–142.

Different provenances of eastern white pine (*Pinus strobus* L.) were tested using height growth in a two-year greenhouse study and a five-year field study on two sites in Ontario: Turkey Point (112 provenances) and Sault Ste. Marie (92 provenances). A randomized block design with 10 seedlings per plot with 15 replicates was used for the greenhouse test, and a randomized block design with 10-tree row plots and four blocks were used at each of the two field sites. Considerable genetic variation in growth potential was present among eastern white pine

populations in Ontario, and genetic gain could be obtained through seed source selection in reforestation programs. Seed transfer was recommended to be not more than 1.5–2.0° latitude south of its origin, but further research was needed to investigate differences in cold hardiness before safe north to south seed transfer distances could be determined.

299 Katovich, S.A. 1992. White pine weevil and gypsy moth: potential pests of eastern white pine. Pages 126–136 *in* R.A. Stine and M.J. Baughman, eds. White pine symposium proceedings: history, ecology, policy and management, Duluth, MN, 16–18 September 1992. University of Minnesota, Extension Service Distribution Center, St. Paul, MN. 202 p.

The life history of the white pine weevil (*Pissodes strobi* (Peck)) was described and management strategies proposed to minimize its damage. Alternatives suggested included growing young eastern white pine (*Pinus strobus* L.) at high densities (3000–3700 stems per hectare) with side shade, and growing eastern white pine under an overstory with 5–75% full sunlight. High densities were suggested for open-growth plantations, and side shade was suggested for understory eastern white pine. Gypsy moth (*Lymantria dispar* (Linnaeus)) is a defoliator that prefers oak (*Quercus* spp.) and trembling aspen (*Populus tremuloides* Michx.) but also feeds on eastern white pine. Eastern white pine is especially at risk to gypsy moth damage when grown in mixed-hardwood stands and all the more favored foods are exhausted.

300 Katovich, S.A.; Morse, F.S. 1992. White pine weevil response to oak overstory girdling—results from a 16-year-old study. North. J. Appl. For. 9:51–54.

Sixteen years after release, the growth response and number and frequency of white pine weevil (*Pissodes strobi* (Peck)) attacks were evaluated in understory eastern white pine (*Pinus strobus* L.) under different canopy removal treatments in central Wisconsin. A well-stocked, 28-ha hardwood stand was selected for study, and it was composed mainly of low-grade oak (*Quercus* spp.) with a natural understory of about 1850 eastern white pine trees per hectare ranging from 1.5 to 3.0 m high. Five levels of canopy removal were applied, on the basis of the hardwood basal area, leaving a residual basal area of 0, 7, 11, and 16 m^2/ha, and control, by girdling some of the overstory hardwood trees. The control had a basal area of between 23 and 28 m^2/ha. Each treatment was replicated twice in 2-ha blocks with each block containing ten 0.08-ha plots. On each plot, understory trees about 2 m tall were most abundant, and they were selected for analysis of leader growth and white pine weevil damage. Trees in the 0 and 7 m^2/ha basal area were taller and larger in diameter at breast height, but they were significantly more damaged by white pine weevil than those in the other basal area treatments. A basal area of 7–11 m^2/ha provided a good balance between improving tree growth and minimizing white pine weevil attack.

301 Kelty, M.J.; Entcheva, P.K. 1993. Response of suppressed white pine saplings to release during shelterwood cutting. North. J. Appl. For. 10:166–169.

The ability of suppressed eastern white pine (*Pinus strobus* L.) saplings to respond to release following a shelterwood cut where no hardwood control was applied was examined in north central Massachusetts. Height and diameter were sampled on 20-m^2 plots before and 11 years after the establishment cut. Although eastern white pine saplings were most abundant, they were surpassed in height by hardwood saplings and sprout growth. Older, suppressed eastern white pine saplings, 10–38 years old at the time of the cut, responded quickly to release and grew to mean heights of 3.8–5.1 m 11 years after harvest. Eastern white pine younger than 10 years at the time of cutting also responded to release but reached only a height of 2 m after 11 years.

302 Kelty, M.J.; Menalled, F.D.; Carlton, M.M. 2004. Nitrogen dynamics and red pine growth following application of pelletized biosolids in Massachusetts, USA. Can. J. For. Res. 34:1477–1487.

An investigation was conducted of the red pine (*Pinus resinosa* Ait.) growth response and nitrogen dynamics to biosolid fertilizer applications. Twelve 20-m^2 plots were set up in a 51-year-old red pine plantation in Massachusetts that was thinned to a basal area of 30 m^2/ha 10 years earlier to test four pellet treatment amounts (0, 200, 400, and 800 kg/ha total N with little or no added K) with three replicates. Red pine was not a good species for applications of biosolids because it was sensitive to heavy nitrogen applications. Red pine basal area growth did not change with low or medium applications and decreased by half with high applications. A decrease in foliar K:N ratio resulting from high N uptake with little K was hypothesized as the cause for the growth decline.

303 Kershaw, H.M.H. 1993. Early successional processes of eastern white pine and red pine within the Great Lakes–St. Lawrence forest. Rep. No. 8. OMNR, OFRI, Forest Landscape Ecology Program, Sault Ste. Marie, ON. 50 p.

The literature was reviewed on the early succession of red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.) in the Great Lakes–St. Lawrence forest from pine establishment to age 50. The presence of most red and eastern white pine in the region was attributed to fire, which created an appropriate seedbed and reduced the

level of woody competition. The report also discussed seed source and compared eastern white and red pine regeneration, the environmental conditions that promote each, and the diseases that affected these two important species. Beaked hazel (*Corylus cornuta* Marsh.), striped maple (*Acer pensylvanicum* L.), red maple (*A. rubrum* L.), and trembling aspen (*Populus tremuloides* Michx.) were the major early competitors of red and eastern white pine. Natural red pine regeneration continued to decline across the area as fewer major disturbances created the sites required for its establishment. Generally, natural regeneration systems favor eastern white pine over red pine.

304 Kilgore, J.S.; Telewski, F.W. 2004. Reforesting the jack pine barrens: a long-term common garden experiment. For. Ecol. Manag. 189:71–187.

This study evaluated the survival and succession of several tree species in the jack pine (*Pinus banksiana* Lamb.) barrens ecosystem. The investigation made use of a historic silvicultural plantation and a neighboring old field. The plantation was established in 1888 where 41 native and nonnative tree species including red (*P. resinosa* Ait.) and eastern white pine (*P. strobus* L.) were planted on a site in northern Lower Michigan. The recent assessment revealed that only seven conifer species remained on-site. As predicted, native species had greater survival rates, radial growth, height, and regeneration rates. Red pine produced the largest volume and had regenerated under a heterogeneous canopy, whereas eastern white pine, even with high seedling mortality, was expected to produce abundant regeneration leading to a stand dominated by this species in future.

305 Kim, J.H. 1985. Growth and development of coniferous plantations on abandoned agricultural land in southern Michigan. Res. Bull. Exp. For. Kangweon Natl. Univ. No. 5. p. 25–39.

An evaluation was presented of the reforestation potential of six conifer species including red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.) on the basis of the plantation performance of trees 40 years old or older. Thirty-five thinned and unthinned field plots were established in plantations at the Kellogg Experimental Forest of Michigan State University. Height, basal area, and volume growth were measured in the summer of 1981 and 1982. Average survival was >70% for red pine and <30% for eastern white pine. Merchantable volume growth of all plantations exceeded 7 $m^3 \cdot ha^{-1} \cdot year^{-1}$, and red pine had an average volume of 512 m^3/ha in 45-year-old unthinned stands. Thinning significantly increased diameter growth for all species. All factors considered, red pine was recommended as the best species for reforestation in the Michigan area.

306 King, J.S.; Giardina, C.P.; Pregitzer, K.S.; Friend, A.L. 2007. Biomass partitioning in red pine (*Pinus resinosa*) along a chronosequence in the Upper Peninsula of Michigan. Can. J. For. Res. 37:93–102.

Carbon storage was quantified in above- and belowground biomass of red pine (*Pinus resinosa* Ait.), and patterns of biomass partitioning were observed as a function of stand development. The chronosequence studied consisted of nine red pine stands located in the western Upper Peninsula of Michigan. These stands growing on sand to sandy loam soils ranged from 2 to 55 years old. Biomass of young trees was determined by direct measurement; total biomass of the older stands was determined by applying allometric regressions to height and diameter at breast height measurements. Average C concentrations ranged from 40.8 to 49.5% for all plant parts. Variation in C concentration in plant part across the chronosequences was low. Biomass increased from ages 2 to 32 and then decreased at age 55 because of thinnings. Individual tree root:shoot ratios displayed significant within-site variation. The pattern of root–shoot biomass partitioning was maintained at the stand level. Stands of some moderately shade-tolerant species could be managed for greater C sequestration by maintaining higher stem density.

307 Kittredge, D.B., Jr.; Ashton, P.M.S. 1990. Natural regeneration patterns in even-aged mixed stands in southern New England. North. J. Appl. For. 7:163–168.

Natural regeneration patterns were characterized in even-aged mixed stands in northeastern Connecticut with a focus on red oak (*Quercus rubra* L.), red maple (*Acer rubrum* L.), sugar maple (*A. saccharum* Marsh.), cherry birch (*Betula lenta* L.), eastern hemlock (*Tsuga canadensis* (L). Carrière), and eastern white pine (*Pinus strobus* L.). Regeneration surveys were conducted with 300 circular plots each with a 4.0-m radius. There were relationships between overstory density and the amount of regeneration. Eastern white pine regeneration was closely related to the amount of eastern white pine in the overstory, which was not the case for the other species. Red oak and sugar maple regeneration was more abundant when the length of time since the last harvest was longer. The opposite was true for red maple, cherry birch, eastern hemlock, and eastern white pine.

308 Klein, J.I. 1976. Survival and growth of red pine populations in Manitoba 15 years after planting. Department of the Environment, Canadian Forestry Service, Northern Forest Research Centre, Edmonton, AB. Information Report NOR-X-155. 11 p.

A red pine (*Pinus resinosa* Ait.) provenance study was set up near Piney, Manitoba, in May 1958. The study was planted with four-year-old transplant stock at a 1.2-m

spacing using a randomized block design with five replicates. Ten provenances were involved with five from Ontario, and one each from Manitoba, Michigan, Quebec, New Brunswick, and Nova Scotia. Survival varied widely among populations after the first few years. The study was then assessed 15 years after its establishment, and there were no further differences noted among the provenances in survival. Although there were some differences in height at this stage of development, the differences among provenances were considered insufficient to justify any change from the current policy of using local seed for red pine planting in southeastern Manitoba.

309 Klepzig, K.D.; Raffa, K.F.; Smalley, E.B. 1991. Association of an insect–fungal complex with red pine decline in Wisconsin. For. Sci. 37:1119–1139.
Red pine (*Pinus resinosa* Ait.) plantations exhibiting decline symptoms were examined in Wisconsin to determine the agents associated with red pine decline. Research plots were set up at the mortality pocket margin with control plots in asymptomatic stands, and all plots were monitored for three years. Each plot contained 10 pitfall traps, 10 basal trunk screen traps, and 10 lower-stem flight traps placed randomly, and 1 Pherotech multiple funnel pheromone trap in the plot center. Fungal isolations were made from collected insects. Root samples were collected from trenches, and crown condition, levels of insect damage, and radial growth rates were assessed. Incidence of red pine decline was associated with increased numbers of several insect species, with five species of root and lower-stem insects significantly more abundant. The insect data were remarkably consistent on a year-to-year basis. Two fungus species (both *Leptographium* species) were isolated consistently from the five insect species associated with red pine decline. Declining stands had higher root mortality and staining. A complex interaction of organisms and abiotic factors was proposed as the cause of red pine decline.

310 Klepzig, K.D.; Smalley, E.B.; Raffa, K.F. 1995. *Dendroctonus valens* and *Hylastes porculus* (Coleoptera: Scolytidae): vectors of pathogenic fungi (*Ophiostomatales*) associated with red pine decline disease. Gt. Lakes Entomol. 28:81–87.
Red turpentine beetle (*Dendroctonus valens* LeConte) and *Hylastes porculus* Erichson borers were assessed as vectors of their commonly associated fungi to red pine. A healthy 44-year-old red pine (*Pinus resinosa* Ait.) plantation in Wisconsin was used to determine the rates of transmission of *Leptographium terebrantis, L. procerum,* and *Ophiostoma ips* to roots of healthy, mature red pine and to roots of stumps by field-collected *H. porculus* and *D. valens*. Colonization of living red pine by *H. porculus* was examined in a 26-year-old red pine stand exhibiting symptoms of decline. Both *D. valens* and *H. porculus* were capable of vectoring ophiostomatoid fungi to red pine. Transmission rates of *L. terebrantis*, *L. procerum*, and *O. ips* to wounded roots were similar to or higher than the rates at which other root and lower-stem insects transmitted ophiostomatoid fungi in previous studies. An interaction of insects, associated fungi, tree stress factors, and reduced host defensive chemistry was considered responsible for red pine decline disease.

311 Koide, R.T.; Shumway, D.L. 2000. On variation in forest floor thickness across four red pine plantations in Pennsylvania, USA. Plant Soil 219:57–69.
The variation in forest-floor thickness in four plantations of red pine (*Pinus resinosa* Ait.) was studied in Pennsylvania. Plantations were established in 1931, 1936, 1940, and 1951. All stands had little understory, and their soils consisted of well-drained to moderately well drained sandy loams and loams. Soil samples were collected and analyzed and a gradient was noted in the forest-floor thickness: the forest floor became thinner from west to east. Roots and foliar samples were taken to examine mycorrhizae and nutrients, and decomposition rates. Decomposition rates increased from west to east, describing the relationship between forest-floor thickness and the rate of decomposition.

312 Kotar, J. 1992. Managing white pine: finding the proper niche. Pages 150–156 *in* R.A. Stine and M.J. Baughman, eds. White pine symposium proceedings: history, ecology, policy and management, Duluth, MN, 16–18 September 1992. University of Minnesota, Extension Service Distribution Center, St. Paul, MN. 202 p.
Eastern white pine (*Pinus strobus* L.) grows on a wide range of sites playing different ecological roles. Important for eastern white pine success on a given soil type is the relative competitive intensity of the associated species. A useful framework for evaluating interspecific relationships was presented decribing the arrangement of sites (landform–soil combination) and occurrence of various species on a moisture-nutrient gradient. This detailed characterization of eastern white pine sites was based on soils, understory vegetation, and associated tree species. This paper also provided a means for ecological grouping of diverse sites and described the eastern white pine management implications for each site category with emphasis on the Lake States region. Four site quality categories were characterized: (1) dry/nutrient-poor; (2) dry-mesic/nutrient-poor to medium; (3) dry-mesic/medium nutrient; and (4) mesic/nutrient-medium to rich.

313 Kotar, J.; Coffman, M.S. 1985. Site selection based on ecosystem classification. Pages 101–108 *in* R. Marty, ed. Managing red pine. Proceedings of the Second Region V Technical Conference, Society of American Foresters. SAF Publication 85-02. Bethesda, MD.
Almost all red pine (*Pinus resinosa* Ait.) plantations were established on two types of sites: logged and heavily burned sites with sandy soils, and abandoned farm lands usually supporting better soils. Because plantations usually replace some natural forest cover type, site selection should be based on expected reaction of natural vegetation to available plantation establishment techniques. Habitat-type classification is a method that predicts relative growth and competitive interactions of tree species for a wide range of sites. Four indicator-species groups were derived from a habitat-type system, which could be considered for use beyond the region for which the habitat system was intended. Strong evidence suggested that competition-free rapid early growth of red pine seedlings might be more important in terms of subsequent volume production than the inherent site quality. Competition control effects should be concentrated on the first four to five years of plantation growth.

314 Kraske, C.R.; Fernandez, I.J. 1990. Conifer seedling growth response to soil type and selected nitrogen availability indices. Soil Sci. Soc. Am. J. 54:246–251.
Several nitrogen-availability indices were compared by using typical soil types supporting commercial forests in Maine. Two horizons from three soils were sampled including the mineral Ap and upper B horizon from one soil and an organic O and mineral B horizon from two other soil types. The sampled soils were used as growth media for balsam fir (*Abies balsamea* (L.) Mill.), red spruce (*Picea rubens* Sarg.), and eastern white pine (*Pinus strobus* L.) seedlings in a greenhouse. After 26 weeks, seedlings were harvested and measured, and soil samples were taken and analyzed. Seedlings grew better in O horizons than in mineral soils. Nitrogen-availability indices were correlated with seedling growth parameters. Nitrogen availability appeared to be associated with soil organic matter content and soil pH.

315 Kriebel, H.B. 1983. Breeding eastern white pine: a world-wide perspective. For. Ecol. Manag. 6:263–279.
Breeding eastern white pine (*Pinus strobus* L.) was examined from a global perspective, and breeding methods and prospects were reviewed, which varied widely from one region to another. In the northeastern United States, eastern Canada, and southern Lake States, breeding for resistance to white pine weevil (*Pissodes strobi* (Peck)) was considered most critical with some attention to improving vigor as well. In the northern Lake States and central and northern Europe, resistance to white pine blister rust (*Cronartium ribicola* J.C. Fischer) would be the most important objective of eastern white pine breeding programs. On the other hand, in the central States and southern and southeastern Europe, breeding programs could focus on improving eastern white pine growth rates. The blue pine (*Pinus wallichiana* A.B. Jacks.) from Pakistan, Kashmir, and northern India was included in breeding programs because of its exceptional vigor, rust resistance, and wood quality. In Japan and northern Korea, blue pine and eastern white pine hybrids may be of interest in view of their rapid growth and winter hardiness.

316 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. North. J. Appl. For. 21:61–68.
The influence of harvesting intensity and vegetation management on the early growth and health of underplanted eastern white pine (*Pinus strobus* L.) was investigated. In the spring of 1996, 24 plots were set up in a hardwood stand in Minnesota beneath varying overstory densities. Thirty-six bare-root seedlings were planted per plot and weeded according to treatments randomly assigned by row. After five years, seedlings experienced greater height growth under a more open canopy and after the removal of woody vegetation. But these conditions also increased the incidence of seedling injury from insects and disease. Managing eastern white pine regeneration involved considering trade-offs between enhanced growth rates and potential health risks.

317 Krueger, J.A.; Zenner, E.K.; Puettmann, K.J. 2007. Development of eastern white pine (*Pinus strobus* L.) regeneration under a reserve shelterwood after intermediate removals and windthrow. North. J. Appl. For. 24:134–137.
The understory growth response of 12-year-old eastern white pine (*Pinus strobus* L.) regeneration was examined after a shelterwood cut with reserves in a 110-year-old red (*P. resinosa* Ait.) and eastern white pine stand. The study site was located in St. Louis County, Minnesota, on coarse, loamy soils over granite bedrock. After a storm that further reduced the overstory basal area, residual tree basal area averaged 7.9 m^2/ha, average height for eastern white and red pine was 23 m, and average diameter at breast height (dbh) was 35 cm for red pine and 38 cm for eastern white pine. A total of 120 regenerated eastern white pine trees were sampled and measured for height, dbh, basal diameter, and live crown length. Competing vegetation and herbaceous ground vegetation were recorded in a 1-m radius around selected trees. Eastern white pine height increased from 191 cm before release to 368 cm four years after the release cut. Trees responded

differently to the release; for example, trees that showed slower growth before release responded fastest. Woody competitors taller than the sampled trees had a significant negative influence on both dbh and basal diameter growth but not on height growth.

318 La Barre, C.; Veilleux, J.-M. 1973. Traitements sylvicoles appliqués dans des plantations effectuées sur dunes à Saint-Clet et Saint-Lazare, comté de Vaudreuil-Soulanges. Gouvernement du Québec, Ministère des Terres et Forêts, Mémoire No. 15. 42 p. [Silvicultural treatments applied to plantations established on dunes in Saint-Clet and Saint Lazare, Vaudreuil-Soulanges County; English abstract.]

The effects of thinning and fertilizer treatments were studied in conifer plantations planted on sand dunes in Saint-Clet and Saint-Lazare, Quebec. Eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.) grew better than spruce on nutrient-poor soils, and organic fertilizers were recommended rather than chemical fertilizers on soils with poor physical properties. Overall, eastern white pine showed better growth after thinning and pruning, and released red pine showed faster growth than underplanted red pine.

319 Laflamme, G. 1986. Symptôme inusité du chancre scléroderrien sur le pin rouge au Québec. Can. J. Plant Pathol. 8:1–5. [Unusual symptom of scleroderris canker on red pines in Quebec; English abstract.]

An unusual symptom of scleroderris canker, caused by *Gremmeniella abietina* (Lagerb.) Morelet, of red pine (*Pinus resinosa* Ait.) was observed in 1984 in several locations in Quebec. For the first time, the fungus *Ascocalyx abietina* (Lagerb.) Schläpfer-Bernhard attacked two-year-old shoots instead of infecting the terminal buds and the current season's growth, which was recorded previously. The observation of this unusual symptom was discussed regarding the current knowledge of the infection mode of the fungus.

320 Laflamme, G. 1999. Traitement réussi d'une plantation de pins rouges affectée par le *Gremmeniella abietina*, race européenne. Phytoprotection 80:55–64. [Successful control of *Gremmeniella abietina*, European race, in a red pine plantation; English abstract.]

Gremmeniella abietina var. *abietina* Petrini et al. is the causal agent of scleroderris canker on pines (*Pinus* spp.). The European race was introduced to North America and is more destructive than the North American race because it can kill pole-sized trees. In 1982, systematic pruning of lower branches was tested as a control method in a red pine (*Pinus resinosa* Ait.) plantation in Kazabazua, Quebec. The four lower whorls of 12-year-old red pines were pruned, and a year later, the incidence rate of disease was reduced from 67 to 22%. Two other treatments of pruning and cutting dead and dying trees in 1984 and 1985 reduced the disease to an endemic level. Annual recordings for infections took place between 1987 and 1995. Canopy closure in 1995 caused natural pruning that seemed to kill the remaining infected shoots. A control plantation showed an infection rate ranging from 86 to 100%, and by 1995, the rate of tree mortality in it had reached 47%. In plantations <20 years old, pruning the lower half of crown branch whorls was considered effective in reducing the incidence of this canker disease.

321 Laidly, P.R.; Barse, R.G. 1979. Spacing affects knot surface in red pine plantations. Res. Note NC-246. USDA For. Serv., North Central For. Exp. Stn., St. Paul, MN. 3 p.

Red pine (*Pinus resinosa* Ait.) seedlings were planted at 1.5×1.5 m, 2.1×2.1 m, 2.7×2.7 m, and 3.4×3.4 m spacings in northwestern Wisconsin to examine the influences of spacing on branch diameter, number of branches, and knot surface. Measurements were taken at age 23 on six trees growing at each spacing. The size of the branches increased with spacing, whereas the number of branches did not differ. With 2.7×2.7 m spacing and wider, pruning was a necessity when growing trees for poles. Pruning was also a necessity, regardless of spacing, to produce a large proportion of clear wood on rotations of <100 years.

322 Lancaster, K.F. 1984. White pine management—a quick review. Gen. Tech. Rep. NA-FR-27. USDA For. Serv., Northeastern Area, State and Private Forestry, Durham, NH. 13 p.

A review on how to manage eastern white pine (*Pinus strobus* L.) was completed with a main focus on natural regeneration and hardwood control. Growth and development were described, and the following forestry practices were discussed: regeneration, seedling and sapling stands, pole and sawtimber stands, the shelterwood system, pruning, and reforestation. Pruning was considered a necessity in eastern white pine management because it was the only way to develop quality and improve the value of the standing tree. Pruning and thinning should be done soon after each other for rapid growth of selected crop trees and rapid healing of pruned stems.

323 Lancaster, K.F.; Leak, W.B. 1978. A silvicultural guide for white pine in the northeast. Gen. Tech. Rep. NE-41. USDA For. Serv., Northeastern For. Exp. Stn., Broomall, PA. 13 p.

A guide for management of eastern white pine (*Pinus strobus* L.) in the northeast was developed with special measures to regenerate and grow eastern white pine.

Clearcutting, strip cutting, seed tree cutting, and shelterwood were the alternative methods for regenerating eastern white pine. Two-cut shelterwood was considered to be the most successful of these options. Other management implications were discussed, and stocking charts and yield tables were provided. The effects of soil–site relationships were incorporated in the stand prescriptions, which were directed toward increasing production of eastern white pine sawlogs. Prescriptions focused on increasing the proportion of eastern white pine on better sites and developing pure stands on the poorer hardwood sites.

324 Larocque, G.R. 1998. Functional growth analysis of red pine trees under variable intensities of competition. For. Chron. 74:728–735.

The application of the functional approach to examine long-term development of individual red pine (*Pinus resinosa* Ait.) trees subject to different intensities of stress was discussed. Data were obtained from a 40-year-old spacing trial near Petawawa, Ontario, with initial square spacings of 1.2, 1.5, 1.8, 2.1, 2.4, 3.0, and 4.3 m. Diameter at breast height (dbh) was measured every five years between 1962 and 1992, and selected trees were measured for total height, crown width, crown length, and stump and upper-stem diameter. Individual trees were sampled from plots in the 1.5-, 2.4-, and 4.3-m spacings. Coefficients of the Chapman-Richards function were derived for dbh growth with age and represented adequately the growth trends of individual trees. Although cumulative growth indicated a fairly consistent pattern, absolute growth rate was not related to tree size. At this stage of plantation development, the ratio of absolute growth rate to crown width indicated that the ability of trees to occupy the aerial growing space was not related to tree size.

325 Larocque, G.R. 2002. Examining different concepts for the development of a distance-dependent competition model for red pine diameter growth using long-term stand data differing in initial stand density. For. Sci. 48:24–34.

A new approach in the derivation of a distance-dependent individual-tree model for red pine (*Pinus resinosa* Ait.) was examined by redefining the concept of zone of influence. Individual tree data originated from a spacing trial near Petawawa, Ontario, with original spacings ranging from 1.2×1.2 m up to 3.0×3.0 m and trees measured every five years between the ages of 13 and 43. Crown dimensions of open-grown trees were measured as well. A highly significant relationship was observed between crown width and diameter at breast height. This distance-dependent individual-tree model provided a more accurate prediction of long-term diameter growth than the model derived using three existing competition indices.

326 Larocque, G.R.; Beaulieu, J.; Daoust, G.; Ung, C.-H. 2007. Juvenile development of 25 open-pollinated families of eastern white pine (*Pinus strobus* L.) interplanted with grey alder (*Alnus incana*). Natural Resources Canada, Canadian Forest Service, Laurentian Forestry Centre, Sainte-Foy, QC. Information Report LAU-X-129. 21 p.

Crown, branch, and stem development were assessed using eastern white pine (*Pinus strobus* L.) trees from 25 families in five provenances from Quebec and Vermont. The eastern white pine seedlings were interplanted with speckled (also called gray) alder (*Alnus incana* ssp. *rugosa* (Du Roi) J. Clausen) in June 1989 at two sites in Quebec. The trees were measured in 1993, 1995, and 2000. Although a relatively small number of families were used in this study, they did not differ significantly in stem, crown, or branch traits. Future studies should include more families from a broader range and they should be tested in eastern white pine progeny tests without any of the possible effects of interplanting with speckled alder.

327 Larocque, G.R.; Beaulieu, J.; Daoust, G.; Zhang, S.Y. 2007. Wood density development in young open-pollinated eastern white pine (*Pinus strobus* L.) families. Natural Resources Canada, Canadian Forest Service, Laurentian Forestry Centre, Sainte-Foy, QC. Information Report LAU-X-131. 10 p.

Little information exists on the extent of genetic variation in wood density among provenances of eastern white pine (*Pinus strobus* L.). The objectives of this study were to compare radial development in wood density and examine variation between branch development traits and wood density in 25 families in five provenances from Quebec and Vermont. Eastern white pine had been interplanted with speckled alder (*Alnus incana* ssp. *rugosa* (Du Roi) J. Clausen) in June 1989 on two sites in Quebec. Increment cores were taken at stump height in summer 2001, and relative density was measured using a direct reading densitometer. Ring density for all families decreased with increasing cambial age from age 4 to 13. The family effect was small and was significant only when it interacted with the block. The variation observed suggested that genetic selection for wood density would not result in significant wood quality gains. The relationship between wood density and average branch growth was somewhat more significant in these young trees.

328 Larocque, G.R.; Marshall, P.L. 1993. Evaluating the impact of competition using relative growth rate in red pine (*Pinus resinosa* Ait.) stands. For. Ecol. Manag. 58:65–83.

Relationships between relative growth rate (RGR) and tree size were studied to evaluate the competitive status of

stands. Data from a red pine (*Pinus resinosa* Ait.) spacing trial near Petawawa, Ontario, with initial square spacing ranging from 1.2 to 4.3 m were included in this study. A portion of the 3.0-m spacing was thinned to 6.0-m spacing before crown closure. Diameter at breast height was used to calculate absolute growth rates (AGRs) and RGRs for each tree for all ages and spacings. The competitive status of the trees was determined by evaluating their crown ratio (crown length:tree height). An increase in tree size at a given spacing before the onset of competition resulted in a decrease in RGR. AGR was positively related to tree size. RGR was considered a better descriptor of the impact of competition on red pine stands than AGR.

329 Larocque, G.R.; Marshall, P.L. 1994a. Crown development in red pine stands. I. Absolute and relative growth measures. Can. J. For. Res. 24:762–774.

Little was known about relationships that predict crown dimensions from diameter at breast height (dbh) and height for young stands. This study was initiated to determine whether such relationships could be derived for red pine (*Pinus resinosa* Ait.) trees originating from a wide range of initial spacings and ages. Data for this study were obtained from a planted red pine study near Petawawa, Ontario, with initial square spacings of 1.2, 1.5, 1.8, 2.1, 2.4, 3.0, and 4.3 m. Some parts of the area were thinned before crown closure to a 4.3- and 6.0-m spacing. Circular sample plots were set up in each spacing treatment. Trees were measured at 13, 18, 23, 28, and 33 years old. Subsets of three trees per 30-cm height class were measured in more detail. Average crown widths and lengths for the various spacings were similar at a young age. Good linear relationships were derived between crown width and dbh and height. Spacings affected the relationship with dbh and height significantly for both crown width and crown ratio. These relationships were tested on relatively young trees. The model would need further testing using studies with a greater range of age classes.

330 Larocque, G.R.; Marshall, P.L. 1994b. Crown development in red pine stands. II. Relationships with stem growth. Can. J. For. Res. 24:775–784.

Crown development was studied across a range of ages and spacings that captured the onset of intraspecific competition in red pine (*Pinus resinosa* Ait.) plantations. Stem growth of individual trees was related to absolute and relative measures of their crowns across a range of spacings and ages. Data from a spacing trial near Petawawa, Ontario, included initial square spacings ranging from 1.2 to 4.3 m, plus one area thinned to 6.0 m before crown closure. In each treatment area, circular sample plots were established. Trees were measured at 13, 18, 23, 28, and 33 years old. Subsets of three trees per 30-cm height class were measured in more detail including crown width, crown length, and stump and upper-stem diameter. Three measures of growth efficiency that were similar in concept to relative growth rate were used: diameter at breast height (dbh) increment/crown width, dbh increment/crown projection, and dbh increment/foliage biomass. These three measures of efficiency decreased with increasing dbh in the absence of severe competition and increased with increasing dbh under severe competitive stress. Absolute and relative growth rates for dbh and the three measures of growth efficiency were closely related to absolute and relative measures of crown development.

331 Larocque, G.R.; Marshall, P.L. 1995. Wood relative density development in red pine (*Pinus resinosa* Ait.) stands as affected by different initial spacings. For. Sci. 41:709–728.

The effects of widely divergent initial spacings and tree sizes on wood density of red pine (*Pinus resinosa* Ait.) at different ages were examined to determine how well the changes in wood density were related to crown development. Data from a spacing trial near Petawawa, Ontario, included initial square spacings ranging from 1.2 to 4.3 m, plus one part thinned to 6.0 m before crown closure. Basic tree measurements were recorded and increment cores were taken at breast height and assessed using an X-ray densitometer. The different spacings were compared for ring width, ring relative density, earlywood relative density, latewood relative density, and percentage of earlywood. Mean ring width at breast height decreased with age for all spacings after 12 years old. Ring relative density and earlywood relative density were highly correlated at all ages and indicated the primary influence of earlywood development on the relative density of entire rings. Tree density strongly affected the wood density of red pine with a general trend of a decrease in wood density as inter-tree spacing increased.

332 Larson, B.C.; Moser, W.K.; Mishra, V.K. 1998. Some relationships between silvicultural treatments and symmetry of stem growth in a red pine stand. North. J. Appl. For. 15:90–93.

The effects of silvicultural treatments on the symmetry of tree stems were studied in a red pine (*Pinus resinosa* Ait.) plantation in southern New Hampshire. Part of the plantation was a mixed-species planting with eastern white pine (*P. strobus* L.). The red pine overtopped the eastern white pine in the interplanted area leading to uneven levels of eastern white pine mortality. Rows were oriented north–south, and the plantation had been thinned once. Trees were cored on two sides (north and east) and at three heights (0.4, 1.4, and 5.4 m), and the north and east

radii of the crowns were measured. The results did not show any significant relationships between silvicultural treatments and stem symmetry or between crown radii and stem growth. It was concluded that silvicultural treatments greatly affecting stand spatial patterns might not have a lasting effect on asymmetry of tree boles in red pine.

333 Lavallée, R.; Albert, P.; Mauffette, Y. 1994. Larval development and adult feeding preferences of the white pine weevil, *Pissodes strobi* (Peck), on water stressed white pine, *Pinus strobus* L. Pages 54–67 *in* R.I. Alfaro, G. Kiss, and R.G. Fraser, eds. The white pine weevil: biology, damage and management. Symposium proceedings, Richmond, British Columbia, 19–21 January 1994. FRDA Rep. No. 226. 311 p.

The development of the white pine weevil (*Pissodes strobi* (Peck)) was followed on plants exposed to different watering regimes, and adult white pine weevils were assessed for their sensitivity to bark quality when the bark was modified by a watering regime extending from well-watered to nearly permanent wilting point of the plant. Five- and six-year-old eastern white pines (*Pinus strobus* L.) were grown in greenhouse conditions for two years; subjected to white pine weevil feeding and oviposition; and grown under dry, medium, and wet water regimes. Leaders were harvested regularly and larval development was noted. Results suggested that insect attacks modified bark chemistry and the resulting feeding preference, and the fitness of the white pine weevil would be greater in vigorous growing plants rather than in water-stressed plants.

334 Law, B.E.; Riitters, K.H.; Ohmann, L.F. 1992. Growth in relation to canopy light interception in a red pine (*Pinus resinosa*) thinning study. For. Sci. 38:199–202.

Basal area growth from the most recent 5 years of a 40-year thinning study was compared to the amount of visible light intercepted by the tree canopies for a range of stand densities in a 119-year-old red pine (*Pinus resinosa* Ait.) forest in north central Minnesota. Five thinning treatments were applied leaving residual basal areas of 14, 18, 23, 28, and 32 m^2/ha. Diameter measurements were taken at regular intervals, and photosynthetically active radiation transmittance was measured through the red pine canopy under clear sky conditions. Stand growth efficiency (SGE) and tree growth efficiency were estimated as well. Basal area growth was proportional to the amount of light intercepted in the stand, and individual tree growth was inversely related to the amount of light intercepted by the canopy. Results suggested SGE might be more suitable as an indicator of forest condition because SGE would allow for comparing forests with various stand densities without the need for stratification by stand density.

335 Leaf, A.L.; Leonard, R.E.; Wittwer, R.F.; Bickelhaupt, D.H. 1975. Four-year growth responses of plantation red pine to potash fertilization and irrigation in New York. For. Sci. 21:88–96.

Fertilization and irrigation were assessed at stand level to determine their effects on 35–40-year-old red pine (*Pinus resinosa* Ait.) plantations on glacial outwash sandy soils in New York. Four 0.08-ha plots were established. One plot was treated with a potash fertilizer (448 kg/ha of elemental K as muriate of potash), one was irrigated (seven equal applications of 5 cm of water once every 15 days), one was both fertilized and irrigated, and one was left untreated for control. Plots were monitored for four growing seasons. Fertilization increased leader growth, radial growth at breast height, and radial growth at base of live crown, mainly in the third and fourth growing seasons. Leader growth increase was most striking in the third and fourth frost-free seasons after first treatment. Fertilization increased aboveground biomass by 5%. Responses to irrigation were not evident and most likely because of sufficient precipitation falling during the study period.

336 Leak, W.B. 1981. Do stocking guides in the eastern United States relate to stand growth? J. For. 79:661–664.

Stocking guidelines were compared for northern hardwoods and eastern white pine (*Pinus strobus* L.) in New England and upland oaks (*Quercus* spp.) in the Central States. Several major growth studies were used as a basis for these comparisons. Stand growth of the hardwoods peaked below the recommended residual basal areas, whereas growth of eastern white pine was best at densities well above the recommended residual basal areas. A reevaluation was recommended of whether or not residual stocking recommendations based on crown dimensions or crown competition relationships provided adequate information on how a stand would respond in terms of growth, quality, or other stand attributes.

337 Leak, W.B. 1982. More on stocking guides. J. For. 80:503.

The author dealt with some questions that Leak (1981) (see annotation 336) raised about eastern white pine (*Pinus strobus* L.) stocking. Stocking guides should be based on some practical measure such as board-foot growth or dollar return. Further, eastern white pine could be grown at somewhat lower densities in some areas than suggested earlier, but caution was recommended because low-density management might lead to some additional costs including quality losses and damage from white pine weevil (*Pissodes strobi* (Peck)) and snow.

338 Leak, W.B. 1986. Stocking of white pine. Pages 51–54 *in* D.T. Funk, comp. Eastern white pine: today and tomorrow. Symposium proceedings, Durham, NH, 12–14 June 1985. Gen. Tech. Rep. WO-51. USDA For. Serv., Northeastern For. Exp. Stn., Durham, NH. 124 p.

Growing eastern white pine (*Pinus strobus* L.) under high and low stand densities was investigated. High density consisted of little or no thinning until 15–20 cm diameter at breast height (dbh), and maintaining a basal area of 20–23 m^2/ha in poletimber stands and 28–32 m^2/ha in sawtimber with some pruning. The low density included thinnings starting at 10–15 cm dbh, and a basal area of 7–9 m^2/ha in poletimber and 14–18 m^2/ha in sawtimber. The high-density approach should result in maximum volumes of medium-quality pine, low investments, and little hardwood understory development. Low-density management required a heavy commitment to pruning and hardwood understory control. The latter approach resulted in lower volumes per hectare but in earlier returns and higher log quality. A need for additional research in eastern white pine stocking was stressed and should include long-term growth, yield, and quality of managed stands related to stocking level or thinning intensity.

339 Leak, W.B.; Cullen, J.B.; Frieswyk, T.S. 1995. Dynamics of white pine in New England. Res. Pap. NE-699. USDA For. Serv., Northeastern For. Exp. Stn., Radnor, PA. 8 p.

The growth, regeneration, and quality of eastern white pine (*Pinus strobus* L.) between the 1970s and 1980s were analyzed for the six New England States from inventory and analysis data from the early 1970s through the early to mid-1980s. Growth rates seemed very comparable in all states except Rhode Island where it was lower. In all states combined, the proportion of area in seedling/sapling stands was too small (8%) to sustain the current volume and acreage of eastern white pine. Because eastern white pine can endure partial shade, it was regenerating to some extent under a partial overstory or in very small gaps. Increases in wood quality were evident because of an increase in tree size and past stand improvement practices.

340 Leal, D.B.; Thomas, S.C. 2003. Vertical gradients and tree-to-tree variation in shoot morphology and foliar nitrogen in an old-growth *Pinus strobus* stand. Can. J. For. Res. 33:1304–1314.

Vertical patterns in shoot and needle morphology, anatomy, and chemistry in old-growth eastern white pine (*Pinus strobus* L.) stands were examined using a canopy walkway. This walkway was situated in a 120-year-old stand allowing crown access to many individual trees. Measurements of internode length and width and needle production and survivorship were conducted on each of the last four years of growth. Anatomical analyses were made on the seven trees with the deepest crowns, and canopy openness was measured as well. Shoots in the upper part of the canopy showed higher internode elongation and needle mortality compared with the middle and lower canopy. Leaf mass per projected leaf area was higher for upper-canopy leaves as well. Tree-to-tree variation in foliage characteristics possibly increase generally with stand age, as trees respond to their variable biotic and abiotic environments through time. Over 50% of variance in needle size, tissue density, and N content was attributed to tree-to-tree differences.

341 Leary, R.A. 1997. Testing models of unthinned red pine plantation dynamics using a modified Bakuzis matrix of stand properties. Ecol. Model. 98:35–46.

Models of stand dynamics can be evaluated in different ways. In this study, a simplification of the Bakuzis matrix, a comprehensive graphical matrix of even-aged stand property interdependence, was presented and used to compare model predictions with general relationships of stand behavior. The use of the matrix was demonstrated with two models of unthinned red pine (*Pinus resinosa* Ait.) plantation dynamics in the Lake States (STEMS and REDPINE) and one from Ontario (yield tables of red pine from Petawawa). Use of this matrix showed inconsistencies in all three models, and recommendations were made to improve model construction.

342 Ledig, F.T.; Smith, D.M. 1981. The influence of silvicultural practices on genetic improvement: height growth and weevil resistance in eastern white pine. Silvae Genet. 30:30–36.

Silvicultural activities can affect genetic composition by modifying both selection pressures and breeding structure. In this study, the genetic effects of improvement cutting in eastern white pine (*Pinus strobus* L.) were examined. Seed was collected from three pairs of stands in New Hampshire, with and without prior thinning, and from two stands of scattered trees left standing after a hurricane. Seed was raised as 3+0 stock and planted in Eastford, Connecticut, at a 1.8 × 1.8 m spacing using a compact family block with six replicates. Height and terminal leader mortality due to white pine weevil (*Pissodes strobi* (Peck)) attack was recorded at age 9 and 12. Results showed a highly consistent relationship between height and white pine weevil attack in families, but little relationship among families. Thinning, if properly applied, could be used to maximize long-term genetic improvement as well as

short-term returns or it could lead to genetic deterioration if genetic principles were not addressed.

343 Lee, C.H. 1974. Geographic variation of growth and wood properties in eastern white pine—15-year results. Pages 36–41 *in* Proceedings of the 21st northeastern forest tree improvement conference, Fredericton, NB, 27–30 August 1973. University of New Brunswick, Fredericton, NB.

In 1955, the United States Forest Service initiated a range-wide provenance study of eastern white pine (*Pinus strobus* L.). Seeds were collected from 21 natural stands throughout the species' natural range in the fall of 1956. In 1971, study material was sampled for growth rates and wood properties. Generally, southern Appalachian provenances grew faster than trees from the other seedlots, although this could change. There were significant differences among seedlots in specific gravity, although the differences were not large and did not follow a clear geographic pattern. No differences among seedlots or geographic trends were observed for tracheid length.

344 Lester, D.T. 1967. Variation in cone production of red pine in relation to weather. Can. J. Bot. 45:1683–1691.

A study was initiated to determine the effect of environmental influences on red pine (*Pinus resinosa* Ait.) cone production. Two-year-old red pine cones on 78 trees in Wisconsin were counted annually for 15 years and correlations made between cone counts and mean monthly temperature or precipitation for the 54 months preceding each count. Cone production exceeding 50% of the largest crop occurred normally at two- to three-year intervals. A high proportion of the cone crop was damaged because of insect attack in most years, except in the years of heaviest cone production. Significant correlations were found with July, August, and September mean daily temperature in the presumed season of pistillate cone initiation. Correlation with April mean temperature might reflect temperature effects on phenology of shoot development. Results showed promise for predicting the relative size of the potential cone crops up to two years in advance.

345 Li, P.; Beaulieu, J.; Daoust, G.; Plourde, A. 1997. Patterns of adaptive genetic variation in eastern white pine (*Pinus strobus*) from Quebec. Can. J. For. Res. 27:199–206.

A regional provenance–progeny test was initiated in Quebec to provide additional information on patterns of variation for eastern white pine (*Pinus strobus* L.) in Canada. A sample of 66 provenances was tested, and total height was measured at different times up to four years old. Four-year branch numbers and three-year bud burst and bud set were recorded. Analysis showed significant differences among provenances and families within provenances with one exception. Variance due to provenances was on average twice that due to families within provenances. Models describing the patterns of provenance variation were used to guide seed transfer and to delineate two provisional breeding zones.

346 Liechty, H.O.; Mroz, G.D.; Reed, D.D. 1986. The growth and yield responses of a high site quality red pine plantation to seven thinning treatments and two thinning intervals. Can. J. For. Res. 16:513–520.

The effects of different residual thinning densities, thinning methods, and thinning intervals on growth and yield of red pine (*Pinus resinosa* Ait.) were examined using a plantation growing on a high-quality site in Michigan. Eight thinning treatments (control; leaving a residual basal area of 13.8, 20.7, and 27.5 m^2/ha; removing alternate rows; removing every third row; and spacings of 20 and 30% of height) were applied. Twenty-four 0.04-ha plots plus a 3.7-m buffer were established in a complete block design with three replicates. Measurements were taken before and up to 10 years after the thinning treatments were completed. All thinning methods had a positive effect on diameter growth, but the individual tree selection methods showed better results than row thinning. Basal area growth showed less response to thinning. Thinning at a 6-year compared with a 10-year interval increased tree diameter growth, but volume growth per unit area was reduced.

347 Liechty, H.O.; Reed, D.D.; Mroz, G.D. 1988. An interim economic comparison of thinning treatments in a high site quality red pine plantation. North. J. Appl. For. 5:211–215.

A model was developed to analyze the effects of seven thinning treatments (control; leaving a residual basal area of 13.8, 20.7, and 27.5 m^2/ha; removing alternate rows; removing every third row; and spacings of 30% of height) on the economic returns from a highly productive red pine (*Pinus resinosa* Ait.) plantation in Michigan. Twenty-four 0.04-ha plots were established in a randomized block design with three replicates and they were then evaluated 10 years after thinning. Harvesting costs were estimated using machine productivity rates developed for loblolly pine (*Pinus taeda* L.). Higher product values were associated with larger tree diameters. After 30–35 years, returns from stands managed on high-quality sites with a lower residual density (13.8 m^2/ha) after thinning were similar to stands with a high (27.5 m^2/ha) residual basal area. This was because of the larger returns from the initial heavy thinnings and lower harvesting costs associated with harvesting larger and fewer trees in the heavier thinned treatment. It was not clear how the results would

change if a longer (40–60-year) rotation were used or the number of thinning cycles were increased.

348 Lister, G.R.; Slankis, V.; Krotkov, G.; Nelson, C.D. 1968. The growth and physiology of *Pinus strobus* L. seedlings as affected by various nutritional levels of nitrogen and phosphorus. Ann. Bot. 32:33–43.

The fate of recent photosynthate and the extent of mycorrhizal development were investigated in eastern white pine (*Pinus strobus* L.) seedlings grown at different levels of nitrogen and phosphorus. Two hundred potted eastern white pine seedlings were grown in granitic gravel either in outdoor cold frames or in growth chambers. They were watered every other day with a salt solution containing different amounts of nitrogen and phosphorus. After 13 weeks, individual seedlings were illuminated in the presence of $^{14}CO_2$, and their rates of photosynthesis, respiration, and translocation of recent ^{14}C-photosynthate to their roots were observed. Plants grown at the intermediate levels of nitrogen and phosphorus nutrition showed better mycorrhizal development, and higher growth, photosynthesis, and translocation of recent ^{14}C-photosynthate to the roots. A group of substances, rather than any single substance, might determine the formation of a mycorrhizal association.

349 Logan, K.T. 1962. Growth of white pine seedlings beneath an aspen stand. Tech. Note 121. Department of Forestry, Ottawa. 13 p.

The influences of a trembling aspen (*Populus tremuloides* Michx.) overstory and undergrowth on eastern white pine (*Pinus strobus* L.) seedlings were studied at the Petawawa Forest Experiment Station in Ontario. A 16-ha area originally supporting eastern white pine burned twice and now supported an aspen stand. A few mature eastern white pine trees surrounded the area, which was thinned to 2000 trembling aspen per hectare and underplanted with eastern white pine seedlings the following year. The area was divided into three sites on the basis of moisture regime. Understory competition varied with moisture regime. Four blocks were established on each of the three sites. A split-plot layout was used with treatments arranged in 6-m squares. Treatments consisted of clearcut overstory trees and understory competition, cut of undergrowth only, and control. Fourteen 4+0 eastern white pine seedlings of local origin were planted on each of the 48 blocks. Light levels increased from <5 to 36% of full sunlight when undergrowth was harvested, and as much as 65% when the trembling aspen was also cut. Eastern white pine could be grown underneath trembling aspen on fresh to very moist sandy soils with little reduction in height if undergrowth were controlled until the seedlings were 1.2–1.5 m tall. Overstory trembling aspen 9–12 m tall could be beneficial in protecting eastern white pine from white pine weevil (*Pissodes strobi* (Peck)) attacks and improving seedling nutrition.

350 Logan, K.T. 1966. Growth of tree seedlings as affected by light intensity. II. Red pine, white pine, jack pine and eastern larch. Publication No. 1160. Department of Forestry, Ottawa. 19 p.

The effects of shade on seedling development were examined for several tree species. Eastern white (*Pinus strobus* L.), red (*P. resinosa* Ait.), and jack pine (*P. banksiana* Lamb.) and eastern larch (preferred common name is tamarack, *Larix laricina* (Du Roi) K. Koch) seedlings were grown in an open area and in three shelters providing 13, 25, and 45% of full sunlight. Twenty seedlings per species were placed in each of two rows located at random in each treatment. Growth was compared after five years (eastern white pine and eastern larch) or six years (jack and red pine), both within and between treatments in terms of height, root and shoot weight, needle length, and diameter of leader and root collar. Eastern white pine and eastern larch reached a maximum height in 45% of full sunlight, whereas jack and red pine reached a maximum height and weight when grown in full sunlight. Growth of all species tested was definitely less at the lower levels of light, that is, 13 and 25% of full sunlight.

351 Lombardero, M.J.; Ayres, M.P.; Ayres, B.D. 2006. Effects of fire and mechanical wounding on *Pinus resinosa* resin defenses, beetle attacks, and pathogens. For. Ecol. Manag. 225:349–358.

A 44-year-old red pine (*Pinus resinosa* Ait.) plantation in Wisconsin was studied to test the interactions among fire, physical wounding, fungal pathogens, and bark beetles. Four treatments (simulated burning, mechanical wounding, both, or control) were applied to a group of 15 trees. Resin flow was measured on treated and untreated sides of all trees, before and three times after treatment. The monitoring of bark beetles (the pine engraver, *Ips pini* (Say), and the eastern fivespined ips, *Ips grandicollis* (Eichhoff)), began three days after the burning treatments. Ten days after fire treatment, sample trees were inoculated with four species of fungal pathogens associated with *Ips* bark beetles. After an initial reduction of resin flow, all treated trees showed a significantly higher resin flow almost two months after treatment. Combinations of treatments did not increase resin flow. The highest number of bark beetles (landing rates) was found in the week following treatments when 25% of all landings occurred. Treatments did not affect landing rates, but actual beetle attacks were more than twice as high in burned trees. Some differences in lesion size were found among trees within treatment, but no difference was found among the treatments. The results suggested

the possibility of a fire-driven coevolution between red pine and bark beetles.

352 Lothner, D.C.; Bradley, D.P. 1984. A new look at red pine financial returns in the Lake States. Res. Pap. NC-246. USDA For. Serv., North Central For. Exp. Stn., St. Paul, MN. 4 p.

Although red pine (*Pinus resinosa* Ait.) plantations and natural stands made up only 2.5% of the Lake States commercial forest, red pine was well recognized for its versatility and its strength. As a result, red pine commanded the highest price for any coniferous species in the Lake States. This study explored which existing and potential red pine sites warranted investment and how they should be managed to achieve the best financial performance. Two investment criteria were used: the soil expectation value and the internal rate of return. Analyses were made for three site indices (60, 70, and 80) and several treatment combinations: survival densities after 5 years of planting of 1000, 1500, or 2000 trees per hectare; residual basal area after thinning of 13.8, 18.4, 23.0, and 27.5 m^2/ha; and rotation ages of 50–95 years. The analyses predicted returns of 5, 6, and 7% on red pine sites with site index 18, 21, and 24, respectively. A rather low initial stocking of 1000 trees per hectare was considered optimal for all sites. Optimum basal area after thinning increased with site quality from 18.4 m^2/ha for site index 60 to 23.0 m^2/ha for site indices 70 and 80.

353 Lowe, J.J. 1994. Volume distribution of eastern white pine in Canada. For. Chron. 70:369–371.

The forest inventory of 1991 was used to summarize the volume distribution of eastern white pine (*Pinus strobus* L.) in Canada. This national inventory is an aggregation of local inventories completed with the cooperation of provinces and territories. Eastern white pine volume classes were mapped to indicate its occurrence by forest region and forest type. The highest concentrations of eastern white pine were in southeastern Ontario, southwestern Quebec, and the Maritimes, with most (114 million m^3) in the Great Lakes–St. Lawrence forest region where it represents 11% of the coniferous volume. Eastern white pine grew frequently in close association with other tree species with 53% of its volume in mixedwoods and 12% in hardwood stands.

354 Lu, P.; Joyce, D.G.; Sinclair, R.W. 2003a. Effect of selection on shoot elongation rhythm of eastern white pine (*Pinus strobus* L.) and its implications to seed transfer in Ontario. For. Ecol. Manag. 182:161–173.

A question in seed source planning for reforestation programs was how much of a change in growth rhythm was acceptable to maintain population adaptation while maximizing growth. The relationships between accumulated shoot increment and growth rhythm variables were studied by analyzing shoot elongation curves of two-year-old greenhouse-grown seedlings and seven-year-old field-grown trees from 112 natural populations of eastern white pine (*Pinus strobus* L.) in Ontario. Height increments were measured from May to late July at three-day intervals for the greenhouse seedlings and at seven-day intervals for the field trees. The faster growth in eastern white pine was associated with both an earlier start and later cessation of shoot elongation for individuals and populations. Estimates of shoot elongation curve parameters and predicted growth rhythm variables varied both among and within populations. Spatial patterns showed a north–south clinical trend with eastern white pine seed sources 2° latitude or more south of a regeneration site or 26 days in growing season length suggested as safe regarding synchronization in shoot growth rhythm.

355 Lu, P.; Joyce, D.G.; Sinclair, R.W. 2003b. Geographic variation in cold hardiness among eastern white pine (*Pinus strobus* L.) provenances in Ontario. For. Ecol. Manag. 178:329–340.

Cold hardiness was a major concern for seed transfer between regions in temperate and boreal forests. Shoot and needle samples collected from 110 eastern white pine (*Pinus strobus* L.) provenances in Ontario at different growing stages and in different years were subjected to artificial freezing tests to determine provenance differentiation in fall and winter cold hardiness. Under the natural cold acclimation process, needle and shoot samples were able to withstand low freezing temperatures in September and October that exceeded long-term extremes for the same period. The sensitivity of eastern white pine to cold temperatures decreased from September to November. Seed transfer between regions was not recommended if the annual mean maximum temperature differed by >2.5°C.

356 Lu, P.; Joyce, D.G.; Sinclair, R.W. 2003c. Seed source selection of eastern white pine. For. Res. Note 64. OMNR, OFRI, Applied Research and Development, Sault Ste. Marie, ON. 4 p.

This research note used seed from 112 natural populations collected across Ontario, Canada, to summarize an eastern white pine (*Pinus strobus* L.) genecology research trial. Growth potential and adaptation were tested for two years in the greenhouse and for five more years in two field trials, and frost tolerance was tested under artificial weather conditions. Seed from sources of warmer and more southerly areas generally have higher growth potential but were less cold hardy. Recommendations for seed transfer included not using seed sources from 1.0 to 1.5° latitude north of a given reforestation area, using seed sources from 1.5 to 2.0° latitude south of a given reforestation area could possibly

promote eastern white pine growth without incurring more frost damage risk, and a 6.5–13.0% height gain could be expected by selecting a seed source from within 1.0 to 2.0° latitude of the reforestation area.

357 Lu, P.; Sinclair, R.W. 2006. Survival, growth and wood specific gravity of interspecific hybrids of *Pinus strobus* and *P. wallichiana* grown in Ontario. For. Ecol. Manag. 234:97–106.

Ontario's program of breeding eastern white pine (*Pinus strobus* L.) for resistance to white pine blister rust (*Cronartium ribicola* J.C. Fischer) began in the late 1940s. The survival, growth, and wood specific gravity of the first generation crosses and backcrosses of interspecific hybrids of eastern white and blue pine (*P. wallichiana* A.B. Jacks.) grown in Ontario were assessed. Over 23 field trials and clone banks of eastern white pine interspecific hybrids were established, mostly with 3+0 bare-root stock, and initial spacings ranging from 1.8 × 1.8 m to 3.0 × 3.0 m. The trials were assessed at varying ages for survival, health status, and height. Nine trials were remeasured in fall 2004, and core samples of 95 sample trees were collected to assess wood specific gravity. Low survival rates of blue pine compared with the first-generation interspecific hybrids, the first generation backcross hybrids, and pure eastern white pine were caused by insufficient cold hardiness. Survival and growth of the interspecific hybrids increased with a higher proportion of eastern white pine parentage. Means of wood specific gravity were highest for blue pine and lowest for eastern white pine. Despite the lack of cold hardiness of blue pine, the use of first-generation hybrids and backcrosses might have been justified on sites where eastern white pine regeneration was limited by white pine blister rust.

358 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. Manag. 214:344–357.

Inherited seedling resistance to white pine blister rust (*Cronartium ribicola* J.C. Fischer) was investigated in selected families of eastern white pine (*Pinus strobus* L.) and interspecific hybrids. Four consecutive artificial inoculation experiments were completed using a randomized complete block design in a greenhouse between 2002 and 2004. Eastern white pine demonstrated the highest mortality and therefore lacked significant inherent resistance to white pine blister rust. Some of the interspecific hybrids showed promise. The greatest survival rates following innoculation were in hybrids of eastern white pine crossed with either Japanese white pine (*P. parviflora* Siebold & Zucc.), Korean pine (*P. koraiensis* Siebold & Zucc.), or blue pine (*P. wallichiana* A.B. Jacks.). Strong resistance to white pine blister rust was successfully transmitted from the previous generations of hybrid eastern white pine. The efficiency of multispecies hybridization in breeding to increase tree growth and resistance to white pine blister rust required further evaluation.

359 Lundgren, A.L. 1965. Thinning red pine for high investment returns. Res. Pap. LS-18. USDA For. Serv., Lake States For. Exp. Stn., St. Paul, MN. 20 p.

Investment returns from growing red pine (*Pinus resinosa* Ait.) were influenced by thinning practices and rotation age. This study evaluated the basal area left after thinning and its effect on investment returns using examples that represented a wide range of initial stand densities and thinning programs. Leaving a basal area of 20.7 m^2/ha when thinning red pine gave higher investment returns throughout a wide range of stand conditions, and past histories of thinning, costs, and prices than any higher residual basal area. It was also demonstrated how financial rotations varied widely with stand conditions, investment alternatives, costs, and prices. Financial rotation ages for certain stand conditions commonly found in the Lake States were suggested for cordwood and sawtimber. Poles, posts, and mine timber products were not included in the management recommendations and therefore higher stand densities might be needed to optimize high-quality pole production. Evaluating an entire forest property could be difficult, unless the costs and returns from growing timber in each stand were understood.

360 Lundgren, A.L. 1981. The effect of initial number of trees per acre and thinning densities on timber yields from red pine plantations in the Lake States. Res. Pap. NC-193. USDA For. Serv., North Central For. Exp. Stn., St. Paul, MN. 25 p.

The effects of stand density on tree and stand characteristics and timber yields in red pine (*Pinus resinosa* Ait.) plantations in the Lake States region of the United States were reviewed. Growth and yield in red pine plantations were simulated using the REDPINE model. The stand densities ranged from 124 to 3954 trees per hectare. The basal area left after thinning ranged from 13.8 to 41.3 m^2/ha. Volume and diameter growth were both affected by number of trees per hectare and thinning densities. Initial stand densities had a major impact on the amount and quality of product yields. Further, the higher the site index was, the higher the basal area density that was required to achieve maximum yields.

361 Lundgren, A.L. 1983. New site productivity estimates for red pine in the Lake States. J. For. 81:714–717.

Red pine (*Pinus resinosa* Ait.) was one of the most widely planted conifers in the Lake States. Site productivity estimates for this region had earlier been based on old normal yield

tables for unmanaged stands. The new growth models presented were from data on permanent sample plots situated in both thinned and unthinned stands. These new models predicted an increase of expected yields of merchantable cubic volume from unthinned plots of 18% and from thinned plots of 32%. Previous publications were reviewed for comparison, and they strongly supported the proposed new productivity curves.

362 Lynham, T.J.; Curran, T.R. 1998. Vegetation recovery after wildfire in old-growth red and white pine. Natural Resources Canada, Canadian Forest Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON. Frontline Tech. Note No. 100. 4 p.

A high-intensity, large wildfire in August 1995 burned 25 000 ha of forest in Quetico Provincial Park in northwestern Ontario. The burned area included large stands of old-growth red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.). Six weeks after the fire, the burned area was examined, and a year later vegetation and soil sample plots were set up and assessed. Many tree and shrub species had sprouted after six weeks. The fire consumed almost all the organic soil layer in some places. Red and eastern white pine regeneration was generally low partly due to a poor cone crop. Further investigations were suggested during the next 5–10 years to assess the pattern of recovery for red and eastern white pine.

363 Machado, J.-L.; Walters, M.B.; Reich, P.B. 2003. Below-ground resources limit seedling growth in forest understories but do not alter biomass distribution. Ann. For. Sci. 60:319–330.

This four-year study investigated the effect of increased soil resource availability from trenching on the growth, morphology, biomass distribution, and survival of five conifer species of differing shade tolerances. Both red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.) were included in the study that was conducted on two research sites in northern Wisconsin. One-year-old seedlings were planted in 11 pairs of plots (one trenched, one control per pair) with 12 seedlings of each species planted at approximately a 30-cm spacing in 1 × 1 m subplots. Higher soil resource availability increased seedling growth, but it did not favor either tolerant or intolerant species. Red and eastern white pine survival was not affected by trenching. Earlier studies had shown little or no variation in aboveground seedling growth under low-light conditions in response to variations in soil resource availability.

364 MacHattie, L.B.; Horton, K.W. 1963. Influences of microclimates on mortality and growth of planted white spruce, jack pine and white pine. For. Chron. 39:301–312.

On the south and north side of a ridge in the Petawawa Forest Experiment Station in Ontario, a 20-m strip was cleared and microclimatological stations installed. Four conifer species were planted along the strips, red (*Pinus resinosa* Ait.), eastern white (*P. strobus* L.), and jack pine (*P. banksiana* Lamb.), and white spruce (*Picea glauca* (Moench) Voss), with eight seedlings per species per row for a total of 2080 trees. Competing vegetation was removed periodically, and height growth and mortality were evaluated for four years. Fifty percent of the seedlings died during the first summer after planting, and a relationship was noted between mortality and topography. The physiographic influences made it difficult to isolate microclimatic influences on seedling development. Correlations suggested some possible relationships, for example, between mean air temperature for the previous summer and eastern white pine height growth.

365 Mack, T.J.; Burk, T.E. 2005. A model-based approach to developing density management diagrams illustrated with Lake States red pine. North. J. Appl. For. 22:117–123.

Density management diagrams (DMDs) were used to guide thinning scheduling for even-aged stands, but they typically had inherent weaknesses such as a lack of automation, poor age and mortality accounting, inflexible product-yield reporting, and an inability to address economic aspects. Resinosa, a new and improved DMD for Lake States red pine (*Pinus resinosa* Ait.), was designed to help overcome these limitations and allow foresters to make more comprehensive comparisons among alternative management regimes.

366 Mader, D.L. 1976. Soil-site productivity for natural stands of white pine in Massachusetts. Soil Sci. Soc. Am. J. 40:112–115.

Soil and site characteristics were evaluated in 82 eastern white pine (*Pinus strobus* L.) stands in Massachusetts and used to predict growth of eastern white pine. Soil descriptions, site characteristics, and stand growth were recorded, and soil samples were collected and analyzed for physical and chemical properties. Periodic growth was determined by completing a remeasurement after six years. Step-wise multiple regression analyses were done to relate various growth measures to site and soil factors. Height was predicted most accurately with age plus soil variables accounting for 80–90% of the variation. Volume was also predicted accurately by age and soil-site factors, but basal area was not. The equations for site index, total height, and periodic cubic volume growth appeared promising for use in predicting eastern white pine productivity.

367 Mader, D.L.; MacConnell, W.P.; Mawson, J.C.; O'Keefe, J.F. 1983. Forest site productivity assessment: meeting needs in Massachusetts. Pages 31–35 *in* R. Ballard and S.P. Gessel, eds. IUFRO symposium on forest site and continuous productivity, Seattle, Washington, 22–28 August 1982. Gen. Tech. Rep. PNW-163. USDA For. Serv., Pacific Northwest For. Range Exp. Stn., Portland, OR.

A need for greater site-productivity assessment in Massachusetts was identified because of the trend to more intense forest management. A map-based site classification system was designed consisting of five consecutive levels of separation (major geographic zones, elevation, slope, aspect, and soil groups). A modification of the system was still being tested for prime timberlands classification. This proposed new system had three categories of prime land with a dual productivity rating system based on both eastern white pine (*Pinus strobus* L.) and red oak (*Quercus rubra* L.). The national standard for prime forest land had a potential mean annual net increment of 6.0 $m^3 \bullet ha^{-1} \bullet year^{-1}$. The highest productivity class of prime land for eastern white pine would produce a mean annual volume increment of >10.9 m^3/ha at the age of culmination.

368 Mader, D.L.; Owen, D.F. 1961. Relationships between soil properties and red pine growth in Massachusetts. Soil. Sci. Soc Am. Proc. 25:62–65.

Relationships were examined between soil properties and growth of red pine (*Pinus resinosa* Ait.) plantations in Massachusetts. Forty-seven plots, mostly 0.04 ha, were set up in plantations that were fully stocked and unaffected by interspecific competition. Trees were measured and soils sampled and analyzed. Growth was evaluated in height at 25 years, height increase from 20 to 30 years, volume at age 25, and volume increase for the 5 years after stand volume reached 105 m^3/ha. Organic matter, nitrogen, and drainage class showed some value for assessing site productivity. Fifty-eight percent of the variability in growth could be accounted for using multiple regression techniques that related eight soil factors to growth. Volume growth was more closely correlated with site factors than either total or periodic height growth.

369 Madgwick, H.A.I. 1964a. Estimation of surface area of pine needles with special reference to *Pinus resinosa*. J. For. 62:636.

The surface area of pine needles was usually estimated by assuming that their shape conforms to some simple geometric shape. Four methods of estimating the surface of pine needles were compared: three already published methods using different geometric shapes and a proposed new method that estimates the surface area by numerical integration of the needle profile using the repeated Simpson's Rule. Thirty-nine fascicles from a range of needle age, tree size, and site were collected from two red pine (*Pinus resinosa* Ait.) stands and assessed. The three previously published methods gave results +5.6, −12.0, and −19.6% of values of the proposed method. Further research was needed to determine the proportion of the fascicle surface that was ecologically and physiologically important.

370 Madgwick, H.A.I. 1964b. The chemical composition of foliage as an index of nutritional status in red pine (*Pinus resinosa* Ait.). Plant Soil 21:70–80.

Leyton's hypothesis stating that only deficient nutrients would be significantly and positively related to growth in multiple regression equations was tested. A potassium-deficient site was planted in 1951 with 4+0 red pine (*Pinus resinosa* Ait.) stock at a 2×2 m spacing. Three plots were selected for study in 1960 and they received three treatments: control, fertilization in nursery with potash fertilizer, and fertilized after planting with potassium chloride. After 10 years, 26 trees per plot were measured and needles were dried and weighed. Multiple regressions were calculated relating tree height and leader length to foliar concentrations of sodium, potassium, calcium, magnesium, manganese, phosphorus, nitrogen, and silica. Leader length correlated to foliar potassium in all three plots. Leyton's hypothesis was supported by the combined data and by the data from the trees fertilized in the nursery, but not from the two other single plots. Results of this study confirmed earlier work that excellent growth of red pine was possible when there was a minimum of 450 mg K/100 g of current year needle mass.

371 Magnussen, S. 1991. Efficiency of early selections for stem volume and predictions of size distributions of selections in a red pine spacing trial. For. Sci. 37:593–612.

An assessment was made on whether or not the performance of mature red pine (*Pinus resinosa* Ait.) trees could be predicted by using tree growth at an early age. A red pine spacing trial at Petawawa, Ontario, was studied to quantify the trends in selection efficiencies on the basis of age at which the selection was made, initial spacing, and intensity of selection. The target trait was stem volume at age 34. Markov chain transition probabilities were used to develop a simple matrix-oriented model to predict future size distributions and age-to-age correlations. Simulated phenotypic selections for superior stem volume at age 34 were made using Markov chains (transition probability matrices). The efficiency of early selections for stem volume size increased with age but decreased with increasing initial spacing. Interactions between spacing, age, and the intensity of selection modified the overall efficiency of early selections. Relatively close spacings

(1–2 m) were recommended for early selections in tree improvement programs.

372 Magnussen, S.; Brand, D.G. 1989. A competition process driven growth model for red pine. Forestry Canada, Petawawa National Forestry Institute, Chalk River, ON. Information Report PI-X-89. 38 p.

The trends in selection efficiencies for red pine (*Pinus resinosa* Ait.) were quantified on the basis of age at which the selection was made, initial spacing of the plantation, and the intensity of selection. Data from a red pine spacing trial at Petawawa, Ontario, with square spacings of 1.2, 1.5, 1.8, 2.1, 2.4, 3.0, 4.3, and 6.0 m were used to develop a simulation model for predicting individual tree growth and mortality. On the basis of stand data at age 10, the model was used to predict tree volume distributions until age 35. Many graphs and tables of model output were produced and compared with observed data. The model realistically generated the temporal dynamics of volume distributions in even-aged red pine plantations. The model application was limited to initial spacings between 1.5 and 3.0 m due to failure to predict stand development beyond a square spacing of 3.0 m and poor predictions for the 1.2-m spacing. A limited requirement for input data made this model an attractive tool for growth and yield simulation.

373 Magnussen, S.; Burgess, D. 1997. Stochastic resampling techniques for quantifying error propagations in forest field experiments. Can. J. For. Res. 27:630–637.

Statistical analyses of forest field experiments often failed to account fully for the uncertainty inherent in the results. The importance of integrating all known sources of tree-to-tree variation into the results on a per-plot basis was examined using data from a red pine (*Pinus resinosa* Ait.) spacing trial at Petawawa, Ontario. The spacing trial, with two spacings (2.1 × 2.1 m and 3.0 × 3.0 m) and four replicates, was analyzed with and without stochastic (random) resampling. The reliability of a direct analysis (no resampling) averaged 0.84. Stochastic resampling resulted in higher among-plot variances of tree size and volume, which consequently lowered the significance level of pairwise *t*-tests of no spacing effect. Stochastic resampling lowered the *t*-test statistics by an average of 18% and their significance levels by about 75%. Resampling techniques that completely account for all relevant sources of variation held promise for further application in data analyses in forestry.

374 Maier, C.A.; Teskey, R.O. 1992. Internal and external control of net photosynthesis and stomatal conductance of mature eastern white pine (*Pinus strobus*). Can. J. For. Res. 22:1387–1394.

The importance of internal factors in the regulation of the rate of net photosynthesis was examined. During an extremely dry, warm year, and a normal year, leaf gas exchanges and water relations were measured in the canopy of two 30-m tall eastern white pines (*Pinus strobus* L.) in western North Carolina. Measurements were taken on the second and third whorl of branches using the same branches each time. Both internal and external factors influenced seasonal and diurnal variation in net photosynthesis and leaf conductance. Photosynthetic capacity of one-year-old foliage in the spring appeared to be controlled primarily by assimilate demand in growing tissues, and growth had a major impact on the photosynthetic capacity of existing foliage.

375 Maley, M.; Bowling, C. 1993. A 30-year remeasurement of a red pine provenance trial: implications for management in northwestern Ontario. TN-22. OMNR, Northwest Region Science and Technology, Thunder Bay, ON. 10 p.

Increasing the use of red pine (*Pinus resinosa* Ait.) to help meet wood-supply gaps in northwestern Ontario was investigated. Red pine showed good growth potential in the northwest region. The 30-year remeasurement of a range-wide provenance trial planted at a 1.8 × 1.8 m spacing near Sioux Lookout, Ontario, indicated that nonlocal provenances from elsewhere in Ontario and the Lake States were performing as well as local provenances. On the basis of these results, and the fact that the local red pine seed supply was limited, the authors suggested that nonlocal seed sources be considered to augment local red pine seed supplies.

376 Mallik, A.U.; Roberts, B.A. 1994. Natural regeneration of *Pinus resinosa* on burned and unburned sites in Newfoundland. J. Veg. Sci. 5:179–186.

Because of a general decline in natural regeneration, red pine (*Pinus resinosa* Ait.) had become a scarce species in Newfoundland. Natural regeneration around mature red pine trees was studied in a burned and an unburned stand. Burn temperatures were 800, 600, 400, and 200°C with two unheated samples for control. Seedlings were measured in a 5-m radius from the stems of ten 60–100-year-old isolated red pine stems; soil samples were taken and greenhouse tests completed to determine the effects of watering and burning on red pine and sheep laurel (*Kalmia angustifolia* L.). Burning generally had a positive influence on seedling growth, and red pine regeneration increased by decreasing the thickness of duff layer. Burning temperatures of 600°C showed the best results for root growth. Burning temperatures between 400 and 600°C might create the optimum seedbed conditions for seedling growth.

377 Maloy, O.C. 2001. White pine blister rust. Plant Health Prog. [online]. Doi: 10.1094/PHP-2001-0924-01-HM http://www.plantmanagementnetwork.net/pub/php.management/whitepine/

White pine blister rust (*Cronartium ribicola* J.C. Fischer) biology, management, and resistance were reviewed. The disease was probably the most destructive disease of five-needle pines in North America, although logging largely depleted stands of eastern white pine (*Pinus strobus* L.) before white pine blister rust was introduced into North America. The history of white pine blister rust and its symptoms were described and management recommendations presented. Earlier studies showed that 95% of white pine blister rust infections occurred within 3 m of the ground, and removing lower branches eliminated these primary infection points. Pruning therefore was recommended as one way to control white pine blister rust. Pruning was normally restricted to the first 1.8–2.4 m aboveground and therefore did not remove >50% of live branches.

378 Martin, G.L.; Ek, A.R. 1984. A comparison of competition measures and growth models for predicting plantation red pine diameter and height growth. For. Sci. 30:731–743.

The results and implications of testing and comparing growth models and associated measures of competition were discussed using data from 17 permanent sample plots (PSPs) in red pine (*Pinus resinosa* Ait.) plantations in Wisconsin. The PSPs ranged in age from 20 to 58 years and in basal area from 4.9 to 58.5 m^2/ha. A total of 11 plots received one or more thinning treatments and the remaining 6 unthinned plots were used as controls. The models were derived using nonlinear regression analyses. Simple empirical models provided slightly better fits for height growth than semiempirical or constrained model forms. The semiempirical model with a distance-independent index was possibly more accurate for unmanaged stands and for extrapolating beyond the range of data.

379 Martin, J.L. 1964. The insect ecology of red pine plantations in central Ontario. II. Life history and control of Curculionidae. Can. Entomol. 96:1408–1417.

The role of weevils (Curculionidae) in the insect ecology of old-field red pine (*Pinus resinosa* Ait.) plantations was examined, and their possible relations to red pine mortality in plantations in the Algoma District, Ontario. The species studied were seedling debarking weevil (*Hylobius congener* Dalla Torre et al.), two-spotted pine weevil (*Pissodes affinis* Randall), northern pine weevil (*P. approximatus* Hopkins), and the weevil *Magdalis perforata* Horn. The distribution, hosts, life history, and habits of each species were discussed. When considering habitat preferences, the species were divided into two groups: *H. congener* and *P. affinis* preferred older, closed stands, whereas *P. approximatus* and *M. perforata* were most abundant in young, open plantations. *Pissodes approximatus* was the only weevil species found to be of considerable economic importance in the study area because it was responsible for high mortality among disease-weakened trees. Control of *P. approximatus* was possible with insecticides or sanitation by removing and burning all newly killed and dying trees.

380 Martin, J.L. 1965a. The insect ecology of old-field red pine plantations in central Ontario. I. Description of the study area. Proc. Entomol. Soc. Ont. 95:70–87.

A preliminary survey of four red pine (*Pinus resinosa* Ait.) plantations in the Algoma District, Ontario, was conducted to provide an introduction and background for future reporting of more specialized faunal studies. The plantations ranged from 1 to 33 years old. Tree size was relatively uniform and therefore a 2% sample was considered sufficient for growth measurements. Ten permanent quadrants were established to measure herbaceous vegetation, shrubs, seedlings, and trees. The red pine grew rapidly until about the 15th year when crown closure occurred. After the 15th year, diameter increment decreased and height growth stabilized. A thinning at 27 years resulted in an increase in diameter growth but had little effect on height growth. The number of herbaceous and shrub species decreased from 20 species to almost none as the stand matured.

381 Martin, J.L. 1965b. The insect ecology of red pine plantations in central Ontario. III. Soil-surface fauna as indicators of stand change. Proc. Entomol. Soc. Ont. 95:87–102.

The composition of the soil-surface arthropod populations was investigated during various stages in the development of old-field red pine (*Pinus resinosa* Ait.) plantations including the changes in relative density of species among stands of different ages and from year to year. The research was conducted in four adjacent red pine plantations in the Algoma District, Ontario, representing four stages referred to as the establishment, transitional, monoculture, and young-forest stages. Four pitfall traps were permanently installed 45 m apart in each stand from 1960 through 1965. Catches were collected once each week from April until October. Limited rainfall in 1963 resulted in a loss of ground cover, which was reflected by decreases in insects of 48 and 55% from previous years in younger stands. In older stands, where ground cover was less important in relation to soil-surface fauna, the decrease was only 35%. A pruning operation was possibly responsible for larger attendant populations of soil and

soil-surface organisms. Changes in the composition of the soil-surface fauna suggested that definite successional trends coincided with stand development.

382 Martin, J.L. 1966. The insect ecology of red pine plantations in central Ontario. IV. The crown fauna. Can. Entomol. 98:10–27.
The insect ecology of red pine (*Pinus resinosa* Ait.) plantations in the Algoma District, Ontario, was studied as a prerequisite to more intensive studies of the arthropod groups as functional units in the community, and it consisted of a description of the composition and density, annual and seasonal fluctuations, succession and food relations of the arthropod fauna in the crown stratum of red pine stands. When crown closure occurred at about 15 years old, the monoculture stage began, and ground vegetation disappeared. Stands were usually thinned when they were about 25 years old by removing every second row of trees, after which ground cover reestablished. The arthropod fauna on trees in the establishment stage were determined by visual inspection. The fauna in the three older stages of pine were sampled by spraying the foliage with insecticide and capturing the falling arthropods in cloth funnels suspended beneath the trees. The most notable difference among the three later stages was the decrease in arthropod density in relation to crown size after the stands reached about 15 years old. But the percentage of predators and parasites in the total population remained remarkably stable, and a ratio of one secondary feeder to three primary feeders was maintained.

383 Marty, R. 1965. The mensurational characteristics of eastern white pine. Res. Pap. NE-40. USDA For. Serv., Northeastern For. Exp. Stn., Upper Darby, PA. 73 p.
Literature was reviewed and summarized to provide comprehensive estimates of eastern white pine (*Pinus strobus* L.) site index, tree volumes, and stand growth and yield predictors. Three ways of estimating site index were described, and various site-indices were presented, on the basis of data from Canada and the United States. Tree volume estimates were presented as cubic-foot volume by diameter at breast height (dbh) and total height; board-foot volume by dbh and total height; board-foot volume by dbh and merchantable length; board-foot volume by dbh, merchantable length, and Girard form class; and pulpwood volumes above sawlog merchantable limits. Growth and yield estimates were given on a per-acre basis, and referred to second-growth rather than virgin stands.

384 Marty, R. 1986. The trouble with white pine. Pages 7–9 *in* D.T. Funk, comp. Eastern white pine: today and tomorrow. Symposium proceedings, Durham, NH, 12–14 June 1985. Gen. Tech. Rep.WO-51. USDA For. Serv., Northeastern For. Exp. Stn., Durham, NH. 124 p.
The current and historical significance of eastern white pine (*Pinus strobus* L.) as an industrial resource was reviewed. Significant expansion in eastern white pine supply and utilization faced three main challenges that were technological, economic, and social. The author suggested that eastern white pine be managed in existing pure eastern white pine stands and it be favored in other stand-types. White pine weevil (*Pissodes strobi* (Peck)) and white pine blister rust (*Cronartium ribicola* J.C. Fischer) problems in the north were recognized, and a better use of white pine blister rust incidence zones was recommended as well as the use of chemicals to control white pine weevil damage. As for economic concerns, eastern white pine in the north was not viewed as a good investment, but many opportunities existed for growing eastern white pine in plantations in the south.

385 Mattson, W.J. 1978. The role of insects in the dynamics of cone production of red pine. Oecologia (Berl.) 33:327–349.
The major causes of cone mortality were examined to determine how cone production was controlled and to distinguish the interactions among the various factors affecting cone production. The mortality of cones was studied in the northern Lake States for five consecutive years in eight red pine (*Pinus resinosa* Ait.) stands. In each stand, 10 trees were selected randomly every year, and all cones were counted on eight randomly picked branches. Each branch was examined four times to document losses during different development stages. Survival of cones ranged from 0 to 82%. Almost all mortality losses could be attributed to insects, and a small amount to overwintering. Insects were also primarily responsible for annual fluctuations in the abundance of mature cones. Cone damage by insects might enhance flower primordia production and thereby the future abundance of cone insect feeding and breeding sites.

386 Mayfield, A.E., III; Allen, D.C.; Briggs, R.D. 2005. Radial growth impact of pine false webworm defoliation on eastern white pine. Can. J. For. Res. 35:1071–1086.
The radial and volume growth impact of pine false webworm (*Acantholyda erythrocephala* Linnaeus) defoliation was quantified for pole- and sawtimber-sized eastern white pine (*Pinus strobus* L.) in New York. Stem analysis was completed in two stands: a 67-year-old defoliated plantation with a basal area of 22.1 m^2/ha and an average height of 22.9 m, and a 70-year-old natural control stand with a basal area of 26.8 m^2/ha and an average height of 22.7 m. Ten and eight trees, respectively, were felled in each stand, and discs were cut and ring widths

measured. Results demonstrated that pine false webworm was capable of causing substantial growth loss in mature eastern white pine. Complete growth loss was most often found in the lower part, that is, the most commercially valuable part of the tree. The ability of pines to survive 10 years of annual defoliations was attributed to the fact that pine false webworm preferred older foliage.

387 McClain, K.M.; Morris, D.M.; Hills, S.C.; Buse, L.J. 1994. The effects of initial spacing on growth and crown development for planted northern conifers: 37-year results. For. Chron. 70:174–182.

The influence of initial spacings on the growth and crown development of boreal plantations was studied including how these patterns relate to the self-thinning theory. An 8-ha spacing trial near Thunder Bay, Ontario, containing three species, red pine (*Pinus resinosa* Ait.), black spruce (*Picea mariana* (Mill.) BSP), and white spruce (*P. glauca* (Moench) Voss), had been established at three initial spacings (1.8, 2.7, and 3.6 m) with three replicates. Diameter at breast height (dbh), height, and crown length and width were assessed four times between ages 25 and 37, and a cost/benefit analysis was conducted for the 37-year-old plantation. At age 37, crown closure had occurred for all species/spacing combinations. Wider spacing increased dbh, crown length, and crown width for all species, whereas height decreased. The shift to higher-valued products produced from the wider-spaced plantations possibly provided the best economic return. Red pine outgrew both black and white spruce in terms of total volume production (552, 282, and 331 m^3/ha, respectively, for example, at a 1.8-m spacing). Although red pine represented <4% of Ontario's total regeneration efforts, it showed potential for greater use on some boreal sites.

388 McConkey, T.W. 1965. White pine pruning and branch growth. Res. Note NE-27. USDA For. Serv., Northeastern For. Exp. Stn., Upper Darby, PA. 6 p.

The influences of pruning on residual branch growth were examined in a natural 12-year-old eastern white pine (*Pinus strobus* L.) stand thinned to either a 1.8×1.8 m or 3.7×3.7 m spacing. Four pruning intensities were applied: control, removal of 40% (light pruning), 55% (moderate pruning), or 70% (severe pruning) of the total branch area. After three years, no significant differences in branch growth had developed. Height growth slowed slightly after the first year but had recovered after three years. A net loss of stem volume growth occurred after pruning, which was greater in the 1.8×1.8 m spacing. The rate of main-stem growth recovered, but branch area was still only 70–80% of normal.

389 McFarlane, K.J.; Yanai, R.D. 2006. Measuring nitrogen and phosphorus uptake by intact roots of mature *Acer saccharum* Marsh., *Pinus resinosa* Ait., and *Picea abies* (L.) Karst. Plant Soil 279:163–172.

The depletion method was used in a few earlier studies to measure nutrient uptake by intact roots of mature trees. Modifications in the depletion method on net uptake of NH_4^+, NO_3^-, and PO_4^{3-} by intact roots of 60-year-old sugar maple (*Acer saccharum* Marsh.), red pine (*Pinus resinosa* Ait.), and Norway spruce (*Picea abies* (L.) Karst.) were examined. The methods tested included applying pretreatment solutions, the use of training roots, and varying concentrations of nutrient solution. The study site in Dryden, New York, contained 0.4-ha plots planted with either a single species or a mixture of species. Roots were trained by pruning and placing them in bags with a mixture of soil and sand. On the day of the experiments, 7–10 trained and freshly excavated (zero-recovery) roots were selected for each species, washed, and placed in a plastic tube with 27 ml of fresh nutrient solution (1, 5, and 10 times the simulated soil solution concentration). Roots and controls were exposed for two hours to each of the three concentrations of nutrient solutions. All three tree species showed a higher net uptake of NH_4^+ than NO_3^-. Uptake rates likely would change through time as the solutions became depleted. The use of training roots did not affect uptake rates measured using the depletion method.

390 McLaughlin, J.A. 2001. Impact of Armillaria root disease on succession in red pine plantations in southern Ontario. For. Chron. 77:519–524.

Aerial photography was used to identify openings created by mortality from armillaria root disease caused by the fungus *Armillaria ostoyae* (Romagn.) Herink in 13 plantations (mostly red pine, *Pinus resinosa* Ait.) in Simcoe and Dufferin Counties, Ontario. The openings were measured and mapped, and the natural regeneration of both tree and shrub species in the root disease mortality center was surveyed. Eastern white pine (*Pinus strobus* L.) and black cherry (*Prunus serotina* Ehrh.) were considered the most important tree species occupying the openings, but both had higher mortality from armillaria than the other tree species present. Long-term survival of eastern white and red pine regeneration was doubtful. Hardwoods less susceptible to armillaria than black cherry were expected to successfully colonize the openings.

391 McNab, W.H.; Ritter, B.A. 2000. The old orchard white pine plantation at Biltmore. J. For. 98:18–23.

In 1899, a 2.3-ha eastern white pine (*Pinus strobus* L.) plantation was established near Asheville, North Carolina, on a relatively steep hillside with deep but severely eroded

clay–loam soils. At age 18, three plots were set up to investigate the effects of stand density on growth and yield. Earlier thinnings were completed in 1916, 1923, 1929, 1936, 1942, 1953, and 1970. It was thinned for the eighth time in 1999, and trees in all plots were measured before each thinning. At age 100, total stand basal area had not culminated yet, thinning produced standing trees of larger diameter at breast height but did not increase sawtimber volumes, and site quality influenced yield more than thinning. This study demonstrated the value of maintaining permanent forest research plots for long-term ecological and silvicultural research.

392 McRae, D.J.; Lynham, T.J.; Frech, R.J. 1994. Understory prescribed burning in red pine and white pine. For. Chron. 70:395–401.

Red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.) are ecologically adapted to fire, and where wildfires are suppressed, alternatives are needed for managing pine. Understory prescribed burning as a method for regenerating eastern white and red pine and controlling hardwood competition was reviewed. Different aspects of understory prescribed burning were discussed, such as fire behavior and time of burning. Prescribed burning had proven to be a successful method for regenerating eastern white and red pine, but a lack of knowledge of applying fire and the fear of fires spreading uncontrollably had prevented greater use of understory prescribed burning.

393 McRae, D.J.; Weber, M.G.; Ward, P.C. 2001. Site preparation—prescribed fire. Pages 201–219 *in* R.G. Wagner and S.J. Colombo, eds. Regenerating the Canadian forest: principles and practice for Ontario. Fitzhenry & Whiteside Limited, Markham, Ontario.

Prescribed burning was reviewed and discussed as a very effective method of site preparation. Its use for fuel reduction and competition control was also discussed as well as the Canadian forest fire rating system with its two subsystems, the Canadian forest fire weather index and the Canadian forest fire behavior prediction system, and their relationships to forest soils. A detailed description was given on how to conduct a prescribed burn, mainly focusing on prescribed burning in Ontario following Ontario Ministry of Natural Resources policies and procedures. Forest and fire management personnel must work as a team to realize the benefits of prescribed burning.

394 Meier, R.J. 1992. Genetic tree improvement of eastern white pine. Pages 145–149 *in* R.A. Stine and M.J. Baughman, eds. White pine symposium proceedings: history, ecology, policy and management, Duluth, MN, 16–18 September 1992. University of Minnesota, Extension Service Distribution Center, St. Paul, MN. 202 p.

The genetic literature of eastern white pine (*Pinus strobus* L.) since 1970 was reviewed and it encompassed studies from across the range of eastern white pine. Provenance tests were discussed as well as several approaches used to improve resistance to white pine blister rust (*Cronartium ribicola* J.C. Fischer) and the white pine weevil (*Pissodes strobi* (Peck)). Several studies were completed to improve resistance to white pine blister rust, but little work was accomplished as of 1992 on the genetics of resistance to the white pine weevil. Present and future programs were discussed including the development of white pine blister rust-resistant seedlings for planting.

395 Messier, C.; Parent, S.; Chengaou, M.; Beaulieu, J. 1999. Juvenile growth and crown morphological plasticity of eastern white pines (*Pinus strobus* L.) planted along a natural light gradient: results after six years. For. Chron. 75:275–279.

Juvenile growth and crown morphology of eastern white pine (*Pinus strobus* L.) planted in cut-strips were assessed after six years in a light gradient varying between 10 and 66% of full sunlight. The light gradient was caused by an overstory of intolerant hardwoods subjected to partial harvesting. Four-year-old eastern white pine seedlings were planted in a second-growth forest dominated by trembling aspen (*Populus tremuloides* Michx.) and red maple (*Acer rubrum* L.) with an average canopy height of 18 m. During summer 1994, 63 eastern white pine saplings from six half-sib families were selected. Light reaching the top of each sapling crown was measured as well as its total height, terminal leader length, length of the longest lateral branch of the first whorl, live crown length, average crown diameter, and root collar diameter. Decreases in above-canopy light (between 10 and 66% of full sunlight) resulted in significant decreases in height and diameter of eastern white pine, especially below 30% full sunlight. Crown morphology changes were not correlated with light availability. For the first six years, at least, young eastern white pine can survive at 10% full sunlight, but both total height and diameter growth tend to reach near maximum at 40% light. Eastern white pine does not grow well in deep shade.

396 Methven, I.R. 1971. Prescribed fire, crown scorch and mortality: field and laboratory studies on red and white pine. Department of the Environment, Canadian Forestry Service, Petawawa For. Exp. Stn., Chalk River, ON. Information Report PS-X-31. 10 p.

The crown response of eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.) to heat flux from a prescribed fire was studied in the field as well as a simulated study in the laboratory. For the laboratory study, potted eastern white and red pine seedlings were enclosed in a heat chamber

and subjected to one of six heating regimes with temperature peaks between 50 and 100°C. Mortality was based on the absence of terminal bud flush the next spring. In the field, data were collected from two natural stands following prescribed burns. Mortality was based on the absence of green foliage the following year. The laboratory study indicated that pine seedlings could withstand up to 95% needle scorch with little effect on survival, whereas the field studies involving mature trees showed a greater susceptibility to heat damage. Results also showed that estimates of mortality due to crown scorch could be made immediately following fire rather than after one year.

397 Methven, I.R. 1973. Fire, succession and community structure in a red and white pine stand. Department of the Environment, Canadian Forestry Service, Petawawa For. Exp. Stn., Chalk River, ON. Information Report PS-X-43. 18 p.

In a 90-year-old natural eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.) stand, a prescribed burn was conducted in two consecutive years to determine the influence of fire on vegetative components, and to assess the possibility of altering forest succession to maintain eastern white and red pine. Before and after the burns, intensive vegetation surveys were made using 25 permanent sample plots. Both fires were gentle on average. The fires had the biggest impact on herbaceous species, seedlings, and saplings. The differences in vegetation one year after the fires compared with the vegetation three years before the fires were largely changes in species density rather than in species composition. Fire damage to the overstory trees was considered minimal and confined largely to balsam fir (*Abies balsamea* (L.) Mill.) and white spruce (*Picea glauca* (Moench) Voss).

398 Methven, I.R.; Murray, W.G. 1974. Using fire to eliminate understory balsam fir in pine management. For. Chron. 50:77–79.

In a 90-year-old, natural red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.) stand with a dense understory of balsam fir (*Abies balsamea* (L.) Mill.), a prescribed burn was used to reduce understory competition. Four plots were set up and three were burned once in successive years (1965, 1966, 1967). The fires were not intense, but sufficient to kill all the balsam fir saplings. No damage was done to the overstory trees. Regeneration was tallied in 1968, 1969, and 1972 on 20 randomly located 1-m^2 plots. Eastern white pine regeneration showed a slow and steady increase after fire with an average throughout the three burned plots of 12 300 eastern white pine seedlings per hectare in 1972. A shelterwood cut was suggested to improve availability in the understory.

399 Miller, J.S. 1978. Mechanical site preparation methods as part of a silvicultural system to regenerate white and red pine. Pages 87–93 *in* D.A.Cameron, comp. White and red pine symposium, Chalk River, ON, 20–22 September 1977. Symposium Proceedings O-P-6. Department of the Environment, Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. 178 p.

Site preparation was discussed as a means to favor the establishment and subsequent growth of red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.). Several site preparation methods and tools were described including blading and anchor chains dragged behind a skidder. An overview was given of the specific site preparation tools used in several regions in Ontario. The method of site preparation selected for use must consider the site conditions, timing, the silvicultural system, and the tree species to be regenerated as well as any possible future treatments required.

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

The red pine cone beetle (*Conophthorus resinosae* Hopkins) kills whole cones and reduces yields in seed production areas of red pine (*Pinus resinosa* Ait.). Adults overwinter in the ground. The vulnerability of adults in hibernation to prescribed burning was examined. Several plots in red pine stands and seed production areas in Minnesota, Wisconsin, and Michigan were subjected to low-intensity fires in either spring or fall. The low-intensity burnings killed 95–100% of adults compared with 52% in the control, which reflected winter mortality. In the seed production areas >4 ha, fire greatly reduced the red pine cone beetle. Burning areas of sufficient size in heavy crop years in the fall or spring before harvest might be a promising approach to protect seed production areas from cone-killing insects. But the weather conditions had to be suitable for prescribed burning, and these conditions might occur for only one week each year. Accomplishing the prescribed burns needed to control beetle populations therefore required careful scheduling and prompt action.

401 Miller, W.E.; Wambach, R.F.; Anfang, R.A. 1978. Effect of past European pine shoot moth infestations on volume yield of pole-sized red pine. For. Sci. 24:543–550.

Although the immediate effects of injury by the European pine shoot moth (*Rhyacionia buoliana* (Denis & Schiffermüller)) were known, little information was available about how future timber yields were affected. A method for estimating population densities in past years was described and used to estimate insect densities throughout the development of pole-sized red pine (*Pinus*

resinosa Ait.) plantations. Observed and expected growth of red pine was related to reconstructed insect densities. Annual estimates of late-larval densities were obtained from 11 young red pine plantations, and these same plantations were assessed for residual injuries 10–18 years later. An additional 25 unthinned pole-sized red pine plantations in Lower Michigan and Ohio were studied to assess European pine shoot moth impact on volume growth. Estimated moth population densities peaked early in plantation development because of insect winter mortality above snow depth as the trees aged. Pole-sized trees have sufficient time to recover from early injury. Observed diameter at breast height, total height, and volume growth did not differ significantly from expected values predicted using a red pine growth and yield model.

402 Mirov, N.T. 1967. The genus *Pinus*. Ronald Press Company, New York, NY. 602 p.

This is the first publication that attempted to summarize all available information on the biology and distribution of the genus *Pinus*. All species in the genus were included and they totaled more than 100 pine species. Of these, 32 pine species occurred in North America, 33 in Central America, 3 in northern Eurasia, 12 in the Mediterranean region, and 23 in east and southeast Asia. The main emphasis was on the biology of the individual species. It included a discussion on their history, paleobotanical record and paleography, geography, genetic aspects, morphology and reproduction, physiology and ecology, chemical aspects, chemical geography, and taxonomy.

403 Mittal, R.K.; Wang, B.S.P.; Harmsworth, D. 1987. Effects of extended prechilling on laboratory germination and fungal infection in seeds of white spruce and eastern white pine. Tree Plant. Notes 38:6–9.

Moist cold stratification generally improves seed germination. The effect of an extended prechilling period was assessed on fungal development and the germination of eastern white pine (*Pinus strobus* L.) and white spruce (*Picea glauca* (Moench) Voss). Eastern white pine seed was from Algonquin Park, Ontario, whereas white spruce seed was from the Rocky Mountain/Clear Water Forest, Alberta. Seeds were stored at 2–4°C, and four replicates of 100 seeds per species were removed at nine intervals over 15 weeks and placed in germination boxes. Germination and the incidence of mold on seed were assessed every 3 days for 21 days for white spruce and 28 days for eastern white pine. Long-term prechilling increased the rate of seed germination but did not affect the overall percentage of germination. Prechilling increased the incidence of mold on germinants, but seed germination was not affected by fungal infection. Surface sterilization of seed was recommended, nevertheless, in future as a precaution.

404 Morgan, R.E.; de Groot, P.; Smith, S.M. 2004. Susceptibility of pine plantations to attack by the pine shoot beetle (*Tomicus piniperda*) in southern Ontario. Can. J. For. Res. 34:2528–2540.

A total of 43 sites in southern Ontario were examined to determine the relationship between tree–site characteristics and attacks by the pine shoot beetle (*Tomicus piniperda* L.). At each site, many stand characteristics were measured including the density of recently dead pine (*Pinus* spp.) snags, tree diameters, pine canopy cover, and duff depth. There was a strong positive relationship between the number of attacked pine shoots and the density of recently dead pine snags. The pine shoot beetle was mainly a secondary pest, feeding mostly on the shoots of dying or stressed trees, attacking healthy trees only when beetle population numbers were high. The recently dead pines provided breeding sites for the beetles, thus increasing the frequency of attacks. By removing dead or less vigorous trees regularly in thinnings, and by avoiding offsite plantings of pine, the number of pine shoot beetle attacks could be reduced significantly.

405 Morneault, A.; McPherson, S.; Davidson, B.; Othmer, D. 2003. Aerial herbicide release treatments in a uniform shelterwood system for white pine. Tech. Note No. 08. OMNR, Science and Information Branch, Southern Science and Information Section, North Bay, ON. 9 p.

The efficacy of aerial spraying of glyphosate and triclopyr herbicides on shelterwood stands was assessed as well as the growth response of eastern white pine (*Pinus strobus* L.) regeneration. Three aerial spray treatments were applied: one with glyphosate and two with triclopyr at different rates. Nine sample plots were set up under a range of crown closures in areas scheduled for aerial spraying, each consisting of a cluster of eight 2×2 m subplots. Data were collected before spraying and one and two years after treatment. Glyphosate was more effective at controlling white birch (*Betula papyrifera* Marsh.), whereas triclopyr was more effective at controlling red maple (*Acer rubrum* L.). Both herbicides were effective at controlling trembling aspen (*Populus tremuloides* Michx.). The eastern white pine regeneration would be monitored for five years because the effects of spraying on the pine regeneration were not yet clear.

406 Morneault, A.E.; Naylor, B.J.; Schaeffer, L.S.; Othmer, D.C. 2004. The effect of shelterwood harvesting and site preparation on eastern red-backed salamanders in white pine stands. For. Ecol. Manag. 199:1–10.

The effects of a partial harvest and four site preparation alternatives on populations of eastern red-backed salamander (*Plethodon cinereus* (Green)) were studied in a 90–100-year-old eastern white pine (*Pinus strobus*

L.) forest in central Ontario. A randomized complete block design was used with three replicates and five treatments (no harvest or site preparation; harvest, no site preparation; harvest and mechanical site preparation; harvest and chemical site preparation; harvest and both mechanical and chemical site preparation). A grid of 20 boards (76 × 20 × 2.5 cm) providing salamander cover was surveyed 10 times each year to monitor salamander abundance. Shelterwood harvesting and site preparation had some immediate negative effects on the abundance of red-backed salamander populations, but effects were possibly short-lived (less than five years). If managers want to minimize stand-level effects, they should regenerate harvested sites as rapidly as possible using the lowest intensity of site preparation required, and retain refugia for recolonization by leaving untouched patches in the harvest block.

407 Mosseler, A. 1992. Life history and genetic diversity in red pine: implications for gene conservation in forestry. For. Chron. 68:701–708.
The life history and genetic diversity of red pine (*Pinus resinosa* Ait.) were reviewed with a particular focus on Newfoundland's red pine populations. Because red pine occurs as small, highly fragmented populations throughout its geographical range, it is particularly vulnerable to genetic and demographic changes that can lead to local extinction and losses of genetic variation. Tree species that lose their genetic diversity might not recover the genetic variation required for effective adaptive responses to future environmental challenges. Genetic resources can be protected by establishing gene pool reserves with natural populations or cultivated collections. Setting up a series of ecological reserves across the natural range of red pine was recommended to maintain some unique natural forest ecosystems and help protect and conserve red pine's gene pool.

408 Mosseler, A.; Egger, K.N.; Hughes, G.A. 1992. Low levels of genetic diversity in red pine confirmed by random amplified polymorphic DNA markers. Can. J. For. Res. 22:1332–1337.
Random amplified polymorphic DNA (RAPD) markers were used to detect genetic variation in red pine (*Pinus resinosa* Ait.) that was not evident from isozyme gene marker analysis, and to assess correspondence between isozyme gene and RAPD markers. Seed was collected for both a range-wide sample and a Newfoundland sample, and grown under glasshouse conditions to obtain needle tissue for DNA extraction. Results with RAPD markers corresponded with genetic diversity estimates using isozyme gene markers, and provided further confirmation of low levels of genetic variation in the red pine genome. Very little genetic variation was detected between the island and mainland populations of red pine. A lack of genetic diversity might have developed after red pine's southern migration during the glacial advances. The low levels of genetic variation in red pine demonstrated the long time periods required for recovery from a loss in genetic diversity in long-lived organisms such as trees.

409 Mosseler, A.; Innes, D.J.; Roberts, B.A. 1991. Lack of allozymic variation in disjunct Newfoundland populations of red pine (*Pinus resinosa*). Can. J. For. Res. 21:525–528.
The genetic structure of red pine (*Pinus resinosa* Ait.) populations in Newfoundland was investigated because of their isolation from the mainland populations of the species for 8000–10 000 years. The objective was to determine whether the Newfoundland populations could be differentiated genetically from the mainland populations, and whether the effects of geographic isolation were reflected in their genetic structure. Seed was collected from a range-wide sample of 27 trees growing near Maple, Ontario, and 69 trees native to Newfoundland. Seed was prepared and their enzymes examined using gel electrophoresis and standard staining procedures. No allelic variation was detected in 23 putative loci from the 12 enzyme systems assayed. The Newfoundland populations were identical in their enzyme banding patterns. A more direct analysis of DNA variation might provide the genetic markers necessary to infer genetic structure.

410 Moyers, G.B. 1979. Management of eastern white pine in the south. Pages 58–62 *in* Symposium for the management of pines of the Interior South. Tech. Publication SA-TP-2. USDA For. Serv., Southeastern Area State and Private Forestry, Atlanta, GA.
Silvicultural characteristics unique to eastern white pine (*Pinus strobus* L.) were examined, especially as they relate to its management in the southern United States. Crescent Land and Timber Corporation's approaches to eastern white pine regeneration and management were highlighted in North and South Carolina. Eastern white pine was very important economically in the southern Appalachian Mountains, and in some areas, it offered the best opportunity for intensive high-yield forestry. Systems for the successful establishment of planted or natural eastern white pine regeneration were developed and used operationally. Lumber grade yield at age 21, which was considered midrotation age, was expected to be higher than for old-growth trees.

411 Mullin, R.E. 1978. Plantation performance averages for white pine. For. Res. Note 18. OMNR, Maple, ON. 2 p.
This note provided a graphical presentation of the average survival and height growth of eastern white pine (*Pinus*

strobus L.) plantations planted throughout Ontario with 3+0 stock and 2+2 stock. Data were collected from research plantations. Thirty plots were planted with 3+0 stock and 11 with 2+2 stock. All plots contained over 500 trees and had an average planting density of 2950 trees per hectare. Plots with a survival rate of <50% were rejected. Only small differences in survival or growth performance were noted between 3+0 and 2+2 seedling stock.

412 Mullin, R.E.; Bowdery, L. 1977. Effects of seedbed density and nursery fertilization on survival and growth of 3–0 white pine. Tree Plant. Notes 28:11–13 & 39.
The effectiveness of the nursery fertilization program as well as the effects of seedbed density on 3+0 eastern white pine (*Pinus strobus* L.) seedling stock was studied at two nurseries in southern Ontario. (**Note**: The symbol for transplant was standardized to + throughout the bibliography to indicate the time the seedling was in the sowing bed and in the transplant bed.) A split-plot design was used with five replicates and three levels of fertilization at recommended amounts, double the recommended amounts, and control. Seedbeds were thinned at the 1+0 stage to 161 trees per square metre and 323 trees per square metre. Seedlings were remeasured at the 3+0 stage. Fertilization did not have a significant effect on size or shoot-to-root balance of the trees. Seedbed density had a major effect. The 161 trees per square metre density were larger and sturdier (on the basis of lower shoot:root ratio) than the 323 trees per square metre density. Five years after outplanting, fertilization in the nursery still did not have a positive growth effect, but the seedlings from the lower density seedbeds had better growth.

413 Mullin, R.E.; Christl, C. 1982. Morphological grading of white pine nursery stock. For. Chron. 58:40–43.
Eastern white pine (*Pinus strobus* L.) seedlings (2+2 and 3+0) were measured for height, root length, stem diameter, and root:shoot ratio before planting to investigate correlations between planted seedling size and field performance. After planting, survival and terminal leaders were measured annually for five years. The 2+2 stock was superior in survival, growth, and cost-effectiveness and therefore 2+2 stock was recommended for eastern white pine shipping stock. Further, seedling height, stem diameter, and root volume were good indicators of subsequent field performance and therefore could be used in combination to provide seedling culling standards.

414 Munson, A.D.; Margolis, H.A.; Brand, D.G. 1993. Intensive silvicultural treatment: impacts on soil fertility and planted conifer response. Soil Sci. Soc. Am. J. 57:246–255.
The effects of scarification, fertilization, and brush control on available nutrients, soil N mineralization, nitrification, total N, and C/N of humus and surface mineral soil were examined as well as their effects on eastern white pine (*Pinus strobus* L.) and white spruce (*Picea glauca* (Moench) Voss) seedling growth four years after planting. Seedlings (3+0 stock) were planted at a 2 × 2 m spacing on a clearcut site at Petawawa, Ontario, using a randomized complete block, split-plot factorial design. Twelve treatments were applied consisting of three levels of site preparation, two levels of fertilization, and two levels of herbicide use. Soil moisture and temperature conditions were monitored, and soil and foliar samples were taken and analyzed. After four years, the most important changes in the environmental conditions resulted from application of vegetation control and scarification. Control plots showed very low levels of available NH_4^+ and NO_3^- in surface soil. After four years, the effects of scarification and fertilization on conifer growth had declined, while the effects of vegetation control on tree growth had become much more prominent. The impact of nutrient losses after using herbicides or scarification should become more evident when nutrient demand increases as the plantation ages.

415 Munson, A.D.; Margolis, H.A.; Brand, D.G. 1995. Seasonal nutrient dynamics in white pine and white spruce in response to environmental manipulation. Tree Physiol. 15:141–149.
This study examined the effects of scarification, fertilization, and herbicide use on nutrient-use efficiency. It tested the hypotheses that nutrient retranslocation is related to the growth rate of current foliage and that retranslocation is related to the plant's nutrient status. White spruce (*Picea glauca* (Moench) Voss)) and eastern white pine (*Pinus strobus* L.) were compared in a split-plot factorial design. Two levels of site preparation (blade scarification and control), two levels of fertilization (30 g of slow release fertilizer, increasing to 90 g, and control), and two levels of vegetation control (2.0 kg/ha glyphosate herbicide and control) were applied. Five eastern white pine and five white spruce seedlings were selected randomly for foliar sampling. At the end of the fourth growing season, five trees of each species were selected randomly from each plot and harvested for growth measurements. A species-specific response of retranslocation was made to the different environmental conditions created by the intensive silvicultural treatments. Correlations of retranslocation with growth rate showed a strong positive relationship for eastern white pine and a negative relationship for white spruce. Eastern white pine showed a large growth response to increasing light and consequently placed large demands on internal nutrient supply.

416 Murray, W.G. 1977. A winter pruning operation in white and red pine. For. Chron. 53:164–165.

A winter pruning operation in a middle-aged eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.) stand at Petawawa, Ontario, was described to improve future lumber grades through the formation of knot-free wood. Seven stands with a total area of 73 ha were pruned in February and March 1972. Only healthy eastern white and red pine trees were pruned, 10.2 cm diameter at breast height or larger, with a maximum number of 250 trees per hectare. Pros and cons of winter pruning were discussed. The advantages made winter pruning a feasible proposition with experienced crews able to prune 250 trees in about 22 person-hours.

417 Murray, W.G. 1991. Predicting biomass of white pine regeneration. Forestry Canada, Petawawa National Forestry Institute, Chalk River, ON. PNFI Technical Report 10. 3 p.

Eastern white pine (*Pinus strobus* L.) regeneration was scattered throughout the understory of a mixed jack (*P. banksiana* Lamb.), eastern white, and red pine (*P. resinosa* Ait.) stand located at Petawawa, Ontario. The density and height of the eastern white pine in the understory varied with crown closure, which ranged from 34 to 79%, and with the proximity of seed trees. Young eastern white pines were selected randomly for measurement and destructive sampling from throughout the stand. They were 0.25–3.5 m high. Biomass equations were derived from estimates of stem, branch, and needle dry weights. Basal diameter was a much better predictor than height of eastern white pine biomass in all instances.

418 Myers, E.R.; Chung, M.Y.; Chung, M.G. 2007. Genetic diversity and spatial genetic structure of *Pinus strobus* (Pinaceae) across an island landscape inferred from allozyme and cpDNA markers. Plant Syst. Evol. 264:15–30.

The Beaver Island Archipelago (BIA) in Lake Michigan offered an opportunity to compare genetic diversity of isolated eastern white pine (*Pinus strobus* L.) stands with stands growing on the mainland. A total of 20 sample plots were set up on four islands, and 376 trees were measured and needle tissue collected. Data from two stands on the mainland were used for comparison. The needle tissue samples were used for allozyme and cpDNA analyses. A similar level of allozyme variety was found for both the BIA and the mainland populations. A low but significant degree of genetic divergence was observed among populations for allozymes. Migration via largely pollen dispersal by wind occurred frequently enough to maintain genetic diversity and prevent differentiation across the island landscape during several thousand years of isolation.

419 Nadelhoffer, K.J.; Aber, J.D.; Melillo, J.M. 1983. Leaf-litter production and soil organic matter dynamics along a nitrogen-availability gradient in Southern Wisconsin (U.S.A.). Can. J. For. Res. 13:12–21.

Estimates were made for soil N mineralization and N uptake by vegetation, and relationships were identified between N uptake and both leaf litter production and N content of leaf litter. Net N mineralization was measured for one year in the 0–10-cm mineral soil zone in nine different forest stands (five broadleaf and four conifer stands including eastern white, *Pinus strobus* L., and red pine, *P. resinosa* Ait.) on silt–loam soils in Wisconsin. Measurements were taken along a 20-m transect at each site using a series of in situ soil incubations. Litterfall was collected and analyzed for N. Differences among sites were evident with N mineralization ranging from 0.54 to 2.10 mg N mineralized annually per gram of soil organic matter. Net N mineralization rates fluctuated throughout the years with the highest rates in June and low rates during the winter. The percentage of N in needle litter of eastern white pine was 1.3 times that of N in red pine needle litter. Strong relationships were found between annual leaf production and N uptake, and a significant relationship was found between N returned in leaf litter and N uptake.

420 Naylor, B.J. 1994. Managing wildlife habitat in red pine and white pine forests of central Ontario. For. Chron. 70:411–419.

Red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.) stands supply important habitat for wildlife in central Ontario. The Ontario Ministry of Natural Resources (OMNR) addressed wildlife habitat requirements at three scales by providing site-specific guidelines to modify timber management practices in stands; general stand-level habitat prescriptions to ensure the provision of cavity trees, down woody debris, and supercanopy trees; and forest-level planning to ensure that a mosaic of habitats exists across the forest landscape. Areas where further progress was required were identified. Twenty-five species that use pine forests were identified as area-sensitive, and these species were thought to require >150 ha of contiguous patches of forest. Current OMNR activities focused on habitat management at site and stand level, but it was recommended that guidelines be tested to evaluate their effectiveness. OMNR initiated planning for landscape diversity in the context of forest management plans.

421 Neumann, D.D.; Dickmann, D.I. 2001. Surface burning in a mature stand of *Pinus resinosa* and *Pinus strobus* in Michigan: effects on understory vegetation. Int. J. Wildland Fire 10:91–101.

The ecological responses were described in a mature, mixed red (*Pinus resinosa* Ait.) and eastern white pine

(*P. strobus* L.) plantation in southern Michigan after the introduction of periodic fire. Plots 0.4–0.5 ha were set up and burned once, three times at biennial intervals, or not burned at all. All burns occurred in May. Vegetation measurements were done before the burns and after the last one. Unburned plots contained many large seedlings and saplings, whereas plots burned once had fewer and contained 60% of the large seedlings and only 7% of the saplings compared with control. No large seedlings and few saplings were found in the plots burned biennially. Cover of low and herbaceous vegetation was double in all the burned plots compared with the unburned plots, and the plots burned biennially showed the most rapid recovery of low vegetative cover. Plant diversity was also greatly enhanced in the burned plots. Using a fire interval of 5–10 years was recommended for red and eastern white pine stands managed to maximize ecological benefits and develop stands with old-growth characteristics.

422 Newnham, R.M. 1993. Twenty-five years' growth in a young red pine stand. For. Chron. 69:57–63.
A natural red pine (*Pinus resinosa* Ait.) stand at Petawawa, Ontario, was measured for height and diameter at breast height (dbh) at 5-year intervals from age 20 to 45 years. Site index was near 24 m, and total volume at age 45 was 448 m^3/ha. Growth was comparable to eastern Ontario plantations with similar site index. A single regression was acceptable for estimating height from dbh and age. These analyses supported the applicability of the Weibull function for fitting diameter distributions.

423 Newton, P.F. 2003. Systematic review of yield responses of four North American conifers to forest tree improvement practices. For. Ecol. Manag. 172:29–51.
The expected yield gains of black spruce (*Picea mariana* (Mill.) BSP), jack pine (*Pinus banksiana* Lamb.), white spruce (*Picea glauca* (Moench) Voss), and red pine (*Pinus resinosa* Ait.) to correct provenance–progeny selection and first and second generational selection strategies were summarized from the scientific literature. Four sequential steps were taken: searching for tree improvement studies, assessing the publications for their applicability, collecting the results of the studies in terms of height growth gains, and estimating rotational yields by using prediction models. Although documented long-term yield responses were scarce, enough information was found to discuss the results for each species. Successful selection in red pine provided gains of 8% for height growth at 15 years, and a mean merchantable volume increment increase of 7% for plantations at age 50, which was lower than for the other three species tested.

424 Nijenson, S.E.; Schaberg, P.G.; Hawley, G.J.; DeHayes, D.H. 2005. Genetic subpopulation structuring and its implications in a mature eastern white pine stand. Can. J. For. Res. 35:1041–1052.
Patterns of genetic structuring were investigated in a 10-ha eastern white pine (*Pinus strobus* L.) stand in Vermont. A GIS database of the physical, spatial, temporal, and genetic attributes of all trees was used to examine genetic structuring and to assess the potential influence of partial harvesting on stand genetics. Inventory data were collected and they included size, age, growth, vigor, crown class, and spatial location of 232 trees. Genetic characteristics were determined using starch gel electrophoresis for the 220 seed-producing trees. Heterozygosity generally increased with tree age class. A circle surrounding a mature tree, generally about a 35-m radius, circumscribed its zone of genetic similarity. Trees within 5 m of one another were highly related, but the level of relatedness decreased with increased distance between the trees. Most simulated harvests left a residual stand with similar genetic diversity. Partial harvesting could potentially alter genetic diversity though, depending on the selection criteria used.

425 Noland, T.L.; Mohammed, G.H.; Wagner, R.G. 2001. Morphological characteristics associated with tolerance to competition from herbaceous vegetation for seedlings of jack pine, black spruce and white pine. New For. 21:199–215.
Correlations were examined between preplanting morphological features of conifer seedlings and the survival and growth of various stock types in the presence and absence of competing herbaceous vegetation. Jack pine (*Pinus banksiana* Lamb.), black spruce (*Picea mariana* (Mill.) BSP), and eastern white pine (*Pinus strobus* L.) were planted on a flat site with medium-textured sandy soil in Ontario using a randomized complete block, split-plot design with six replicates. Different stock types were chosen representing a range of morphological types used operationally in Ontario. Each half-block was selected randomly for either herbaceous vegetation control or no vegetation treatment. Morphological assessments were made before planting and after the fifth growing season. Volume growth was greater with medium containers and large bare-root stock when compared with small containers and medium-sized bare-root stock. Root collar diameter and root volume of initial planting stock were positively correlated to volume growth. Stock type should be considered before planting. Morphological attributes and physiological tests such as chlorophyll fluorescence could be useful in predicting seedling performance potential in competitive environments.

426 Noland, T.L.; Parker, W.C.; Morneault, A.E. 2006. Natural variation in seed characteristics of eastern white pine (*Pinus strobus* L.). New For. 32:87–103.

Little knowledge exists on the variation in seed characteristics among individual trees, and the objective was to determine whether seed characteristics differed between two natural eastern white pine (*Pinus strobus* L.) stands in above-average seed years, and whether a relationship existed between seed characteristics and morphological traits of the parent trees. Two second-growth mixed eastern white pine–hardwood stands located in central Ontario were assessed by selecting 100 eastern white pine canopy trees in each stand in a 50 × 100 m area. Trees were stem mapped and measured. Both stands were then partially harvested to create a shelterwood dominated by eastern white pine. Cones and seed were collected the year before and year after harvest. At least 200 seeds from each parent tree and seed year were X-rayed. The trees produced an average of 46 and 54 seeds per cone in seed year one and two, respectively. No difference in total or sound seed yield per cone was observed between stands in either year; but when the data from both stands were combined, total and sound seed per cone were significantly higher in seed year two. These trends probably were associated with partial harvesting, which would have improved the canopy environment for pollen dispersal, pollination, and flower fertilization.

427 Nolet, P.; Bouffard, D.; Lorenzetti, F. 2006. Release of naturally established white pine seedlings from competition: an objective field index. North. J. Appl. For. 23:184–191.

The influence of competitor species on the relationship between the vigor of naturally established eastern white pine (*Pinus strobus* L.) seedlings and several competition indices was examined as well as which variables most influenced this relationship. A 13-ha uneven-aged hardwood–eastern white pine stand near Maniwaki, Quebec, was harvested in a good seed year, and 10 circular gaps, each with a 45-m diameter, were created. In four-year-old gaps, the volume of the current year whorl of branches and needles was used to develop an index of seedling vigor, and the distance of competitive species to eastern white pine seedlings was recorded for use in developing competition indices. Competition indices predicted eastern white pine seedling vigor better when competition was primarily from pin cherry (*Prunus pensylvanica* L. f.) compared with trembling aspen (*Populus tremuloides* Michx.). A composite competition index was developed to be used as a decision rule to determine when eastern white pine seedlings should be released from competition, and a formula was derived to estimate the costs of release of eastern white pine seedlings.

428 Nyland, R.D. 1996. Silviculture, concepts and applications. McGraw-Hill, New York, NY. 633 p.

This valuable book describing the different silvicultural systems and their applications discussed many aspects of silviculture including methods of site preparation, obtaining natural and artificial regeneration, thinning and harvesting regimes for both uneven- and even-aged stands, and approaches for improving stand health and quality. The applications of each silvicultural technique were provided for many management goals and a variety of landowners, rather than focusing on the silviculture of individual tree species. A specific reference to red pine (*Pinus resinosa* Ait.) was made on site suitability, and to both red and eastern white pine (*P. strobus* L.) on the success of direct seeding only after spot seeding on a suitable seedbed.

429 O'Connell, B.M.; Kelty, M.J. 1994. Crown architecture of understory and open-grown white pine (*Pinus strobus* L.) saplings. Tree Physiol. 14:89–102.

Eastern white pine (*Pinus strobus* L.) was classified earlier as intermediate in shade tolerance. Crown architecture and growth allocation were assessed and compared in central Massachusetts between 15 naturally regenerated understory saplings growing in two mixed hardwood–conifer stands and 15 planted open-grown saplings of eastern white pine of similar height (a height range of 180–250 cm) growing on a site with an overstory of scattered mature red oak (*Quercus rubra* L.). Mean ages of understory and open-grown trees were, respectively, 25 and 8 years. Understory trees had a broader crown shape with a lower degree of apical dominance, shorter crown length, and more horizontal branch angle. Total leaf area was higher for open-grown saplings, but the ratio of projected leaf area to total leaf area was greater in understory pine (0.154) than in open-grown pine (0.128), indicating that understory trees exposed a greater percentage of their leaf area to direct overhead light. Current year production was less for understory trees, but they had a higher percentage of it allocated to foliage in shoots. These modifications in crown structure and allocation were similar to those reported for spruce (*Picea* spp.) and fir (*Abies* spp.), but they were generally smaller in eastern white pine, which might limit its ability to persist in shade as long as spruce and fir.

430 Oliver, C.D. 1981. Forest development in North America following major disturbances. For. Ecol. Manag. 3:153–168.

A general pattern of forest development following major disturbances was described, and it addressed three themes that were contrary in some respects to earlier ideas: (1) the single age-class pattern of forest succession was more common than previously thought, (2) recruitment of new stems into a forest occurred during a relatively short

period after disturbance rather than species being gradually replaced by other species, and (3) several different forest communities could potentially inhabit the same area for an indefinite period. After disturbances, four general stages of forest development occurred: stand initiation, stem exclusion, understory reinitiation, and old growth. Major disturbances were often neglected as important factors in succession because they typically happened at intervals longer than the life span of humans. The severity of such disturbances was important and determined which species would dominate, and often they remained in a dominant postion for a very long time. The frequency of disturbance was also important because it determined the general forest type throughout a large area.

431 Oliver, C.D.; Larson, B.C. 1990. Forest stand dynamics. McGraw-Hill, New York, NY. 467 p.

Forest stand structure changes with time, especially during and after major disturbances. This book described in great detail the range of stand growth patterns, and provided knowledge and perspective on forest development through time. It described how similar development patterns were occurring in many different forests both in North America and elsewhere, and synthesized the knowledge on stand dynamics and the effects of silvicultural practices. Many topics were discussed including limitations to growth, tree architecture, disturbances and tree invasion, stand development patterns, and the general stages and quantification of stand development.

432 Oliver, C.D.; Stephens, E.P. 1977. Reconstruction of a mixed-species forest in central New England. Ecology 58:562–572.

The history of an area was reconstructed by intensively analyzing a 0.36-ha area in an old, mixed-species, deciduous forest in Massachusetts. Several natural as well as human-caused disturbances of different magnitudes had occurred periodically. Evidence indicated that two hurricanes and a fire had happened before 1803, and between 1803 and 1952, 14 disturbances occurred and 10 of them were harvests. Total basal area by species provided the best available index of forest composition. Large disturbances created new age classes, whereas small disturbances did not. Eastern white pine (*Pinus strobus* L.) was present earlier, but it did not regenerate well after a logging in 1854. Pines that did re-establish were almost all eliminated after the 1938 hurricane, and deciduous species now dominated the area. Contrary to the hypothesis, the stand did not consist of a mosaic of small stands in which all individuals arose after the same disturbance, but rather some trees initiated after each major disturbance, and they were distributed relatively uniformly. After a major disturbance, a new cohort was initiated, whereas after a minor disturbance, only the residual trees occupied the site.

433 Olson, D.P.; Weyrick, R.R. 1987. White pine management with prescribed fire. Res. Rep. No. 113. New Hampshire Agric. Exp. Stn., Durham, NH. 15 p.

A total of 41 prescribed burns in eastern white pine (*Pinus strobus* L.) stands in southern New Hampshire were evaluated including stands of different ages throughout a rotation, thinned and unthinned stands, and areas with slash concentrations after clearcutting. The fires were conducted between 1974 and 1986, and stand sizes varied from 0.2 to over 4 ha. The use of prescribed fire was discussed for thinning, partial pruning, understory hardwood control, eastern white pine regeneration, and converting mixed-hardwood stands to eastern white pine. Prescribed burning in older and pole-sized stands decreased hardwood competition, but the rate of eastern white pine growth was not affected. Burning eastern white pine stands two to three times before harvest in the spring of the year could increase eastern white pine regeneration when using low-intensity back fires. A preliminary model was presented for the application of prescribed burning at various stages in the rotation of eastern white pine.

434 Ontario Ministry of Natural Resources. 1986. Managing red pine plantations. OMNR, Queen's Printer for Ontario, Toronto, ON. 134 p.

This detailed guide on managing red pine plantations in Ontario summarized available information for forest managers to use as a reference when preparing work plans, on-the-ground management evaluations, and decisions regarding red pine (*Pinus resinosa* Ait.) plantations. The guide included much information on the silvics of red pine; its soil and site requirements; stand establishment; fire damage, prevention, and control; pest management; tending treatments; growth and yield prediction; markets and products; and methods and timing of harvesting.

435 Ontario Ministry of Natural Resources.1993. Natural establishment and early growth of eastern white pine and red pine in the Great Lakes–St. Lawrence Forest: an annotated bibliography. Rep. No. 10. OMNR, OFRI, Forest Landscape Ecology Program, Sault Ste. Marie ON. 66 p.

This annotated bibliography included work on the natural establishment and early growth of eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.) in the Great Lakes–St. Lawrence forest. Seven broad subject categories were included: regeneration, soils, wildfire, fire, ecology, succession, and management. A selection of publications up to December 1993 was included.

436 Ontario Ministry of Natural Resources. 1998. A silvicultural guide for the Great Lakes–St. Lawrence conifer forest in Ontario. OMNR, Queen's Printer for Ontario, Toronto, ON. 424 p.

This silvicultural guide was written to assist forest managers with the complications involved in implementing ecologically sustainable silvicultural practices. It described mandated practices and those considered to represent best practices on the basis of knowledge and experience at that time. Silvicultural practices were described and recommendations included for managing forest ecosystems in central Ontario that were dominated by eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.), white spruce (*Picea glauca* (Moench) Voss), red spruce (*P. rubens* Sarg.), eastern hemlock (*Tsuga canadensis* (L.) Carrière), and eastern white-cedar (*Thuja occidentalis* L.). The guide consists of two parts. The first part summarizes the existing information on the ecology of the Great Lakes–St. Lawrence conifer forests with a focus on the dominant tree species. The second part provides forest managers with some recommended strategies and standards to achieve ecological sustainability by matching where possible the silvicultural practices with the effects of natural disturbances.

437 Osborn, J.E. 1985. White pine: the resource and its utilization. Proc. Entomol. Soc. Ont. 116(Suppl.):11–20.

Inventory and utilization statistics for eastern white pine (*Pinus strobus* L.) in Ontario were compiled. The data summaries were from data collected in Ontario's Forest Resource Inventory and were presented to examine losses attributed to pests. There were approximately 610 000 ha of operational forest in the eastern white pine working group (which was made up of stands that were predominantly eastern white pine) in Ontario, containing approximately 110 million m^3 of gross total volume. The volume of eastern white pine harvested annually from crown land was about 500 000 m^3, which was only about 3.5% of the total volume of wood cut and scaled from crown land in Ontario. This volume was still considered significant because of its higher economic value when compared with most other commercial tree species in Ontario.

438 Ouimet, R.; Tremblay, S.; Périé, C.; Prégent, G. 2007. Ecosystem carbon accumulation following fallow farmland afforestation with red pine in southern Quebec. Can. J. For. Res. 37:1118–1133.

A chronosequence study of red pine (*Pinus resinosa* Ait.) on former farmland in southern Quebec was sampled to estimate organic C stocks of vegetation biomass, forest floor, and mineral soil. Soil profile descriptions and soil horizon physicochemical properties were assessed using archived data from 348 sites in southern Quebec, which had been sampled earlier in the 1970s. For each profile, organic C in the mineral soil was measured or a pedotransfer model was developed and used to predict organic C concentrations. Most organic C was accumulated in the vegetation biomass, in which after 22 years four times more C had accumulated than in the forest floor. There was no relation between accumulated organic C in the forest floor and either soil order or soil texture. The concentration of organic C in the mineral soil was affected by soil texture. Planting red pine on abandoned agricultural fields, especially on loamy soils, in Quebec was considered to be a worthwhile approach to sequestering additional soil C in the first two decades after planting.

439 Page, A.C.; Smith, D.M. 1994. Returns from unrestricted growth of pruned eastern white pines. Bull. No. 97. Yale University School of Forestry and Environmental Studies, New Haven, CT. 24 p.

The effects of thinning and pruning were studied on the growth and financial returns from pruned eastern white pine (*Pinus strobus* L.). Trees were cut and processed from four different locations. Stands from Massachusetts were a natural stand and a plantation, which had been heavily thinned. The stands from New Hampshire originated on old farmlands. One stand was hit heavily by the 1938 hurricane leaving some isolated trees, and another stand had been lightly thinned. All pruned trees were pruned up to at least 3.6 m. When an annual diameter growth of at least 0.6 cm was achieved, there was a minimum of a 6% return on the actual investment. The study demonstrated that very good returns could be made if eastern white pine were pruned early and thinned heavily enough for the tree crowns to expand freely. The results were also used to create a recommended thinning schedule for a model tree or plantation with unrestricted growth.

440 Palik, B.; Levy, L., comps., eds. 2004. Proceedings of the Great Lakes silviculture summit. Gen. Tech. Rep. NC-254. USDA For. Serv., North Central Res. Stn., St. Paul, MN. 49 p.

The major goal of the summit was to develop and strengthen a collaborative research network in the Great Lakes region that focused on silvicultural information needs of various user groups. A series of papers was presented that examined silvicultural needs and issues as a background for the development of a research agenda for silviculture in the Great Lakes region. Some information needs that were identified included a need for cost/benefit analyses of silvicultural options for maturing and overstocked softwood stands; thinning and fertilization of pine; the ecological implications of plantation management; carbon sequestration

potential; management systems for red pine (*Pinus resinosa* Ait.)–eastern white pine (*P. strobus* L.) or eastern white pine–eastern hemlock (*Tsuga canadensis* (L.) Carrière) that incorporate multicohort structure and reintroduction of fire; and growth and yield data for long-rotation management, especially red pine. Silviculture research cooperatives were encouraged to develop to improve communication, and experimental forests were seen as useful for the testing of new ideas and for information transfer.

441 Palik, B.; Zasada, J. 2003. An ecological context for regenerating multi-cohort, mixed-species red pine forests. Res. Note NC-382. USDA For. Serv., North Central Res. Stn., Grand Rapids, MN. 8 p.

Previous studies have shown that natural red pine (*Pinus resinosa* Ait.) ecosystems and age structures were more complex than in the managed red pine forests of today. A greater understanding of the effects of natural disturbances and of the benefits of complex stand structures increased interest in managing mixed-species, multi-aged stands. A conceptual approach for adding structural and compositional complexity to red pine forests was discussed, and the extent to which red pine management incorporates complexity was presented. It was hypothesized that by altering the spatial pattern of the residual overstory from dispersed to large aggregates, the resource environment in the understory would alter to favor different species with different retention treatments. Further, other ecosystem attributes would also be affected, such as disease occurrences and variations in wildlife habitat.

442 Palik, B.J.; Kern, C.C.; Mitchell, R.; Pecot, S. 2005. Using spatially variable overstory retention to restore structural and compositional complexity in pine ecosystems. Pages 285–290 *in* C.E. Peterson and D.A. Maguire, eds. Balancing ecosystem values: innovative experiments for sustainable forestry. Proceedings, Portland, OR, 15–20 August 2004. Gen. Tech. Rep. PNW-635. USDA For. Serv., Pacific Northwest Res. Stn., Portland, OR. 389 p.

Approaches to introducing structural complexity were tested in operational-scale studies in a southern Georgia longleaf pine (*Pinus palustris* P. Mill.) and a northern Minnesota red pine (*P. resinosa* Ait.) ecosystem to examine the influence of retention pattern on resource availability and tree regeneration. Four retention treatments were assigned randomly, namely an uncut control, dispersed retention, small gap cutting (0.1 ha), and large gap cutting (0.3 ha). For red pine, the residual basal areas were 18 m^2/ha. After harvest, the red pine study was planted with an equal mixture of red, eastern white (*P. strobus* L.), and jack pine (*P. banksiana* Lamb.) seedlings. Early results show that the spatial pattern of retention has a major impact on stand-scale resource availability and growth of the regeneration.

443 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. Manag. 67:191–201.

The relationships between remnant eastern white pine (*Pinus strobus* L.) seed sources and regenerating eastern white pine populations were studied. The number, size, and location of eastern white pine seed trees in a forest dominated by largetooth (*Populus grandidentata* Michx.) and trembling aspen (*P. tremuloides* Michx.) in northern Michigan were related to the structure of postdisturbance eastern white pine populations. Sixteen 475-m^2 circular plots were set up randomly in four stands. Regenerating eastern white pine in proximity to several large seed trees were larger, established earlier after disturbance, and contained a greater diversity of age and height classes relative to populations with fewer available seed trees. When harvesting aspen (*Populus* spp.) stands with an eastern white pine component, it was recommended to have at least one to two eastern white pine trees per hectare to encourage eastern white pine regeneration. Retention of eastern white pine seed trees in commercial aspen forests might be an important tool for maximizing structural and compositional diversity in managed stands.

444 Parker, W.C.; Elliott, K.A.; Dey, D.C.; Boysen, E.; Newmaster, S.G. 2001. Managing succession in conifer plantations: converting young red pine (*Pinus resinosa* Ait.) plantations to native forest types by thinning and underplanting. For. Chron. 77:721–734.

The influence of five thinning treatments in a red pine (*Pinus resinosa* Ait.) plantation was evaluated by assessing the growth and survival of underplanted eastern white pine (*P. strobus* L.), red oak (*Quercus rubra* L.), and white ash (*Fraxinus americana* L.) seedlings, and the abundance and diversity of naturally regenerated understory vegetation. Twenty 30×32 m plots were set up in a 32-year-old, 3.2-ha red pine plantation in Durham Regional Forest, Ontario. The southern parts of the plots were planted with 2+0 eastern white pine, red oak, and white ash, leaving the northern parts unplanted as a control. Thinning treatments consisted of row thinning, selection thinning, creating small canopy gaps, and control. Five years after thinning, seedling growth was positively correlated with thinning intensity and the size of canopy openings, and eastern white pine seedlings showed a higher growth potential. Early thinning of red pine plantations helped to produce high-value timber and enhanced the artificial and natural regeneration of the other native tree species.

Species richness increased with thinning intensity and the proximity to neighboring plant communities.

445 Parker, W.C.; Noland, T.L.; Morneault, A.E. 2004. Effect of seed mass on early seedling growth of five eastern white pine (*Pinus strobus* L.) families under contrasting light environments. Can. J. Bot. 82:1645–1655.

The influence of seed mass was assessed on early seedling growth, morphology, and biomass partitioning under two light levels that represented the understory of shelterwoods and undisturbed, closed canopy eastern white pine (*Pinus strobus* L.). Seed was collected from 195 eastern white pine trees, and five half-sib families were selected with an average bulk seed mass ranging from 13.6 to 26.6 mg/seed. Seedlings were grown in a greenhouse under moderate and low light intensities, and harvested after 8 or 15 weeks. Seedlings were measured, and roots, stems, and foliage were dried and weighed. Light environment did not influence survival but did have a significant effect on seedling dry mass components, root length, and biomass partitioning after 8 and 15 weeks of growth. Low light reduced seedling biomass and root development, and increased biomass allocation to shoot production. When soil resources were not limiting, seed mass had a significant positive effect on initial seedling size but little effect on biomass allocation pattern and relative growth rates.

446 Parker, W.C.; Noland, T.L.; Morneault, A.E. 2006. The effects of seed mass on germination, seedling emergence, and early seedling growth of eastern white pine (*Pinus strobus* L.). New For. 32:33–49.

The influence of seed mass on regeneration was examined to better understand the factors that limit regeneration. Eastern white pine (*Pinus strobus* L.) seed was collected from seven half-sib families in two mixedwood stands in central Ontario. After stratification, seeds from five families were sealed in plastic dishes with filter paper and deionized water and placed in a controlled environment. A second assessment using composite seedlots was initiated to minimize any genetic effects on germination. In two adjacent, climate-controlled greenhouse cubicles, seedlings were grown under moderate (47% of full light) or low (13% of full light) light environments. Emergence was recorded daily for 28 days. Seedlings were grown for eight weeks, after which they were removed, measured, and dry weights recorded. Seedling emergence was unrelated to seed mass, but families with heavier seeds showed faster emergence. Low light increased the rate and percentage of emergence. Biomass partitioning did not differ among families, but stem mass ratio was higher and root mass ratio lower under low light. Germinants emerging from larger seed possibly showed more rapid emergence, larger initial size, and a higher investment in stem relative to root biomass.

447 Pastor, J. 1992. Browsing damage to white pine. Pages 132–144 *in* R.A Stine and M.J. Baughman, eds. White pine symposium proceedings: history, ecology, policy and management, Duluth, MN, 16–18 September 1992. University of Minnesota, Extension Service Distribution Center, St. Paul, MN. 202 p.

Patterns of browsing by mammals on eastern white pine (*Pinus strobus* L.) and other pine (*Pinus* spp.) species, and the responses of trees to browsing were reviewed. White-tailed deer (*Odocoileus virginianus* (Zimmermann)) preferred eastern hemlock (*Tsuga canadensis* (L.) Carrière) and eastern white-cedar (*Thuja occidentalis* L.). Eastern white pine was browsed by many animals including white-tailed deer. Moose (*Alces alces* (Linnaeus)) and deer browsed the current annual twigs and needles of the terminal leader. Browsing by deer and moose did not necessarily kill trees, but the commercial value of a tree was decreased. Porcupine (*Erethizon dorsatum* (Linnaeus)) fed on the bark of boles and branches, and needles high in the crown, and this resulted in crown deformation and sometimes death. Two general control measures were discussed: hunting and trapping, and protection of the trees. Trapping seemed to be the only way to control porcupine. The effects of control measures should be evaluated in light of how much browsing was reduced because it was almost impossible to eliminate browsing.

448 Peichl, M.; Arain, M.A. 2007. Allometry and partitioning of above- and belowground tree biomass in an age-sequence of white pine forests. For. Ecol. Manag. 253:68–80.

Partitioning of above- and belowground biomass in eastern white pine (*Pinus strobus* L.) in relation to stand age was examined. Further, biomass expansion factors for above- and belowground tree components of eastern white pine forests were identified for four different stand stages and across an entire age sequence. An eastern white pine chronosequence was examined that included a 2-, 15-, 30-, and 65-year-old plantation near Turkey Point, Ontario. Five seedlings were harvested in the two-year-old stand, and five dominant trees were harvested in the other stands. The seedlings and parts of the mature trees were oven-dried and their biomass determined. Biomass expansion factors were calculated by using the ratio between stem wood volume and biomass of other tree components. In the 65-year-old stand, biomass had increased at an average growth rate of 8.5 kg/year. Root biomass was an important element of total forest biomass and increased from 0.1 kg per 2-year-old seedling to 99 kg for a 65-year-old tree. As a stem aged, the stem became the major component of aboveground biomass, while the relative portion of foliage and branch biomass decreased. Allometric equations for individual aboveground tree components were

age dependent, and this can be used to improve biomass and carbon sequestration predictions at a broader scale.

449 Penner, M.; Robinson, C.; Burgess, D. 2001. *Pinus resinosa* product potential following initial spacing and subsequent thinning. For. Chron. 77:129–139.
A red pine (*Pinus resinosa* Ait.) spacing trial was evaluated near Petawawa, Ontario, 45 years after planting to assess tree growth and pole quality. This plantation was set up with 2+2 red pine stock planted at square spacings ranging from 1.2 to 4.3 m. Ten and 13 years after planting, two plots were thinned to a 4.3- and 6.1-m spacing, respectively. After 30 years, portions of the plantations were thinned to three residual basal areas (37.9, 32.3, and 25.3 m^2/ha); the remaining areas were left uncut. Top height was not significantly different among the spacing treatments. As spacing increased, quadratic mean diameter increased, while stand basal area and volume declined. Knot surface increased with mean diameter at breast height and spacing, becoming significant with the 3.0-m spacing or wider, which led to a significant number of trees failing to meet utility pole standards because of excessive, large knots at this stage of plantation development. Initial spacings of 1.8–2.4 m resulted in good growth with higher utility pole potential and low mortality numbers. Thinning was required for the lower initial spacings to minimize mortality and maintain good diameter growth.

450 Perera, A.H.; Baldwin, D.J.B. 1993. Spatial characteristics of eastern white pine and red pine forests in Ontario. Rep. No. 9. OMNR, OFRI, Forest Landscape Ecology Program, Sault Ste. Marie, ON. 82 p.
Eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.) forests and mixed pine stands across Ontario were examined. A 27.5 million-ha portion of Ontario was selected as a study area because it had a high probability of having eastern white or red pine forests older than 40 years. A spatial database was created using Landsat Thematic Mapper imagery and aerial photographs. Spatial distribution and representativeness, spatial configuration, and degree of fragmentation were all characteristics of interest. The study revealed that 2.3% of the land area was in eastern white and red pine forests. The forest types of interest were concentrated in central Ontario and ecoregion 5E. The eastern range included stands that were often twice as large as stands in the west. Major provincial parks were shown to have high pine representation within their boundaries. Mixed stands were the most abundant followed by eastern white pine-dominated stands. Red pine-dominated stands were rare. The majority of eastern white and red pine forests were small (<100 ha). Stands larger than 500 ha were uncommon. Stand isolation was low, and many stands had forest interiors when a smaller width of stand edge was used as a selection criterion.

451 Périé, C.; Munson, A.D. 2000. Ten-year responses of soil quality and conifer growth to silvicultural treatments. Soil Sci. Soc. Am. J. 64:1815–1826.
The effects of scarification, fertilization, and brush control on planted eastern white pine (*Pinus strobus* L.) and white spruce (*Picea glauca* (Moench) Voss) seedlings were investigated 10 years after treatment. Seedlings were planted at Petawawa, Ontario, using a randomized complete block design. Soil and foliar samples as well as tree growth measurements were collected and analyzed. Three- and four-factor ANOVAs were used for statistical analyses. The results after 10 years were presented and compared with those obtained 3–4 years after planting. At both measurement times, the herbicide treatment increased tree growth and generally improved foliar nutrition, but it also had the greatest negative effect on soil quality by reducing organic C mass by 46%, total N mass by 15%, and acid phosphatase activity by 64%. The negative effects of the herbicide treatment were offset when it was combined with the fertilizer treatment. The impacts on soil quality could have consequences for long-term forest productivity.

452 Peterson, C.J.; Squiers, E.R. 1995a. Competition and succession in an aspen–white pine forest. J. Ecol. 83:449–457.
Changes in tree abundance, dominance, diversity, size inequality, and growth in a 60-year-old second-growth trembling (*Populus tremuloides* Michx.) and largetooth aspen (*P. grandidentata* Michx.)–eastern white pine (*Pinus strobus* L.) stand in northern Michigan were studied for 10 years. Size inequalities were measured as a coefficient of diameter. Abundance, dominance, and size inequalities appeared to decrease for aspen (*Populus* spp.) and increased for eastern white pine. Aspen possibly provided a net indirect facilitation of growth for neighboring eastern white pine. Competition between close neighbors was more asymmetric than between distant neighbors. The infertile, excessively drained, poor sandy soil of the study site increased the importance of belowground competition. Forest changes and species succession were affected greatly by the individual clonal characteristics of the aspen, which is an alternative to the gap dynamics that drives tree replacement in many natural forests.

453 Peterson, C.J.; Squiers, E.R. 1995b. An unexpected change in spatial pattern across 10 years in an aspen–white pine forest. J. Ecol. 83:847–855.
The application of spatial pattern models was explored using populations in a mixed-forest setting in which

eastern white pine (*Pinus strobus* L.) was replacing dominant clonal trembling (*Populus tremuloides* Michx.) and largetooth aspen (*P. grandidentata* Michx.). An aspen (*Populus* spp.)–eastern white pine forest in northern Michigan was examined during a 10-year period for changes in spatial pattern due to mortality in a 60-year-old second-growth stand. A 40×40 m plot divided into 5×5 m subplots was assessed, and trees were measured twice in a 10-year interval. Spatial location and abundance of eastern white pine was influenced negatively by the locations of aspen ramets, which suggested that the clonal aspen inhibited eastern white pine establishment. In fact, the eastern white pine regeneration was clumped at all scales, and its distribution showed a significant repulsion from aspen.

454 Phelps, W.R.; Weber, R. 1968. Antibiotics do not control blister rust in eastern white pine seedlings. Res. Note NC-52. USDA For. Serv., North Central For. Exp. Stn., St. Paul, MN. 3 p.

The ability of two antibiotics, cycloheximide and phytoactin, in preventing white pine blister rust (*Cronartium ribicola* J.C. Fischer) on eastern white pine (*Pinus strobus* L.) seedlings was tested. A randomized complete block design was used to test pre- and postplanting applications of the antibiotics consisting of 12 treatments of 100 seedlings each replicated five times. Untreated trees were used as controls. Cycloheximide was too toxic to be of practical use on young seedlings, and phytoactin was ineffective in protecting eastern white pine seedlings from white pine blister rust.

455 Phelps, W.R.; Weber, R. 1969. An evaluation of chemotherapeutants for control of blister rust cankers in eastern white pine. Plant Dis. Rep. 53:514–517.

The effectiveness of 18 chemicals and 3 antibiotics at suppressing or eliminating white pine blister rust (*Cronartium ribicola* J.C. Fischer) cankers on eastern white pine (*Pinus strobus* L.) was investigated in Wisconsin. The performance of the chemicals on scarified and nonscarified cankers was evaluated three years after treatment. Scarification consisted of cutting vertical scratches with a modified and sharpened hand cultivator just before treatment. Cankers on 435 trees were scarified and treated with the 18 chemicals and 3 antibiotics. Some of the chemotherapeutants reduced canker growth, but none of the chemicals gave satisfactory control of white pine blister rust. Although none of the chemicals tested were better than cycloheximide at controlling white pine blister rust, several others did reduce canker growth and activity. Overall, none of the compounds tested were effective under field conditions in controlling white pine blister rust.

456 Phelps, W.R.; Weber, R. 1970. An evaluation of carriers for chemotherapeutic treatment of blister rust cankers in eastern white pine. Plant Dis. Rep. 54:1031–1034.

Eleven chemotherapeutants and several different carriers were tested for controlling white pine blister rust (*Cronartium ribicola* J. C. Fischer) by treating scarified and nonscarified white pine blister rust cankers on eastern white pine (*Pinus strobus* L.). Tree and canker data were recorded for 308 plantation trees in Wisconsin and Michigan. The trees were 29 years old before treatment and were evaluated for 4 years following treatment. Every chemical that killed the white pine blister rust also killed host tissue. Cycloheximide was the most effective chemical in controlling white pine blister rust with every carrier combination in which it was applied, but it was also the most phytotoxic and therefore it killed many of the treated trees. Mobil sol L, No. 2 fuel oil, vegetable oil, and xylene were effective carriers for chemotherapeutants on scarified white pine blister rust cankers on eastern white pine.

457 Philbrook, J.S.; Barrett, J.P.; Leak, W.B. 1973. A stocking guide for eastern white pine. Res. Note NE-168. USDA For. Serv., Northeastern For. Exp. Stn., Upper Darby, PA. 3 p.

This stocking guide for eastern white pine (*Pinus strobus* L.) in the northeastern United States applied to nearly pure, even-aged eastern white pine stands. It described two tree density levels or A and B curves for different mean tree diameter sizes through time where the A curve represents 80% of full stocking (from Frothingham's yield data), and is considered the upper limit of stocking for operationally managed stands; the B curve denotes minimum stocking for full site utilization. Generally, stands were considered for thinning when stocking density was greater than the midpoint between the A and B curve lines.

458 Phillips, T.W.; Lanier, G. N. 1983. White pine weevil, *Pissodes strobi* (Coleoptera: Circulionidae), attack on various conifers in New York. Can. Entomol. 115:1637–1640.

Six conifer species in Cortland Co., New York, eastern white (*Pinus strobus* L.), red (*P. resinosa* Ait.), and Scots pine (*P. sylvestris* L.), and Norway (*Picea abies* (L.) Karst.), white (*P. glauca* (Moench) Voss), and Colorado spruce (*P. pungens* Engelm.), were examined for their susceptibility to attack by white pine weevil (*Pissodes strobi* (Peck)). Five trees of each species were selected on which adult white pine weevils were placed and confined in fiberglass screen sleeves enclosing host leaders from May until July. Eastern white pine was the most susceptible to attack and the most suitable for brood production. Scots pine and red pine were rarely

attacked. Some spruce leaders were killed by the white pine weevil, but spruce leaders were the least suitable for brood production because no adult white pine weevil progeny emerged from them.

459 Piché, Y.; Ackerley, C.A.; Peterson, R.L. 1986. Structural characteristics of ectendomycorrhizas synthesized between roots of *Pinus resinosa* and the E-strain fungus *Wilcoxina mikolae* var. *mikolae*. New Phytol. 104:447–452.

Ectendomycorrhizas are found in nurseries on pine (*Pinus* spp.) and other conifers and are recognized as one of the mycorrhizal forms associated with tree roots. Little was known earlier about the development and structure of ectendomycorrhizas and their association with red pine (*P. resinosa* Ait.). Therefore ectendomycorrhizas were synthesized between red pine seedlings and the E-strain fungus *Wilcoxina mikolae* var. *mikolae* (C. S. Yang & Wilcox) C.S. Yang & Korf in growth pouches. A mantle consisting of a few hyphae embedded in a matrix was formed on the roots, although the predominant phase involved intracellular hyphae in root cortical cells. There was increasing evidence that ectendomycorrhizal associations occurred normally in certain environments and that they were beneficial to host plants.

460 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. North. J Appl. For. 20:19–26.

Eastern (*Pinus strobus* L.) and western white pine (*P. monticola* Dougl.ex D. Don) were compared for their growth and their resistance to naturally occurring levels of white pine weevil (*Pissodes strobi* (Peck)) and white pine blister rust (*Cronartium ribicola* J.C. Fischer) in the east. Seed of both species was collected and grown in a greenhouse. The seedlings were then planted at two sites, one in New York and the other in Maine, using a completely randomized design with 5–83 replicates per family at a spacing of 1.8 × 2.4 m. At age 14, both plantations were surveyed for survival, structural deformations resulting from white pine weevil, presence of white pine blister rust, and evidence of rust on dead trees. Height and diameter were measured as well. Height and diameter were significantly greater for eastern white pine than for western white pine. Eastern white pine was attacked approximately fourfold more by white pine weevil than western white pine, but western white pine was more affected by the rust on one site. White pine blister rust did not contribute to unusually high levels of mortality for either species. Several families of western white pine showed promise for planting in the east.

461 Pinto, F. 1992. Silvicultural practices in Ontario's white pine forests. Pages 170–178 *in* R.A. Stine and M.J. Baughman, eds. White pine symposium proceedings: history, ecology, policy and management, Duluth, MN, 16–18 September 1992. University of Minnesota, Extension Service Distribution Center, St. Paul, MN. 202 p.

An overview was presented of current eastern white pine (*Pinus strobus* L.) management practices in Ontario. The uniform shelterwood system was the most common method used to manage Ontario eastern white pine forests. The shelterwood system usually involved a series of up to four partial harvests. At each stage, residual trees were retained as future crop trees, seed sources, and for ecological or aesthetic reasons. The earliest cut, the preparatory cut, was used to give more growing space to residual trees. Trees were ideally spaced at 25–30% of their height. The seeding cut was next and residual trees were spaced at about 40% of their height. Its purpose was to favor germination and early development. While the trees were <6 m, there was a removal cut, which was a partial cut that leaves the trees spaced at 50–60% of their height. A final removal cut takes place when the regenerating eastern white pine was >6 m high.

462 Pinto, F. 2003. Adapting forestry practices to address old-growth concerns in the Great Lakes–St. Lawrence forests of Ontario. For. Chron. 79:613–620.

Old-growth forests are defined as forests with a long history of natural disturbances and reproduction. Silvicultural practices could eliminate or change processes and components specific to old-growth forests. In the Great Lakes–St. Lawrence forest region, forest composition and structure are changing because of forestry practices. Many areas that previously supported large eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.) are now growing poplar (*Populus* spp.), white birch (*Betula papyrifera* Marsh.), and red maple (*Acer rubrum* L.). In Ontario, computer models simulating the effects of disturbances were developed to select stands for harvest. Forest management planning has been improved to maintain biodiversity and its function in stands. Five major areas of difference were recognized when comparing conventional silvicultural practices with the in-stand changes resulting from natural disturbances: site and stand damage, maintenance of structural legacy of the original stand, disturbance variability and intensity, wildlife habitat, and genetic diversity of trees.

463 Pinto, F.; Romaniuk, S. 2004. Changes in tree species composition from pre-settlement to present: a case study of the Temagami forest, Ontario. Pages 176–188 *in* A.H. Perera, L.J. Buse, and M.G. Weber, eds. Emulating natural forest landscape disturbances:

concepts and applications. Columbia University Press, New York, NY. 352 p.

The use of forest cover data before European settlement was examined as a basis for emulating natural disturbance. Historical land surveyor data from 1885 to1958 were used to describe forest composition when anthropogenic disturbances were considered to be minimal, and compared with the present forest cover to document changes in forest tree composition after forest fire prevention and logging became widespread. The study was completed on the Temagami Forest Management Unit in northeastern Ontario. Conifers including both red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.) have decreased in abundance, probably mainly a result of logging, fire control, and lack of regeneration effort. If managers want to emulate natural disturbance patterns, a strategy is needed to increase the abundance of both pines (*Pinus* spp.) and spruces (*Picea* spp.) in the Temagami forest.

464 Pitt, D.G.; Meyer, T.; Park, M.; MacDonald, L.; Buscarini, T.; Thompson, D.G. 2006. Application of slow-release tablets to enhance white pine regeneration: growth response and efficacy against white pine blister rust. Can. J. For. Res. 36:684–698.

The effects of slow-release tablets adding fertilizer, fungicide, and insecticide were examined on the growth of eastern white pine (*Pinus strobus* L.) seedlings and their resistance to white pine blister rust (*Cronartium ribicola* J.C. Fischer). Twenty-four different tablets were tested with one of four rates of fungicide (triadimefon at 0, 1000, 2000, or 4000 ppm), one of three rates of insecticide, and with or without fertilization. Two field trials were set up in Ontario: one in Temagami and one near Sundridge. Treatment consisted of placing the tablet in the planting hole immediately underneath the eastern white pine seedling. Each treatment plus a control was replicated 10 times for a total of 250 experimental units. A third trial was set up near Sault Ste. Marie with an eight-treatment subset (fungicide at two levels, insecticide at two levels, and with or without fertilizer). Overall seedling mortality, proportion of infection-free trees, and growth of surviving trees were recorded for five years after treatment. Increased uptake of triadimefon occurred during the first two years after treatment, but uptake declined rapidly after four years. Greater levels of residue were detected in unfertilized trees. Mortality, growth, and incidence of white pine blister rust all differed greatly among sites. Treatment with triadimefon had a positive effect on both survival and white pine blister rust incidence, especially at rates between 1000 and 2000 ppm. A slow-release, fungicide-impregnated tablet was effective in improving survival, health, and growth of eastern white pine seedlings, but an integrated approach was recommended that also considered overstory stand management, avoiding high-hazard areas, stem density regulation, and pruning.

465 Popovich, S. 1978. Tables de production normale pour les plantations de pin rouge (*Pinus resinosa* Ait.) au Québec. Ministère de l'Environnement, Service canadien des forêts, Centre de recherches forestières des Laurentides, Ste-Foy (Québec). Rapport d'Informaton LAU-X-33. 14 p. [Normal yield tables for red pine (*Pinus resinosa* Ait.) plantations in Quebec; English abstract.]

Normal yield tables were constructed for red pine (*Pinus resinosa* Ait.) plantations from data on 120 sample plots measured throughout Quebec. Trees had been planted at square spacings between trees ranging from 1.5 to 2.4 m. The plantations were 15–45 years old and were divided into three types of sites: poor (site index of 10 m), medium (site index of 16 m), and good (site index of 19 m).

466 Prégent, G. 2003. Caractéristiques des arbres coupés et du peuplement résiduel à la première éclaircie commerciale de plantations résineuses. Gouvernement du Québec, Ministère des Ressources naturelles, de la Faune et des Parcs, Direction de la recherche forestière, Mémoire de recherche forestière N° 143. 54 p. [Characteristics of thinned trees and remaining stands after the first commercial thinning in coniferous plantations; English abstract.]

Several commercial thinnings were simulated to study the effects on five conifer species: white spruce (*Picea glauca* (Moench) Voss), Norway spruce (*P. abies* (L.) Karst.), tamarack (*Larix laricina* (Du Roi) K. Koch), and jack (*Pinus banksiana* Lamb.) and red pine (*P. resinosa* Ait.). Data from 617 inventories and 522 sample plots distributed throughout Quebec were used to simulate the initial commercial thinning for several thinning intensities, different intervention times, and two types of thinning (systematic and selection from below). Regression models were used to estimate mean diameter at breast height, total volume, and merchantable volume regarding different thinning parameters. The number of harvested and residual stems per stand was also examined. An immediate increase in average stem diameter occurred with the removal of the smaller stems. Because of the high number of stems, problems with the profitability of the first thinning were discussed.

467 Pronos, J.; Patton, R.F. 1977. Armillaria root rot of red pine planted on oak sites in Wisconsin. Plant Dis. Rep. 61:955–958.

This study was initiated to develop a reliable measure of armillaria root rot (caused by the fungus *Armillaria mellea* (Vahl ex Fr.) Kummer) hazard on Wisconsin oak (*Quercus*

spp.) sites, and to explain the variations in root rot mortality among plantations. Three red pine (*Pinus resinosa* Ait.) plantations throughout Wisconsin were selected. At all three plantations, the red pine had been planted under an oak overstory. After planting, the overstory oak was killed by aerial sprays of 2,4,5-trichlorophenoacetic acid (2,4,5-T) or a mixture of 2,4,5-T and 2,4-dichlorophenoxyacetic acid. Plots were set up randomly six years after planting, and then mortality from armillaria root rot was recorded each fall for five consecutive years. Outbreaks of armillaria root rot caused red pine losses of 12, 18, and 37% in the plantations. Red pine mortality was positively correlated with the total number of dead oak stems per hectare but was not correlated with either total or annual red pine height growth.

468 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. North. J. Appl. For. 16:185–190.

The effects of white pine weevil (*Pissodes strobi* (Peck)) were examined in 17 young, well-stocked eastern white pine (*Pinus strobus* L.) plantations in northern Wisconsin and in a 150-year-old natural eastern white pine stand. Sample plots, each 0.02 ha, were assessed, and white pine weevil-related damages were recorded. A total of 101 trees were sampled in the natural stand. White pine weevil had attacked 87.3% of the trees in the plantations, and the trees in the natural stand were heavily attacked when they were younger, with an average attack rate of more than three times per tree. Management strategies should maintain the vigor and quality of crop trees through selection thinning, keeping eastern white pine in an unsuppressed crown position, and maintaining a minimum level of acceptable stocking.

469 Puettmann, K.J.; Reich, P.B. 1995. The differential sensitivity of red pine and quaking aspen to competition. Can. J. For. Res. 25:1731–1737.

The effects of competition were investigated using indices of resource availability (percentage open sky) and neighborhood stand density in a seven-year-old clearcut in northeastern Minnesota. The site was planted with 2+1 red pine (*Pinus resinosa* Ait.) in 1987, but after two years the site was also well occupied with trembling aspen (*Populus tremuloides* Michx.). Herbicide was applied to randomly selected 7.5-m-wide strips, which resulted in differential release of the residual trees. A total of 39 red pine and 38 trembling aspen were examined using a stratified sampling design to ensure the full range of competitive conditions was evaluated. The density of trembling aspen in the neighborhood explained the highest portion of variation in percentage open sky. Diameter growth of both red pine and trembling aspen was affected by their competitive status. Self-pruning of trembling aspen increased with higher levels of competition. Red pine had a higher specific gravity when growing under competition, which partially offset a reduction in volume growth, demonstrating the importance of assessing wood quality.

470 Puettmann, K.J.; Saunders, M.R. 2000. Eastern white pine (*Pinus strobus*) growth response to partial hardwood overstory release. North. J. Appl. For. 17:89–94.

Three stands in central Minnesota were assessed after eastern white pine (*Pinus strobus* L.) saplings were partially released from overstory competition to determine the response of understory eastern white pines to partial overstory release, and to determine how release timing and release intensity influenced postrelease growth response patterns. The overstory consisted of 65-year-old mixed aspen (*Populus* spp.) and northern hardwoods. All eastern white pine trees >0.7 m high were released from overtopping competition. All aspen and hardwood stems >7.6 cm diameter at breast height and within 6.1 m of eastern white pine trees were girdled. Trees were measured before and five years after release. Eastern white pine in all three stands responded similarly and showed a significant difference in diameter and height growth before and after overstory release with an increasing growth rate with greater release. Height:diameter ratios decreased after release, indicating that stability as well as growth increased after release.

471 Puettmann, K.J.; Saunders, M.R. 2001. Patterns of growth compensation in eastern white pine (*Pinus strobus* L.): the influence of herbivory intensity and competitive environments. Oecologia 129:376–384.

The intensity of herbivory, overstory, and understory competition and how they influenced the compensatory growth response of eastern white pine (*Pinus strobus* L.) seedlings were investigated. Eastern white pine seedlings were clipped at several different intensities and under a range of competitive conditions in early spring to simulate white-tailed deer (*Odocoileus virginianus* (Zimmermann)) browsing damage. The eastern white pine seedlings were planted as 3+0 stock in 17 plots in a partially harvested 45-year-old jack pine (*P. banksiana* Lamb.) plantation in Minnesota. Several clipping classes (unclipped control or removal of the terminal and 25, 50, 75, or 100% of last year's shoots) and levels of brush control were applied, and various aspects of growth response were measured after one growing season. Relative height growth was stimulated by light clipping (removal of 20–40% of last year's shoots). Relative diameter growth, total biomass, and annual biomass growth of seedlings declined sharply with increasing clipping intensity, and all growth parameters

declined with increasing interspecific competition. The results supported the hypothesis that overcompensation might be an adaptation to competitive ability and not a response to herbivory itself.

472 Puttock, G.D.; Bevilacqua, E. 1995. White pine and red pine volume growth under uniform shelterwood management in Algonquin Provincial Park. Natural Resources Canada, Canadian Forest Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON, and OMNR, Northern Ontario Development Agreement, Northern Forestry Program. NFP Tech. Rep. TR-14. 14 p. + append.

A compatible growth and yield model was developed for eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.) under uniform shelterwood management in Algonquin Provincial Park, Ontario. Data were collected from 280 growth plots in the eastern white pine working group and from 42 growth plots in the red pine working group from the eastern portion of Algonquin Park. Total basal area and volume growth of eastern white and red pine under uniform shelterwood management were affected by site productivity and the proportion of pine in the stand. The model developed was a variable density yield model, which incorporated site index, stand age, and basal area to make pine growth projections for up to 25 years.

473 Quinby, P.A. 1991. Self-replacement in old-growth white pine forests of Temagami, Ontario. For. Ecol. Manag. 41:95–109.

The hypothesis that old-growth eastern white pine (*Pinus strobus* L.) forest is self-replacing was examined by assessing an old-growth eastern white pine forest in Temagami, Ontario, using 50 × 20 m plots. Each plot contained a minimum of two eastern white or red pine (*P. resinosa* Ait.) at least 140 years old, and both the live and dead vegetation were surveyed. The old-growth eastern white pine stands had many small- and medium-sized stems of red maple (*Acer rubrum* L.) and balsam fir (*Abies balsamea* (L.) Mill.) under large eastern white pine. The eastern white pine were possibly self-replacing during the past 700 years. Catastrophic fire was not considered to be the primary stimulus for natural eastern white pine regeneration in old-growth eastern white pine forests, but more specific long-term studies were recommended to examine the effects of local disturbance on self-replacement of eastern white pine.

474 Quinby, P.A. 2000. First-year impacts of shelterwood logging on understory vegetation in an old-growth pine stand in central Ontario, Canada. Environ. Conserv. 27:229–241.

The initial effects of shelterwood harvesting on plant species composition and diversity in the understory and sapling strata in an old-growth red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.) forest stand were characterized. A 1400-ha area that included several pine stands near Temagami, Ontario, was thinned for the first time in 1996. The basal area was reduced by approximately 50%. Understory and sapling species were assessed before logging, and in August the year following logging. Some changes in understory vegetation were noted with a total of 68 plant taxa found in the understory; 58 were observed before logging and 54 after logging. Plant taxa not found after logging included horsetails (*Equisetum* spp.), club-moss (*Lycopodium annotinum* L.), interrupted fern (*Osmunda claytoniana* L.), and lady fern (*Athyrium filix-femina* (L.) Roth). White birch (*Betula payrifera* Marsh.) (800%), red maple (*Acer rubrum* L.) (363%), and bracken fern (*Pteridium aquilinum* (L.) Kuhn) (110%) showed overall the greatest increase in abundance (percentage cover). Major decreases included mosses and liverworts (*Bryophyta* spp.) (110%), Canada mayflower (*Maianthemum canadense* Desf.) (49%), and starflower (*Trientalis borealis* Raf.) (28%). Future studies were suggested on the longer term effects of shelterwood management.

475 Racey, G.D.; Glerum, C.; Hutchison, R.E. 1985. Lifting and overwinter storage of white pine in southern Ontario. For. Chron. 61:480–483.

At St. Williams Forest Tree Nursery in Ontario, an overwinter storage trial was completed in two consecutive years to examine lifting times and storage temperatures. Lifted 3+0 eastern white pine (*Pinus strobus* L.) seedlings were placed in either cold storage (1–4°C) or frozen storage (−3°C) and then were outplanted in the spring following a randomized complete block design. After a degree hardening period of 125 days, field performance in the following year was best. In Ontario, degree hardening requirements range from 125 days in the south to a maximum of 165 days farther north. Frozen storage was more effective at controlling mold than cold storage and should be used whenever possible.

476 Radeloff, V.C.; Mladenoff, D.J.; He, H.S.; Boyce, M.S. 1999. Forest landscape change in the northwestern Wisconsin Pine Barrens from pre-European settlement to the present. Can. J. For. Res. 29:1649–1659.

A detailed spatial picture of the pre-European settlement vegetation cover for the northwestern Wisconsin Pine Barrens was developed and compared with the current vegetation cover. The analysis was based on surveyor records of the United States General Land Office. The pine barrens have changed dramatically since the beginning of the European settlement. Logging was responsible for removal of red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.), and fire suppression gave oak (*Quercus* spp.), trembling

aspen (*Populus tremuloides* Michx.), and other hardwood species a competitive advantage in the previously pine (*Pinus* spp.)-dominated landscape. The trend of an increasing hardwood component would probably continue because of fire suppression, current forest management, and soil quality improvement due to hardwood leaf litter.

477 Rajora, O.P.; DeVerno, L.; Mosseler, A.; Innes, D.J. 1998. Genetic diversity and population structure of disjunct Newfoundland and central Ontario populations of eastern white pine (*Pinus strobus*). Can. J. Bot. 76:500–508.

Benchmark information on genetic diversity and structure of disjunct eastern white pine (*Pinus strobus* L.) populations from Newfoundland was collected and used to assess the extent of genetic differentiation. Isozyme analysis was used to compare six isolated eastern white pine stands in Newfoundland with three central Ontario eastern white pine stands for 20 allozyme loci coding for 12 enzymes. Both the Newfoundland and Ontario populations had moderate to high genetic diversity. Furthermore, 8000 years of postglacial geographic isolation and the recent population decline had little or no detectable effect on genetic diversity or differentiation of disjunct Newfoundland eastern white pine populations from their ancestral mainland populations.

478 Rajora, O.P.; Mosseler, A.; Major, J.E. 2002. Mating system and reproductive fitness traits of eastern white pine (*Pinus strobus*) in large, central versus small, isolated, marginal populations. Can. J. Bot. 80:1173–1184.

In six small, isolated stands in Newfoundland and three large, central stands in Ontario, mating system and reproductive fitness traits of eastern white pine (*Pinus strobus* L.) were assessed and compared. Cones were collected from 8 to 24 trees in each population, which meant that >90% of the trees in Newfoundland were sampled, whereas trees in Ontario were randomly sampled because of larger populations. Declining population sizes possibly had a negative influence on mating system and reproductive traits. Ontario populations showed a slower reproductive fitness than Newfoundland populations. Strong interrelationships were detected between the in-stand density of reproductively mature trees and both outcrossing rates and filled seed production. This is one of the first studies to report on outcrossing and inbreeding rates and seed traits involving eastern white pine in small Newfoundland populations and large Ontario populations.

479 Rawinski, J.J.; Bowles, J.A.; Noste, N.V. 1980. Soil properties related to coniferous seedling height growth in northern Wisconsin. Res. Note NC-254. USDA For. Serv., North Central For. Exp. Stn., St. Paul, MN. 3 p.

Jack pine (*Pinus banksiana* Lamb.), red pine (*P. resinosa* Ait.), white spruce (*Picea glauca* (Moench) Voss), and hybrid larch (*Larix leptolepis* (Siebold & Zucc.) Gord. × *L. decidua* Mill.) were tested in northern Wisconsin to determine which soil properties were related to early height growth of seedlings. The study area consisted of a 1-ha site divided into four blocks where each species occupied a 0.25-ha block. In each block, 16 plots were planted with16 seedlings each at a 2-m spacing. Soil samples were collected from the surface to a depth of 15 cm, and tree height growth was measured. Higher soil organic matter was correlated to increased growth of jack pine. Soil pH was negatively correlated to red pine and white spruce growth. Height growth was significantly different between high and low microsites for both jack and red pine. Generally, soil properties were correlated with height growth. On the basis of two years of data, the authors showed that jack pine and hybrid larch had greater height growth on silty soils.

480 Raymond, P.; Munson, A.D.; Ruel, J.-C.; Coates, K.D. 2006. Spatial patterns of soil microclimate, light, regeneration, and growth within silvicultural gaps of mixed tolerant hardwood–white pine stands. Can. J. For. Res. 36:639–651.

The spatial patterns of microclimate and tree regeneration were examined after gaps were created in tolerant hardwood–eastern white pine (*Pinus strobus* L.) stands near Maniwaki, Quebec. The gaps were 45 m in diameter, and all trees and woody vegetation were removed. The distance between gaps was at least 75 m. Each gap had forty 1-m^2 circular subplots. Twenty subplots were scarified and 20 were left unscarified. Eastern white pine seedlings were planted along the north margin of each plot. Regeneration was recorded annually for three consecutive years including the number of planted and naturally regenerated eastern white pine, cumulative diameter growth, soil temperature and moisture, light, and competition cover. Hemispherical photographs were used to estimate seasonal mean light levels; they reached a maximum in the northern portions and a minimum in the southern portions of the gaps. Eastern white pine density was highest along the margins or in the southwest quadrant and lowest in the center of the plots. A high spatial dependence in cumulative diameter growth was found in naturally regenerated eastern white pine seedlings, whereas it was weak or nonexistent in planted seedlings. Testing gap sizes smaller than 45 m was suggested because of the limited seed dispersal and low tolerance of eastern white pine to competition.

481 Raymond, P.; Munson, A.D.; Ruel, J.-C.; Nolet, P. 2003. Group and single-tree selection cutting in mixed tolerant hardwood–white pine stands: early establishment

dynamics of white pine and associated species. For. Chron. 79:1093–1106.

The effects of applying a combination of group and single-tree selection methods in tolerant hardwood–eastern white pine (*Pinus strobus* L.) stands in Quebec were tested to increase eastern white pine, yellow birch (*Betula alleghaniensis* Britt.), white birch (*B. papyrifera* Marsh.), and red oak (*Quercus rubra* L.) regeneration while decreasing or controlling less desired species. It was expected that any differences between the selection methods would be more evident in terms of seedling growth rates. Two areas >10 ha were cut, the first one by 35% single-tree selection cutting and the second one by group selection cutting. Some marking guidelines were circular gaps of 45 m diameter, ≥40 m between the gaps, and 25% single-tree selection cutting between the gaps. Each main plot had 20 scarified and 20 nonscarified 1-m^2 subplots, with half of those subplots seeded with 28 viable eastern white pine seed. Group selection with scarification had a positive effect on eastern white pine, yellow birch, and white birch regeneration. Red oak regeneration was negatively related to scarification. Short-term results suggested that the gaps could be successfully established with natural regeneration when they were also scarified. Eastern white pine seed predation possibly was a critical inhibitor of eastern white pine seedling establishment. Direct eastern white pine seeding was not very effective. A higher rate of direct seeding was recommended in mixed tolerant hardwood–eastern white pine stands.

482 Rhoades, R.W. 2002. Post-disturbance changes in the understory of an oak forest in southwestern Virginia. Castanea 67:96–103.

The postdisturbance changes in a mature oak (*Quercus* spp.) forest were examined. The effects of the 1994 ice storm were particularly interesting. The study site was a 2.5-ha area in Montgomery County, Virginia. Ten randomly distributed 100-m^2 plots were surveyed in 1971 and remeasured in 1994 and 1999 to determine changes in (1) density and basal area of trees; (2) density of saplings, seedlings, and shrubs; (3) relative height growth of seedlings and saplings; and (4) competitive status of various species in the community. The stand continued to be in a state of flux. Changes in overstory density and basal area were generally small, but there was a significant decline in the overstory scarlet oak (*Quercus coccinea* Muenchh.) since 1971. The effects of ice storm disturbance were minor, but any overstory tree death influenced understory composition. There was an increase in total shrub and sapling densities including eastern white pine (*Pinus strobus* L.) following disturbances. A major conclusion was that no plant species had an overwhelming competitive advantage. For instance, annual mortality rates were similar between all sapling species. By about 2020, the stand should be dominated by eastern white pine and red maple (*Acer rubrum* L.) and it should have fewer oaks.

483 Richter, D.A.; Bruhn, J.N. 1993. Mycorrhizal fungus colonization of *Pinus resinosa* Ait. transplanted on northern hardwood clearcuts. Soil Biol. Biochem. 25:355–369.

Changes in the mycorrhizal colonization of three-year-old bare-root nursery red pine (*Pinus resinosa* Ait.) seedling roots were investigated after outplanting seedlings into freshly cleared hardwood sites in northern Minnesota. Mycorrhizal fungus fruiting bodies were surveyed before logging and for four years after planting. Washed root systems were placed in water, and with the aid of a dissecting microscope, mycorrhizae on lateral roots were tallied by morphological type. Changes were related to tree age from outplanting where the number of nonmycorrhizal root tips declined to zero with increasing seedling age. The number of apparently different mycorrhizal fungus species isolated from mycorrhizae increased from 5 in the first year after outplanting to 22 species in the fourth year.

484 Roberts, B.A. 1989. Natural reproduction of red pine (*Pinus resinosa* Ait.) in Newfoundland. Forestry Canada, Newfoundland and Labrador Region, St. John's, NL. Information Report N-X-273. 36 p.

Red pine (*Pinus resinosa* Ait.) is the rarest coniferous tree species in Newfoundland, occurring at only 22 natural locations, and regeneration is sparse in most of these stands. This study examined the various sexual reproductive phases leading to seed production in Newfoundland red pine to determine whether there were differences in cone development among the various stands, and to establish that Newfoundland red pine produced viable seeds. Four stands of red pine were selected for detailed observations, which included recordings of bud swell, first green, first male cone, color, size, and pollen shedding. Regeneration was recorded as well. Only minor differences in cone development between stands were observed, but the better quality stands usually produced the best cone crops and the best quality seed. Lack of red pine regeneration was attributed in most instances to poor seedbed conditions.

485 Roberts, B.A.; Bajzak, D. 1996. Site characteristics, growth and nutrition of natural red pine stands in Newfoundland. Environ. Monit. Assess. 39:509–530.

Growth of red pine (*Pinus resinosa* Ait.) in Newfoundland was assessed to improve understanding of its local ecology. Its distribution, site characteristics, growth, nutrition, and ecology were described. Red pine was found at only

22 locations in Newfoundland on three major site types: medium-textured sands, coarse-textured glacio-fluvial deposits, and on florisols bedrock. All stands were sampled and measured, and needle samples were collected. Although red pine was occupying poor sites, it still reached heights >18 m, diameter at breast height >40 cm, and individual tree volumes >1 m^3 at age 60–70. Red pine grew faster than black spruce (*Picea mariana* (Mill.) BSP) when they occurred on the same sites. Foliar analysis indicated that even the best growing red pine were nitrogen deficient, which further characterized the remarkable growth of red pine on nutritionally poor sites.

486 Roberts, B.A.; Mallik, A.U. 1994. Responses of *Pinus resinosa* in Newfoundland to wildfire. J. Veg. Sci. 5:187–196.
Little was known about the effects of fire on understory dynamics and nutrition of natural red pine (*Pinus resinosa* Ait.) in Newfoundland. Two sites were examined and both had been burned by wildfires. Ground vegetation plots were assessed on both sites before and after fire. Transects were used to measure trees representing pre-fire conditions and trees on the actual burned sites. Leaf and soil samples were taken and analyzed as well. A short wildfire cycle of 15–30 years was found to be a main factor in regulating stand development. Nutrient concentrations were highest three months after a surface fire but dropped considerably one year later. A gradual increase to near postfire levels was achieved four years after the fire. Wildfire was considered a significant factor in regulating stand size, structure, nutrition, and growth of red pine in natural Newfoundland forests.

487 Roe, E.I. 1964. Heavy crop of red pine cones yields many thousands of good seeds. Res. Note LS-36. USDA For. Serv., Lake States For. Exp. Stn., St. Paul, MN. 4 p.
A study was conducted in two managed red pine (*Pinus resinosa* Ait.) stands (age 90 and 50 years) and in one unmanaged, natural red pine stand (90 years old) to gain improved knowledge of seed production. Seed was collected for one year during a heavy cone crop. Seed production in the managed stands was sampled in cutting blocks with five basal areas: 13.7, 18.4, 22.9, 27.5, and 32.1 m^2/ha. The 90-year managed stand was the best producer of seed averaging >2.2 million seeds per hectare. Seed yields were not significantly affected by stand density, although total seed production was possibly affected by stocking. Seedfall occurred throughout the year with a major peak in October and November; some seed fell during winter, early spring, and summer with a smaller peak in June. Seed quality decreased with time—the best quality seed fell first and half of the total amount of seed fell during the first two weeks of October.

488 Rogers, L.L. 1991. Are white pines too valuable to cut? The Minnesota Volunteer, Sept.–Oct., p. 8–21.
Several reasons were presented why older eastern white pine (*Pinus strobus* L.) trees in general and in northeastern Minnesota in particular should be conserved. Eastern white pine seldom regenerated naturally, and planted seedlings were often killed by white pine weevil (*Pissodes strobi* (Peck)), white pine blister rust (*Cronartium ribicola* J.C. Fischer), and heavy browsing by white-tailed deer (*Odocoileus virginianus* (Zimmermann)). In Superior National Forest, large eastern white pines contained >80% of the bald eagle (*Haliaeetus leucocephalus* (Linnaeus)) nests and 80% of the osprey (*Pandion haliaetus* (Linnaeus)) nests in the area surveyed. A study by North Central Forest Experiment Station biologists showed that American black bears (*Ursus americanus* Pallas) with cubs made >95% of their dens next to old eastern white pines. The values of this resource were timber, wildlife, aesthetics, and biodiversity.

489 Rogers, L.L.; Lindquist, E.L. 1992. Supercanopy white pine and wildlife. Pages 39–43 *in* R.A. Stine and M.J. Baughman, eds. White pine symposium proceedings: history, ecology, policy and management, Duluth, MN, 16–18 September 1992. University of Minnesota, Extension Service Distribution Center, St. Paul, MN. 202 p.
The importance of scattered old supercanopy eastern white pine (*Pinus strobus* L.) trees to wildlife was discussed. Earlier studies showed that eastern white pine communities were avoided by American black bears (*Ursus americanus* Pallas), but scattered supercanopy eastern white pine trees with a diameter at breast height >50 cm were preferred black bear refuge trees and den sites. Supercanopy eastern white pine trees comprised only a fraction of a percentage of the trees in the Superior National Forest, but 31 years of nest survey data showed that they held 81% of the bald eagle (*Haliaeetus leucocephalus* (Linnaeus)) nests and 77% of the osprey (*Pandion haliaetus* (Linnaeus)) nests. More research was needed because most inhabitants of Minnesota's eastern white pine range had not been studied sufficiently to determine direct or indirect relationships with specific tree species.

490 Rogers, L.L.; Wilker, G.A.; Allen, A.W. 1988. Managing northern forests for black bears. Pages 36–42 *in* T.W. Hoekstra and J. Capp, comps. Integrating forest management for wildlife and fish. Gen. Tech. Rep. NC-122. USDA For. Serv., North Central For. Exp. Stn., St. Paul, MN.
Habitat information was collected for American black bears (*Ursus americanus* Pallas) that managers could use for resource management plans and area planning. Radio-collared black bears were followed to study their

habitat patterns in northeastern Minnesota, and black bear fecal scats were examined as well. Wetlands were important for black bears feeding in early spring and cooling, whereas young balsam firs (*Abies balsamea* (L.) Mill.) at high densities were used for shade. Eastern white pines (*Pinus strobus* L.) with a diameter >50 cm were used as refuge trees, especially by mother black bears with cubs. In late spring, expanding aspen (*Populus* spp.) leaves formed a major part of the black bear's diet; in summer, berries, nuts, and ants were important foods; and in fall, acorns were the most important foods. Forest management recommendations for each season included recommendations for maintaining red oak (*Quercus rubra* L.) stands and leaving some larger eastern white pine and eastern hemlock (*Tsuga canadensis* (L.) Carrière) trees.

491 Rollins, K.; Forsyth, M.; Bonti-Ankomah, S.; Amoah, B. 1994. Economic analysis of forestry management practices with an application to a white pine improvement cut in Ontario. Natural Resources Canada, Canadian Forest Service, Great Lakes Forestry Centre, Sault Ste. Marie, ON, and OMNR, NODA Note No. 3. 5 p.
Some basic elements of forestry economics were described including that the purpose of an economic analysis was to show the potential production from available labor, capital, and natural resources when using them as efficiently as possible. An economic analysis of forest management consists of calculating the present value of benefits, calculating the present value of costs, and subtracting present valued costs from benefits. These techniques were applied to an eastern white pine (*Pinus strobus* L.) improvement cut experiment near Petawawa, Ontario. This improvement cut involved a release cut in a two-story mixedwood forest leaving a healthy understory of eastern white pine, red pine (*P. resinosa* Ait.), and white spruce (*Picea glauca* (Moench) Voss). The purpose of this experiment was to release the pine and thereby increase the future volume and value of sawtimber. But the analysis presented did not account for the increase in value of the larger size and improved quality of trees or the effects of the pruning of crop trees.

492 Rollins, K.; Forsyth, M.; Bonti-Ankomah, S.; Amoah, B. 1995. A financial analysis of a white pine improvement cut in Ontario. For. Chron. 71:466–472.
An experimental improvement cut was made in 1971 in a two-story eastern white pine (*Pinus strobus* L.) mixedwood forest near Petawawa, Ontario. The cut was designed to release understory eastern white pine and initiate a shelterwood silvicultural system. An economic analysis was completed to determine whether the management regime provided net benefits to society. The analysis showed that the harvest significantly increased the present value of net benefits per hectare compared with the control stands. The results provided were not intended as a comprehensive final analysis because the benefits varied significantly with interest rates, the amenity values were not incorporated into the study, and limited data were available to predict the future timber value.

493 Ross, B.A.; Bray, J.R.; Marshall, W.H. 1970. Effects of long-term deer exclusion on a *Pinus resinosa* forest in north-central Minnesota. Ecology 51:1088–1093.
The effects of a white-tailed deer (*Odocoileus virginianus* (Zimmermann)) exclosure were assessed on herbs, shrubs, and regeneration in a 230-year-old red pine (*Pinus resinosa* Ait.) forest in Itasca State Park, Minnesota. In 1937, a 1-ha deer exclosure was constructed. Before its construction, deer had removed all young trees more than one to two years old. Before 1945, deer numbers and browsing were high. Afterward, hunting was permitted, and deer browsing became moderate as the population fell. Early qualitative observations from scientists involved with the establishment of the exclosure were used to describe the forest before deer exclusion. Data were collected between 1946 and 1969 inside and outside the exclosure. Since 1937, the number of seedlings and saplings in the exclosure increased and followed a typical successional course. Eastern white pine (*P. strobus* L.) became dominant in the exclosure. Other species present were white birch (*Betula papyrifera* Marsh.), red maple (*Acer rubrum* L.), red oak (*Quercus rubra* L.), and balsam fir (*Abies balsamea* (L.) Mill.). As the deer numbers dropped because of hunting, saplings were found outside the exclosure, but only red pine and white birch seedlings exceeded the sapling class in size. This study described the pattern of tree succession in the forest and demonstrated the impact of browsing by deer.

494 Rouse, C. 1985. Fire protection and use in red pine management. Pages 265–273 *in* R. Marty, ed. Managing red pine. Proceedings of the second region V technical conference, Society of American Foresters. SAF Publication 85-02. Bethesda, MD.
Fire can be very destructive to red pine (*Pinus resinosa* Ait.), especially in younger red pine plantations. Once red pine reaches a height of about 18 m, the bark is thick enough to protect the cambium from all but the most extreme fires. Fire prevention is important and starts with plantation layout. Firebreaks or barriers can be set up to protect plantations. Thinning or partial cutting will reduce contact between flammable crowns and thus slow down a spreading fire. The most effective and economical method of protection is likely a combination of techniques incorporating existing physical and vegetative barriers with other management objectives. Besides being a threat,

fire can also fulfill several management objectives, such as site preparation, growth enhancement, pest control, and improved wildlife habitat. Regeneration will increase after a prescribed burning because red pine cannot germinate in thick litter and duff. Red pine and fire are inseparable and when they are both managed in combination, increased production at lower costs can be achieved.

495 Rouse, C. 1988. Fire effects in northeastern forests: red pine. Gen. Tech. Rep. NC-129. USDA For. Serv., North Central For. Exp. Stn., St. Paul, MN. 9 p.
Information was reviewed on the effects of fire in red pine (*Pinus resinosa* Ait.) forests on reproduction and stand development. Fire enhanced red pine germination success because red pine seed germinated best in close contact with mineral soil. Fire can devastate young red pine stands, but trees >18 m tall have a bark thick enough to protect the cambium from all but the most intensive fires. Two consecutive annual fires were enough to control competition, but results of prescribed fire use were difficult to predict. More site-specific information was needed so that managers could use fire as a more reliable management practice, especially for site preparation.

496 Rudolf, P.O. 1990. *Pinus resinosa* Ait. Red pine. Pages 442–455 *in* R.M. Burns and B.H. Honkala, tech. coords. Silvics of North America. Vol. 1. Conifers. USDA For. Serv., Agriculture Handbook No. 654. Washington, DC.
A summary was provided on red pine (*Pinus resinosa* Ait.) silvics, habitat and associated forest covers, life history, reproduction, and growth from the available information on red pine throughout its range. Fire is the only natural agent capable of providing most of the conditions required for natural red pine reproduction. Height growth reflects site quality and the amount of overhead shade or growth limitations. Red pine has been one of the most extensively planted species within its range, not only for wood production but also for dune and sandblow control. Red pine is very uniform genetically, though small but statistically significant differences among provenances have been found for survival, phenological traits, size and growth rates, photoperiodic responses, lammas frequency, and wood quality.

497 Ryall, K.L.; Smith, S.M. 2005. Patterns of damage and mortality in red pine plantations following a major ice storm. Can. J. For. Res. 35:487–493.
The impact of a major ice storm in eastern Ontario on 28 pine plantations consisting of red (*Pinus resinosa* Ait.), Scots (*P. sylvestris* L.), eastern white (*P. strobus* L.), and jack pine (*P. banksiana* Lamb.) was examined for four years after the event. The relationships were examined between levels of damage and forest tree characteristics and longer term patterns of mortality in damaged trees from salvaged and unsalvaged stands. In each stand, one transect (200×2 m) was sampled and recorded as 10 consecutive 20-m sections. Crown loss and tree mortality were noted in relation to other tree and stand characteristics. Jack and Scots pine were 2.5 times more likely to be damaged by an ice storm than red and eastern white pine, and eastern white pine was less susceptible than red pine. Poorly managed and overstocked stands were most affected by storm damage, and unsalvaged stands showed a 75% mortality rate in trees with severe crown losses compared with 45% in salvaged stands. Properly timed thinnings were recommended to increase diameter growth and to remove dead and dying wood from heavily damaged stands to reduce the long-term impacts of ice storms.

498 St. Clair, S.B.; Lynch, J.P. 2005. Element accumulation patterns of deciduous and evergreen tree seedlings on acid soils: implications for sensitivity to manganese toxicity. Tree Physiol. 25:85–92.
The authors tested the hypothesis that leaf phenology and other traits that distinguish evergreen and deciduous tree species influence foliar element accumulation rates and sensitivity to manganese. The experiment had two components. First, seedling foliage of nine deciduous and three evergreen species including eastern white pine (*Pinus strobus* L.) from five similar field sites in Pennsylvania was sampled and analyzed for element accumulation. The second component involved a greenhouse study using a completely randomized factorial design replicated five times. The growth and photosynthetic responses of seedlings from the nine species were tested under applications of two manganese concentrations. Concentrations of manganese in deciduous leaves accumulated twice as high as in coniferous needles. Evergreen species and some deciduous species seemed tolerant of excess manganese. For all species, photosynthesis was negatively correlated to manganese accumulation in foliage.

499 Santoro, A.E.; Lombardero, M.J.; Ayres, M.P.; Ruel, J.J. 2001. Interactions between fire and bark beetles in an old growth pine forest. For. Ecol. Manag. 144:245–254.
The interactions between red pine (*Pinus resinosa* Ait.) trees and bark beetles (*Ips* spp.) in association with prescribed fires were studied in the old-growth forests at Itasca State Park in northwestern Minnesota. Ten old-growth red pine trees in each of 12 sites were selected and resin flow was measured before and after fire. Funnel traps were used to sample abundances of three *Ips* spp. and their specialist predator the checkered beetle, *Thanasimus dubius* (F.), before and after fire. After fire, resin flow

tended to increase, but no correlation was found between the abundance of *Ips* spp. before and after fire. Without fire in the ecosystem, red pine was not regenerating and its population could decrease substantially without fire or management practices to regenerate it.

500 Saunders, M.R.; Puettmann, K.J. 1999a. Effects of overstory and understory competition and simulated herbivory on growth and survival of white pine seedlings. Can. J. For. Res. 29:536–546.

The effects of competition and simulated white-tailed deer (*Odocoileus virginianus* (Zimmermann)) herbivory on eastern white pine (*Pinus strobus* L.) seedlings were investigated in a three-year-old eastern white pine underplanting in southwestern Itasca County, Minnesota. Seedlings were budcapped (10 × 20 cm sheet of paper covering the terminal) every winter and then little deer damage occurred. Sixty plots were set up and in each one two seedlings were assigned randomly to one of three clipping treatments: control, lightly clipped treatment that removed the terminal leader and 50% of the previous year's shoots, and a heavily clipped treatment that removed the terminal leader and 100% of the previous year's shoots. Half the plots received understory brush control. Seedlings were measured before and during two consecutive years following treatments, and light conditions were measured as well. Increased overstory and understory competition reduced seedling growth and survival. Clipping treatments had significant effects on both height and diameter growth. Understory brush control and seedling protection should both be factors considered in the successful regeneration of eastern white pine.

501 Saunders, M.R.; Puettmann, K.J. 1999b. Use of vegetational characteristics and browsing patterns to predict deer damage in eastern white pine (*Pinus strobus*) plantations. North. J. Appl. For. 16:96–102.

Browsing incidence by white-tailed deer (*Odocoileus virginianus* (Zimmermann)) was assessed to describe patterns of browse selection by white-tailed deer, quantify growing conditions for seedlings, and address risk assessment. Eight eastern white pine (*Pinus strobus* L.) plantations in northern Minnesota younger than 10 years old were measured and their browsing history was recorded. All sites were budcapped during previous winters. Chi-square tests of homogeneity were done to determine the influence of seedling height on browse selection. Seedlings up to 130 cm high were very susceptible to terminal damage. Lateral browsing was much more prevalent on all sites than terminal leader browsing, which was most likely because of the budcapping of the terminal and an increase in the number of laterals because of increasing seedling height. Deer also often selected previously browsed seedlings. This study showed the difficulties involved in developing a useful, predictive model, one that should include not only plot and seedling characteristics but also site and landscape characteristics.

502 Schaberg, P.G.; Hawley, G.J.; DeHayes, D.H.; Nijensohn, S.E. 2003. Silvicultural management and the manipulation of rare alleles. Pages 67–74 *in* J. Beaulieu, ed. Silviculture and the conservation of genetic resources for sustainable forest management. Proceedings of a symposium of the North American Forest Commission, Forest Genetic Resources and Silviculture Working Groups, and IUFRO, Québec City, Quebec, 21 September 2003. Natural Resources Canada, Canadian Forest Service, Laurentian Forestry Centre, Sainte-Foy, QC. Information Report LAU-X-128. 112 p.

Rare alleles are considered important to long-term forest health because they provide a means for adaptation. A discussion was presented of whether the selective removal of trees (and genes) through silvicultural management would alter the genetic structure of the forest. The first component of the study evaluated the long-term results of silviculture on the genetics of an eastern hemlock (*Tsuga canadensis* (L.) Carrière) forest. For the second component, computer-based harvests were simulated in a genetically mapped forest that included isozyme data for 220 eastern white pines (*Pinus strobus* L.) growing in central Vermont. Both approaches demonstrated that rare allele frequencies could increase or decrease depending on the selection criteria. The extent to which gene migration ameliorated harvest-induced alterations could have a substantial influence on the importance of silvicultural manipulations on allele frequencies.

503 Scheiner, S.M.; Sharik, T.L.; Roberts, M.R.; Vande Kopple, R. 1988. Tree density and modes of tree recruitment in a Michigan pine–hardwood forest after clearcutting and burning. Can. Field-Nat. 102:634–638.

Patterns of recruitment, mortality, and change in community composition were investigated during the initial stage of secondary succession in a pine (*Pinus* spp.)–hardwood forest. In a second-growth pine–hardwood stand that originated following logging and wildfire, a 120 × 100 m area was clearcut and then burned the following summer. Original stand composition was determined by inventorying all stumps after harvest. It had consisted mainly of largetooth aspen (*Populus grandidentata* Michx.), red oak (*Quercus rubra* L.), and red maple (*Acer rubrum* L.) with eastern white pine (*Pinus strobus* L.) moderately abundant. Sixteen permanent quadrats were set up to follow recruitment and survival, and all aboveground stems were counted for four years after the burn. After the disturbance, largetooth aspen and red maple comprised

66 and 25%, respectively, of all stems. Eastern white and red pine (*P. resinosa* Ait.) were not found after the disturbance, and their future recruitment would have to be from seed or by artificial means.

504 Scherzer, A.J.; Rebbeck, J.; Boerner, R.E.J. 1998. Foliar nitrogen dynamics and decomposition of yellow-poplar and eastern white pine during four seasons of exposure to elevated ozone and carbon dioxide. For. Ecol. Manag. 109:355–366.

The impacts of elevated O_3, and elevated O_3 plus elevated CO_2, on the growth and physiology of field-grown yellow-poplar (preferred common name is tulip-tree, *Liriodendron tulipifera* L.) and eastern white pine (*Pinus strobus* L.) were measured during a five-year study. Yellow-poplar and eastern white pine seedlings growing in two plantations were fumigated in open-top chambers with charcoal-filtered air, ambient air, one time ambient O_3, twice ambient O_3, or twice ambient O_3 plus twice ambient CO_2. The combination of elevated O_3 and elevated CO_2 significantly reduced foliar N concentrations of both yellow-poplar and eastern white pine foliage. O_3 alone had little effect on the foliar N dynamics. Elevated O_3 and CO_2 or O_3 alone did not affect eastern white pine litter decomposition. The sampling schedule, leaf age, and canopy position were important factors in determining the magnitude of response.

505 Schlaegel, B.E. 1971. White pine production best at high stocking. Res. Note NC-115. USDA For. Serv., North Central For. Exp. Stn., St. Paul, MN. 2 p.

Sample plots of approximately 2.4 ha each were thinned in a 95-year-old eastern white pine (*Pinus strobus* L.) stand in north central Minnesota. Each thinning favored the bigger and healthier trees and reduced residual basal areas to 18.4, 23.0, 27.5, or 32.1 m^2/ha. Basal area growth, volume growth, and total volume production increased with the higher residual stand densities, and therefore maturing eastern white pine produced more merchantable volume at the highest stocking level tested (that is, 32.1 m^2/ha).

506 Schmidt, T.L. 2002. Red pine in the northern Lake States. Pages 3–16 *in* D.W. Gilmore and L.S. Yount, eds. Proceedings of the red pine SAF region V technical conference. Staff Paper Series No. 157. University of Minnesota, Department of Forest Resources, St. Paul, MN.

Red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.) forests were one of the dominant vegetative features of the northern Lake States landscape, but intensive logging reduced the area of pine and other forest types. After 1930, forested lands started to dominate this landscape again. The increase of red pine was described here to improve understanding of the resource and help with its management. The Forest Inventory and Analysis Database from the USDA Forest Service indicated that red pine was present on about 4% of all land in the northern Lake States, and that some red pine was found in almost all other forest types. The red pine forest type increased dramatically in area after 1930. Stocking levels were measured since 1980 and they have increased since then. Growing-stock volume increased by 133% between the 1930s and 1990s through natural and artificial regeneration but also mainly through reclassification of other forest types to red pine. The region's average annual net growth for red pine was five times greater than what was harvested.

507 Schomaker, C.E. 1969. Growth and foliar nutrition of white pine seedlings as influenced by simultaneous changes in moisture and nutrient supply. Soil Sci. Soc. Am. Proc. 33:614–618.

The effects of varying water supplies and nutrient solution concentrations on the growth and foliar nutrient concentration of eastern white pine (*Pinus strobus* L.) seedlings were determined in a greenhouse study. Sixteen treatments were applied and consisted of four macronutrient solution concentrations and four periods between successive irrigations in all treatment combinations. Seedling weight increased proportionally with increases in nutrient solution and irrigation schedule. Generally, foliar concentrations of macronutrients were correlated negatively with micronutrients. Fertilization with macronutrients alone might produce micronutrient deficiencies through reduced uptake of these elements, if one or more of the micronutrients were at or near the critical limit level of supply.

508 Schooley, H.O.; Winston, D.A.; Macnaughton, R.L.; Anderson, M.L. 1986. Frost killing of red pine female flowers. For. Chron. 62:140–142.

The effects of frost on cone production were evaluated at Petawawa, Ontario, by assessing 121 trees from 1979 to 1984 in a seed production area, part of which was located in a frost pocket. Temperatures were recorded during the flowering periods of 1980–1983. In early July, immediately following the flowering period, the developing cone crops were examined to see whether frost had killed the flowers. The maximum period of freezing at the coldest recording station was three to seven hours, which suggested that frost damage occurs so rapidly that the duration of the exposure period might be of little importance.

509 Schubert, M.R.; Rennie, J.C.; Schlarbaum, S.E. 2004. Four pine species grown at four spacings on the eastern

highland rim, Tennessee, after 30 years. Pages 433–436 *in* K.F. Connor, ed. Proceedings of the 12th biennial southern silvicultural research conference, Biloxi, MS, 24–28 February 2003. Gen. Tech. Rep. SRS-71. USDA For. Serv., Southern Res. Stn., Asheville, NC.

A spacing trial was set up near Tullahoma, TN, to examine the growth and development of four pine species: eastern white pine, *Pinus strobus* L.; loblolly pine, *P. taeda* L.; Virginia pine, *P. virginiana* P. Mill.; and shortleaf pine, *P. echinata* P. Mill. Trees were planted at four square spacings (1.8, 2.7, 3.7, and 4.6 m) in a split-plot design. After 22 and 30 years, no differences were observed in survival among the species. Closer spacings had lower pine survival likely because of increased competition. Eastern white pine had higher volumes and greater economic value than the other species, and loblolly and eastern white pine had significantly higher stand volumes. Planting of loblolly and eastern white pine was recommended on the Barrens in Tennessee. The choice of species would depend on current markets.

510 Schultz, J.R. 1989. Using disease resistant white pine to meet multiple resource objectives. North. J. Appl. For. 6:38–39.

A silvicultural study was initiated to test disease-resistant eastern white pine (*Pinus strobus* L.) under natural conditions in a mature white birch (*Betula papyrifera* Marsh.) stand in a visually sensitive recreation area in Wisconsin. The 5-ha stand was nearly 100% white birch, and its basal area was reduced by thinning to 13–16 m^2/ha with a crown closure of about 70–90%. The 3+0 bare-root, disease-resistant eastern white pine seedlings were planted at a 2.0×2.5 m spacing. Survival of eastern white pine after three growing seasons was 90%, and their rapid early growth allowed most eastern white pine to remain ahead of the competition. The trees showed no signs of white pine weevil (*Pissodes strobi* (Peck)) or white pine blister rust (*Cronartium ribicola* J.C. Fischer). The success of this approach demonstrated a management alternative for forest managers facing the breakup of stands of short-lived species such as white birch on sites in visually sensitive areas.

511 Schumann, D.R. 1986. White pine marketing opportunities. Pages 102–105 *in* D.T. Funk, comp. Eastern white pine: today and tomorrow. Symposium proceedings, Durham, NH, 12–14 June 1985. Gen. Tech. Rep. WO-51. USDA For. Serv., Northeastern For. Exp. Stn., Durham, NH. 124 p.

Trends in pricing and wood flow for eastern white pine (*Pinus strobus* L.) in New Hampshire were reviewed. Eastern white pine maintained and even improved its posture in the marketplace during downturns in the economy. Stumpage prices of medium quality eastern white pine showed an improvement of 3.1% during the past 11 years. A steady increase of pine imports was seen for the past six years, a trend that was not seen for pine exports. The domestic market was expected to continue to dominate, and the export market to offer limited opportunity for expansion.

512 Schuster, W.S.; Hutnik, R.J. 1987. Community development on 35-year-old planted minespoil banks in Pennsylvania. Reclam. Reveg. Res. 6:109–120.

A characterization was presented of the flora establishing on several Pennsylvanian minespoil sites planted with eight different species including red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.). Plant communities were described using a modified Braun-Blanquet scale, and clustering trends were explored for 24 planted and 7 control plots. Species richness in the eastern white pine was significantly lower relative to white ash (*Fraxinus americana* L.), red oak (*Quercus rubra* L.), Japanese larch (*Larix kaempferi* (Lamb.) Carrière), and control plots, but basal areas of these other tree species were higher because of many site-specific factors. Largetooth aspen (*Populus grandidentata* Michx.) was the most abundant invader in pine (*Pinus* spp.) and white ash plots, whereas black cherry (*Prunus serotina* Ehrh.) was generally the greatest invader in the other plots. Successional changes were discussed regarding the emergence and decline of certain species in the plots through time.

513 Sendak, P.E.; Brissette, J.C.; Frank, R.M. 2003. Silviculture affects composition, growth, and yield in mixed northern conifers: 40-year results from the Penobscot Experimental Forest. Can. J. For. Res. 33: 2116–2128.

A study of timber management has evolved through time to examine stand dynamics, productivity, resiliency, and biological diversity. Eight different silvicultural techniques were evaluated in Maine in the Acadian forest region during a 40-year period, which represents about one half the rotation time for even-aged red spruce (*Picea rubens* Sarg.) stands. The replicated treatments included the selection system on 5-, 10- and 20-year cutting cycles; uniform shelterwoods with two- and three-stage overstory removals; unregulated harvesting; and two variations of diameter-limit cutting. One key management objective was to increase the softwood component, and only the five-year selection treatment was successful in this regard by lowering the hardwood component from 22 to 11%. If timber production was the primary goal, then considering this study, some form of even-aged management with competition control would be recommended to increase the red spruce component and favor the higher valued eastern white pine (*Pinus strobus* L.) over eastern hemlock

(*Tsuga canadensis* (L.) Carrière) or eastern white-cedar (*Thuja occidentalis* L.).

514 Seymour, R.S. 2007. Low-density management of white pine crop trees: a primer and early research results. North. J. Appl. For. 24:301–306.

Low-density eastern white pine (*Pinus strobus* L.) management involves selecting crop trees at unconventionally low stand densities to obtain exceptionally rapid residual tree growth and higher rates of return. A study was set up in 1991 in a 42-year-old eastern white pine plantation in east central Maine to assess a low-density thinning (247–346 trees per hectare); a conventional B-line thinning; and control, nonthinned plots. Plots were 20 × 20 m and the three treatments were assigned randomly in paired plots and replicated eight times. The additional residual trees left to achieve B-line stocking reduced crop-tree development more than they contributed to stand increment. Both methods of thinning grew significantly less wood than the control plots, but growth per residual tree increased after thinning and markedly increased residual tree wood value. Foresters interested in maximizing only volume growth in eastern white pine stands would keep densities well above the B-line and conduct frequent, light thinning treatments to capture mortality. On the basis of the results from this paper, the author challenged the conventional use of the stocking-guide B-line as a density standard and recommended use of a more flexible and less prescriptive density management diagram.

515 Seymour, R.S.; Smith, D.M. 1987. A new stocking guide formulation applied to eastern white pine. For. Sci. 33:469–484.

A procedure was developed for incorporating stand age into the widely used stocking guides on the basis of the crown competition factor. The model could predict diameters of individual trees from crown projection area and total height, and it was tested on 122 eastern white pine (*Pinus strobus* L.) growing on five different sites in New England. On two occasions, height, diameter at breast height, crown radii, and height to the widest point of the crown and to the lowest living whorl were measured on the 122 trees. The model was derived from a three-dimensional relationship between crown volume and total volume of the main stem. Several examples were given and the model was compared with other stocking guides. Complete crown closure could occur before B-level stocking were reached if early thinnings were heavy enough to permit development of large crowns. Better thinning schedules for eastern white pine could be designed with this model. Researchers were encouraged to test this model with other species.

516 Sharik, T.L.; Ford, R.H.; Davis, M.L. 1989. Repeatability of invasion of eastern white pine on dry sites in northern Lower Michigan. Am. Midl. Nat. 122:133–141.

Forest stands occupying similar sites but originating at various times in the past probably do not exhibit the same sequence of changes following disturbance. The study site was in the northern part of Michigan's Lower Peninsula, and the sampled stands originated 4, 30, 36, 48, or 73 years ago, following logging and prescribed burning. A 10 × 10 m grid was superimposed on each stand, and 5-m-radius plots were centered on each of 30 randomly selected points on the grid. Eastern white pines (*Pinus strobus* L.) in plots were grouped into three-year age classes. Invasion was more rapid in stands of recent origin compared with older stands, and net rates of increase in populations of eastern white pine following disturbance varied substantially among stands. The original hypothesis was rejected because results suggested that the process of eastern white pine invasion following disturbance was not repeated, and by extension not predictable, on similar sites. Colonization and population increase were probably not affected by the same mechanisms but both contributed to the nondeterministic nature of eastern white pine development through time and seemed to have important implications for community development.

517 Shepard, R.K.; Shottafer, J.E. 1992. Specific gravity and mechanical property–age relationships in red pine. For. Prod. J. 42:60–66.

Two red pine (*Pinus resinosa* Ait.) plantations and one natural red pine stand were investigated to study the relationships between three wood properties: specific gravity (SG), modulus of rupture (MOR), and modulus of elasticity (MOE) and age, and the ranges that might occur in the number of years required to reach maturity. The mature stage for all three wood properties began at about age 40. Average mature wood values were 90% greater for MOE, 68% greater for MOR, and 22% greater for SG, compared with juvenile wood values. Mean wood property values in the two plantations were generally greater than those in the natural stand.

518 Simon, J.-P.; Bergeron, Y.; Gagnon, D. 1986. Isozyme uniformity in populations of red pine (*Pinus resinosa*) in the Abitibi region, Quebec. Can. J. For. Res. 16:1133–1135.

The genetic structure of six red pine (*Pinus resinosa* Ait.) populations was examined at their northern limit in Quebec where they were affected by different fire disturbance episodes. The six populations comprised 124 trees from 10 to 226 years old. The genetic variability was estimated from the electrophoretic analysis of four isozyme systems, namely esterases, peroxydases, superoxide dismytase, and

acid phosphates. Electropherograms of needle extracts from all 124 trees showed identical isozyme patterns for each of the four enzyme systems examined. Data accumulated to date indicated that red pine was low in variation throughout a large area of its range. Additional analyses were recommended to further test whether the species was genetically uniform within its entire North Amercan range.

519 Simpson, E., comp. 1996. Old growth red and white pine forests: northwest region report on protection. TR-98. OMNR, Northwest Science and Technology, Thunder Bay, ON. 32 p.

The policy on conserving old-growth red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.) in Ontario required that a certain number of old-growth areas be identified and protected from harvest in northwestern Ontario. Despite challenges unique to the region, red and eastern white pine old-growth candidate areas were identified, and some new areas were conserved. During the selection process, red and eastern white pine stands >120 years old were included if they had a species composition of >40% eastern white–red pine and their level of disturbance recorded. All stands in the northern part of the region were conserved if they met these criteria. Southern stands were prioritized where more than one potential candidate stand occurred per physiographic unit in each site district.

520 Sims, D.H. 1986. Eastern white pine in the southern highlands. Pages 115–117 *in* D.T. Funk, comp. Eastern white pine: today and tomorrow. Symposium proceedings, Durham, NH, 12–14 June 1985. Gen. Tech. Rep. WO-51. USDA For. Serv., Northeastern For. Exp. Stn., Durham, NH. 124 p.

Eastern white pine (*Pinus strobus* L.) ranges southward into portions of the Appalachian Highlands, the western Piedmont of Virginia, North and South Carolina, and the northeastern Piedmont of Georgia. With proper management, eastern white pine in the south would yield a higher volume of timber than its associated tree species. Plantation growth was influenced strongly by initial spacing and site quality. Eastern white pine in the southeast had relatively few problems with insects and diseases when compared with other southern pines and with eastern white pine in some other regions.

521 Sims, H.P.; Campbell, G.D. 1970. Red pine seedfall in a southeastern Manitoba stand. Publication No. 1267. Department of Fisheries and Forestry, Canadian Forestry Service, Ottawa. 8 p.

Red pine (*Pinus resinosa* Ait.) seed dispersal and quality were recorded in a partially harvested 2-ha stand in southeastern Manitoba. Seed traps were used to collect seed annually from 1957 to 1967. Throughout the decade, seedfall volume decreased from a heavy crop in 1957 to a crop failure in 1966. Maximum seed dispersal occurred during the fall. Seed quality varied directly with seed quantity. It was very difficult to predict a good seed year for red pine.

522 Slankis, V.; Runeckles, V.C.; Krotkov, G. 1964. Metabolites liberated by roots of white pine (*Pinus strobus* L.) seedlings. Physiol. Plant. 17:301–313.

The metabolites exuded by intact roots of eastern white pine (*Pinus strobus* L.) seedlings were investigated. Eastern white pine seedlings were grown with their intact roots aseptically in a nutrient solution for nine months. When aerial parts of the seedlings were supplied with C^{14}-labeled carbon dioxide for eight days, the roots liberated a complex mixture of more than 35 radioactive organic compounds. The major constituent exuded was malonic acid. The presence of malonic acid in the root exudate could be an important factor in determining the species inhabiting the rhizospere by allowing species that have little capacity for synthesizing the aromatic amino acids to compete more successfully.

523 Smidt, M.F.; Puettmann, K.J. 1998. Overstory and understory competition affect underplanted eastern white pine. For. Ecol. Manag. 105:137–150.

The effect of shelterwood harvesting and understory competition on 3–10-year-old underplanted eastern white pine (*Pinus strobus* L.) seedling growth in six different stand types (on the basis of residual canopy composition) was investigated in north central Michigan. When shade-tolerant softwood species were present in the canopy, lowering overstory basal area had a positive impact on the growth of eastern white pine seedlings. Reducing residual basal area in the absence of shade-tolerant species produced marginal if any eastern white pine seedling growth. The presence of a shade-tolerant midstory of balsam fir (*Abies balsamea* (L.) Mill.) probably was a major factor causing reduced growth of eastern white pine seedlings. Recommendations were made to remove sufficient canopy to create the minimum adequate light level for eastern white pine with complete removal of the understory by scarification and herbicide application.

524 Smith, D.J.; Woods, M.E. 1997. Red pine and white pine density management diagrams for Ontario. SCSS Tech. Rep. No. 48. OMNR, Southcentral Sciences Section, North Bay, ON. 31 p.

Density management diagrams (DMDs) were developed for red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.) that could serve as guidelines for thinning

even-aged pine plantations. DMD figures relate changes of mean tree size to stand density using logarithmically transformed axes, and are essentially a stocking chart for even-aged pure species stands that quantify the dynamic nature of stand development. Data obtained from four red pine and six eastern white pine plantations were used in the calibration of the DMDs, and the DMDs incorporated quadratic mean diameter at breast height, stand density, mean total tree volume, and top (or dominant) height. Basic assumptions accompanying the interpretation of the DMD and examples of the utility of the DMD were described.

525 Smith, D.M. 2003. Effect of method of thinning on wood production in a red pine plantation. North. J. Appl. For. 20:39–42.

A thinning study in a 37-year-old red pine (*Pinus resinosa* Ait.) plantation in southwestern New Hampshire was assessed to determine the effects of different thinning methods on total cubic volume production when residual basal areas were the same. The three thinning treatments tested were thinning from below, crown thinning, and selection thinning. After 12 years, no significant effects were found, although the selection thinning resulted in the highest production. At age 40, *Heterobasidium annosum* (Fr. : Fr.) Bref., the fungus that causes root rot, was first observed in the plantation, and by age 49, the study was terminated because the rot-disease mortality had caused some large gaps in the canopy.

526 Smith, D.M.; Larson, B.C.; Kelty, M.J.; Ashton, P.M.S. 1996. The practice of silviculture: applied forest ecology. John Wiley and Sons, New York, NY. 9th edition. 537 p.

The ninth edition in this series is an extensive review of silviculture practices with a greater focus on forest ecology compared with the previous editions. This edition contains chapters on watershed and wildlife management as well as silvicultural control of damaging agents. Aside from the ecological aspects, thinning and release practices and the expected responses were discussed as well as regeneration practices and stand development and structure for both even- and uneven-aged stands. Silvicultural management objectives were examined including timber production systems and agroforestry.

527 Smith, D.M.; Seymour, R.S. 1986. Relationship between pruning and thinning. Pages 62–66 *in* D.T. Funk, comp. Eastern white pine: today and tomorrow. Symposium proceedings, Durham, NH, 12–14 June 1985. Gen. Tech. Rep. WO-51. USDA For. Serv., Northeastern For. Exp. Stn., Durham. NH. 124 p.

Pruning of eastern white pine (*Pinus strobus* L.) was discussed in combination with thinning treatments. For the production of good quality eastern white pine timber, artificial pruning and severe and very early thinning were recommended to ensure rapid diameter growth. But heavy thinning before pruning and schedules for subsequent thinning should be aimed at optimizing financial returns and not just maximizing cubic volume production. Stand density guidelines for thinning were developed. Data for the guidelines were based on tree observations at the Yale Forest in southeastern New Hampshire where trees had been pruned up to 5.2 m.

528 Smith, I.; Chui, Y.H. 1994. Factors affecting mode I fracture energy of plantation-grown red pine. Wood Sci. Technol. 28:147–157.

Factors were studied that affect mode I fracture energy of red pine (*Pinus resinosa* Ait.). Mode I stress is applied normal to the longitudinal (grain) direction, and crack growth is in the longitudinal direction. Flat-sawn boards were sampled from three premature red pine that had been grown in a plantation in southwestern New Brunswick. Specimens were tested at nominal moisture contents ranging from 7 to 24% with specimens in green condition included as a control. Fracture energy was influenced by moisture content at test and by the direction in which stress was applied in the radial-tangential plane. Secondary influences of moisture conditioning and density on fracture energy were observed with the severity related to the moisture content of the test material.

529 Smyth, J.H.; Methven, I.R. 1978. Application of a numerical index to quantify the aesthetic impact of an improvement cut in pine mixedwoods. Department of the Environment, Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. Information Report O-X-270. 12 p.

A numerical aesthetic index was developed and applied after partial harvesting in a 127-ha field study in pine (*Pinus* spp.) mixedwoods at Petawawa, Ontario. The index measured people's perspectives on various management techniques and harvesting methods. The stands that received partial harvesting maintained high and favorable aesthetic values. The two variables that contributed most toward a decrease of the aesthetics value of stands were overstory species diversity and forest view. This index could be applied in both the planning stages and in postoperation assessments.

530 Spencer, J.S., Jr.; Leatherberry, E.C.; Hansen, M.H. 1992. White pine: status in Lake States forests. Pages 54–63 *in* R.A. Stine and M.J. Baughman, eds. White pine symposium proceedings: history, ecology, policy and management, Duluth, MN, 16–18 September 1992. University of Minnesota, Extension Service Distribution Center, St. Paul, MN. 202 p.

Forest inventory data from the Lake States (Minnesota, Wisconsin, and Michigan) were used to examine the eastern white pine (*Pinus strobus* L.) resource. Since about 1977, the total area of eastern white pine increased by 28% or 44 000 ha. This trend was likely to continue. During the same period, eastern white pine growing stock volume gained 35%, from 28.3 to 39.6 million m^3. In 1992, net annual growth of eastern white pine in the Lake States was estimated at 1.3 million m^3, an increase of 0.4 million m^3. When there was a decrease in eastern white pine stock in an area, disease incidence was identified as the primary cause.

531 Squiers, E.R.; Klosterman, J.E. 1981. Spatial patterning and competition in an aspen–white pine successional system. Am. J. Bot. 68:790–794.

The spatial patterning of competition was decribed between largetooth aspen (*Populus grandidentata* Michx.) and invading eastern white pine (*Pinus strobus* L.) in a 65-year-old forest in northern Michigan, and suggestions were presented on the mechanisms that would explain the successional patterns regarding adaptive strategies. Tree density, diameter, and distance measurements were used to construct various indices to analyze nearest neighbor interactions. A strong pattern of aggregation for largetooth aspen and eastern white pine was observed. A regularity of pattern for eastern white pine in relation to nearest neighbor was apparent and was attributed to the influence of the competing clonal largetooth aspen.

532 Stanosz, G.R.; Smith, D.R.; Albers, J.S. 2005. Surveys for asymptomatic persistence of *Sphaeropsis sapinea* on or in stems of red pine seedlings from seven Great Lakes region nurseries. For. Pathol. 35:233–244.

The potential range in frequency was examined for asymptomatic *Sphaeropsis sapinea* (Fr. : Fr.) Dyko & B. Sutton, a fungal pathogen that causes collar rot and mortality. Sampling of bare-root red pine (*Pinus resinosa* Ait.) seedlings was completed at seven nurseries in Michigan, Minnesota, and Wisconsin. In spring 2002, five groups of 20 asymptomatic seedlings were collected at each nursery near a red pine windbreak if present, and another five groups were collected away from the windbreak. A total of 1400 seedlings were sampled for the disease. In 2003, one Minnesota nursery was sampled more extensively and 525 seedlings were collected. Evidence of the disease was found in all nurseries in Minnesota and Wisconsin, but no evidence was found in Michigan. A greater number of infected seedlings were near windbreaks that contained diseased trees. Removing diseased red pine windbreaks and replacing them with healthy alternative species might reduce or eliminate the risk of *S. sapinea* contraction and spread, as well as reduce the need to apply fungicides.

533 Stearns, F. 1992. Ecological characteristics of white pine. Pages 10–18 *in* R.A. Stine and M.J. Baughman, eds. White pine symposium proceedings: history, ecology, policy and management, Duluth, MN, 16–18 September 1992. University of Minnesota, Extension Service Distribution Center, St. Paul, MN. 202 p.

The biological and ecological characteristics of eastern white pine (*Pinus strobus* L.) were described as well as the relationships between eastern white pine and its associates in northern forests with particular reference to Ontario and the Lake States. Eastern white pine was most successful on well-drained sandy or sandy loam soils in the Lake States and Ontario, but it was capable of growth under a wide range of soil and moisture conditions. Eastern white pine regeneration was favored by disturbance, and early seedling growth was favored by a light overstory. The versatility of eastern white pine was described from it being a pioneer species to a member of the aspen (*Populus* spp.), white birch (*Betula papyrifera* Marsh.), or oak (*Quercus* spp.) communities to a prominent member of the tolerant hardwood forests in the Lake States and Ontario.

534 Stewart, B. 1995. A survey of weevil damage in white pine plantations in Nova Scotia. For. Res. Rep. No. 53. Nova Scotia Department of Natural Resources, Forestry Branch, Truro, NS. 12 p.

Plantations were surveyed in Nova Scotia in 1991 and 1992 to determine the extent of white pine weevil (*Pissodes strobi* (Peck)) infestations, the influence of tree spacing on white pine weevil damage, and the height at which eastern white pine (*Pinus strobus* L.) was susceptible to attack. A total of 25 eastern white pine plantations were sampled using two to seven 4.0-m-radius circular plots per plantation. On average, 83% of the sampled trees were attacked at least once. No correlation was found between spacing and frequency of attack. The attack height for trees >5.5 m peaked between 2.6 and 5.0 m. The sampled trees were not tall enough to examine the trend beyond 5 m, and therefore a height at which injury rates decline could not be determined. Porcupines (*Erethizon dorsatum* (Linnaeus)) were the only other damaging agent recorded in the survey, and they caused a variety of damage including the loss of limbs in the live crown, large trunk scars, and stem girdling, resulting in top kill which destroyed the merchantable value of the tree.

535 Stiell, W.M. 1960. Taper curves and volume tables for plantation red pine. Tech. Note No. 90. Department of Northern Affairs and National Resources, Forestry Branch, Ottawa. 18 p.

Taper curves and volume tables were presented for red pine (*Pinus resinosa* Ait.) plantations in southern Ontario.

Data were collected from pure red pine plantations with an average tree spacing of 1.8 m and from 17 to 35 years from planting. Measurements were taken from full-length felled and limbed trees. The diameter range sampled was 7.6–25.4 cm, and the height range was 7.6–18.3 m. The taper curves were considered useful primarily for estimating the numbers of roundwood products in trees of different size.

536 Stiell, W.M. 1964. Twenty-year growth of red pine planted at three spacings. Publication No. 1045. Department of Forestry, Ottawa. 24 p.

A spacing trial of red pine (*Pinus resinosa* Ait.) was planted on sandy soils at Petawawa, Ontario, to examine development of young red pine plantations in relation to spacing. Initial spacings were 2.1 × 2.1, 3.0 × 3.0, and 3.7 × 3.7 m. Measurements were taken every 5 years for 20 years to determine tree heights and diameters. After 20 years, form class, crown size, and branch numbers were recorded. Mean heights were the same at all spacings. Trees at a wider spacing showed larger crowns, thicker branches, greater diameters, and lower form class. Greater basal area and volume per hectare were obtained at the closer spacing.

537 Stiell, W.M. 1967. Plantation volume estimates from two stand parameters. Publication No. 1199. Department of Forestry and Rural Development, Ottawa. 15 p.

Data from 45 permanent sample plots in red pine (*Pinus resinosa* Ait.) plantations (10–38 years old) and from 45 permanent sample plots in white spruce (*Picea glauca* (Moench) Voss) plantations (12–40 years old) were used to study methods of estimating volumes. Volume per hectare in plantations of red pine and white spruce were highly correlated with simple expressions combining numbers of trees per hectare with either dominant height or average diameter. Regression curves were presented to show these relationships. The expressions used in conjunction with appropriate volume tables could also be applicable to even-aged natural stands.

538 Stiell, W.M. 1968. Thinning technique improves quality of white pine stands. Can. For. Ind. 88:54–56.

At Petawawa, Ontario, white pine (*Pinus strobus* L.) was planted at the very close spacing of 0.7 × 0.7 m to reduce white pine weevil (*Pissodes strobi* (Peck)) damage. A total of 544 trees per hectare were chosen as potential crop trees and they were pruned up to the live crown (3.7–4.6 m). After 19 years, trees were thinned gradually over 5 years by girdling at stump height and left standing. One plot was left unthinned as a control. The thinning was successful at releasing the better-quality stems with little white pine weevil damage, but the high establishment and thinning treatment costs made this approach an expensive option.

539 Stiell, W.M. 1969. Stem growth reaction in young red pine to the removal of single branch whorls. Can. J. Bot. 47:1251–1256.

Single whorls of branches were removed from red pine (*Pinus resinosa* Ait.) trees that were growing in a plantation to examine tree stem growth reactions to whorl removals. Measurements of stem diameter were taken between whorls and at intervals below the crown and were used to evaluate growth at these points. Growth of an internode in the crown was influenced mainly by the whorl immediately above it. Growth of the stem just below the crown depended heavily on all whorls. Whorl foliage did not postively influence the development of either the current or previous year's leader extension, both of which probably depended on stem needles.

540 Stiell, W.M. 1970. Some competitive relations in a red pine plantation. Publication No. 1275. Department of Fisheries and Forestry, Canadian Forestry Service, Ottawa. 10 p.

The competitive effects of tree crowns and roots were investigated at Petawawa, Ontario, in 13-year-old red pines (*Pinus resinosa* Ait.) planted on deep sand at 1.5 × 1.5 m and 2.1 × 2.1 m spacings after trees were released using various methods. Treatments consisted of tree removal, root thinning (roots were killed but trees were retained for light competition), top thinning (the tree top was removed but the rest of the tree remained), negative thinning (adding tops of trees for light competition), and control. The position of neighboring trees strongly influenced tree growth. The effects of root competition could not be explained fully until the root systems were examined using hydraulic excavating, which showed extensive grafting and widely distributed individual tree root systems.

541 Stiell, W.M. 1971. Comparative cone production in young red pine planted at different spacings. Publication No. 1306. Department of the Environment, Canadian Forestry Service, Ottawa. 8 p.

An 18-year-old red pine (*Pinus resinosa* Ait.) stand at Petawawa, Ontario, with spacings ranging from 1.2 × 1.2 m to 4.3 × 4.3 m was assessed to obtain information on the relationship between spacing and cone production. During its first heavy cone crop, cone counts took place between August 31 and September 18 and they were summarized by tree size. Cones were produced on nearly all live whorls, which meant that at wider spacings the trees produced more cones because those trees had more live whorls. In a spacing treatment, more cones were found

on trees with a larger diameter and no cones were found on trees with a diameter < 5 cm.

542 Stiell, W.M. 1978a. Characteristics of eastern white pine and red pine. Pages 7–50 *in* D.A. Cameron, comp. White and red pine symposium, Chalk River, ON, 20–22 September 1977. Symposium Proceedings O-P-6. Department of the Environment, Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. 178 p.

A review of the silvicultural characteristics of eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.) based mainly on previously published literature was prepared with special references to Canadian conditions. The species requirements and the associated forest management implications were outlined and discussed. The review includes a discussion on a range of topics such as distribution, taxonomy and genetics, environmental factors, seed production, morphology, growth and yield, and damage.

543 Stiell, W.M. 1978b. How uniformity of tree distribution affects stand growth. For. Chron. 54:156–158.

Part of a 13-year-old red pine (*Pinus resinosa* Ait.) plantation was thinned to leave stems uniformly distributed, and another part was thinned to leave the same numbers of stems but in equally spaced four-tree clumps to determine how different tree distributions affect stand growth. Ten years after treatment, the trees in clumps showed smaller crowns, lower growth in diameter at breast height and basal area per hectare, and higher form class. No significant differences in volume per hectare between treatments were found. As long as a certain number of trees per hectare were retained, uniform spacing was not critical for maintaining growth. Clumps of five trees or more would almost certainly cause reductions in growth.

544 Stiell, W.M. 1979. Releasing unweeviled white pine to ensure first-log quality of final crop. For. Chron. 55:142–143.

An eastern white pine (*Pinus strobus* L.) plantation planted in 1939 with a spacing of 0.7 × 0.7 m, an extremely close spacing to minimize white pine weevil (*Pissodes strobi* (Peck)) damage, was precommercially thinned at age 19 leaving an unthinned plot as a control. The released trees grew well and mortality was low. The unthinned control plot continued to have a high rate of mortality (only 18% survival by 1977), especially in the lower white pine weevil-attacked crown classes under the larger white pine weevil-free trees. The approach used here could be feasible for application in natural stands but would involve the cost of thinning dense areas of natural eastern white pine regeneration.

545 Stiell, W.M. 1982. Growth of clumped vs. equally spaced trees. For. Chron. 58:23–25.

A thinning experiment at Petawawa, Ontario, in a 13-year-old red pine (*Pinus resinosa* Ait.) plantation was designed to compare growth of uniformly spaced trees with that of trees in four-tree clumps, in both cases leaving the same average tree density or number of trees per hectare at 890 trees per hectare. After 15 years, both stands showed the same crown size, form class, and height, but the clumped trees showed less diameter at breast height, basal area, and total volume per hectare growth. Stand volume would likely be reduced more as the size of clumps increased, and therefore it was recommended that clumps be not larger than three trees.

546 Stiell, W.M. 1984. Improvement cut accelerates white pine sawlog growth. For. Chron. 60:3–9.

In a mixedwood stand on till soils at Petawawa, Ontario, understory eastern white pine (*Pinus strobus* L.) was released by removing the hardwood overstory to promote the development of sawlog-sized eastern white pines. The overstory was 80 years old at the time of release, and the understory was 55 years old. All species larger than 9 cm diameter at breast height, except for healthy overstory and understory pine (*Pinus* spp.) and white spruce (*Picea glauca* (Moench) Voss), were cut. After treatment, the plots were set up at three levels of pine basal area, averaging 6.9, 11.5, and 16.1 m^2/ha. Ten years after the harvest, trees were remeasured, and basal area and volume growth assessed. Volume growth increased directly with tree density. The release treatment increased growth of eastern white pine compared with the control plots by up to 30 m^3/ha in 10 years for mid-density treated plots and by an estimated 71 m^3/ha in 20 years.

547 Stiell, W.M. 1985a. The Petawawa red pine plantation trials. Pages 204–215 *in* R. Marty, ed. Managing red pine. Proceedings of the second region V technical conference, Society of American Foresters. SAF Publication 85-02. Bethesda, MD.

This paper provided an overview of the red pine (*Pinus resinosa* Ait.) spacing trials set up at Petawawa, Ontario. An area of about 135 ha was planted with red pine between 1926 and 1953, which was one third of the reforestation program during this time, at spacings ranging from 1.2 × 1.2 m to 6.1 × 6.1 m. The main purpose of the spacing trials was to assess the development of these plantations on local soils at a variety of spacings. Permanent sample plots were set up and remeasured periodically. Yield tables were created on the basis of the spacing trials, and one such table was included in this paper. Thinning studies were initiated to examine the response and the competitive status of individual trees. Plantaton trials were also

set up for tree improvement and genetic studies, which included provenance tests and single-tree progeny tests.

548 Stiell, W.M. 1985b. Silviculture of eastern white pine. Proc. Entomol. Soc. Ont. 116(Suppl):95–107.
Many aspects of the silviculture of eastern white pine (*Pinus strobus* L.) were described including its growth characteristics, site implications, natural regeneration, thinning, and pest management. Controlling competing vegetation is difficult because it can develop overtop and whip the eastern white pine, but it needs to provide the pine with a certain degree of shade to prevent serious white pine weevil (*Pissodes strobi* (Peck)) damage. The selection of crop trees should be made when the trees reach a height of one log length, and there should be approximately 370 undamaged stems per hectare. Some methods for controlling white pine weevil and white pine blister rust (*Cronartium ribicola* J.C. Fischer), the two major pests damaging eastern white pine, were discussed.

549 Stiell, W.M. 1988. Consistency of cone production in individual red pine. For. Chron. 64:480–484.
A young red pine (*Pinus resinosa* Ait.) plantation at Petawawa, Ontario, produced heavy cone crops in 1970 and 1984. This study compared the two cone crops and an individual tree assessment at the two dates, and examined the relation of tree crop size to stem diameter and to subsequent diameter growth. The stand was set up as a spacing trial with square spacings ranging from 1.2 to 6.5 m. Cone counts were made on selected trees in each of six spacings, and in each case, distributed throughout the range of stem diameters. Regression analysis was used to relate cone crop size to tree size at both dates and to compare 1984 with 1970 crop size. The largest trees did not necessarily produce the most cones, and high cone production did not influence tree growth. High cone producers in 1970 were also the best producers in 1984, and therefore cone production should focus on those high-yielding individuals.

550 Stiell, W.M. 1994. Chronicle of white pine and red pine research at the Petawawa National Forestry Institute. For. Chron. 70:372–381.
The establishment of the first permanent sample plot in an eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.) stand at Petawawa, Ontario, in 1918 marked the first Canadian research on these species. All the research activities conducted on eastern white and red pine between 1918 and 1993 at Petawawa was summarized and presented in two parts. The first part was chronological through 1979 when the Petawawa Forest Experiment Station merged with the Forest Management and the Fire Research institutes to form the Petawawa National Forestry Institute. The second part described eastern white pine research programs and studies at Petawawa until 1993.

551 Stiell, W.M.; Berry, A.B. 1973. Yield of unthinned red pine plantations at the Petawawa Forest Experiment Station. Publication No. 1320. Department of the Environment, Canadian Forestry Service, Ottawa. 16 p.
Data from unthinned plantations of red pine (*Pinus resinosa* Ait.) with high levels of survival at Petawawa, Ontario, were used to develop and present yield tables by 5-year age classes to 50 years old from planting. The tables were based on 56 plots that were each measured one to five times and include information for eight spacings (ranging from 1.2 × 1.2 m to 4.3 × 4.3 m) and five site index classes. Each table provided a summary of the number of trees per hectare, mean diameter at breast height, and merchantable volume. Site index curves and diameter distribution data were also presented.

552 Stiell, W.M.; Berry, A.B. 1977. A 20-year trial of red pine planted at seven spacings. Department of the Environment, Canadian Forestry Service, Forest Management Insitute, Ottawa. Information Report FMR-X-97. 25 p.
The juvenile growth of red pine (*Pinus resinosa* Ait.) was examined using a spacing study near Petawawa, Ontario, involving seven spacing treatments ranging from 1.2 × 1.2 m to 4.3 × 4.3 m. The study was based on remeasurements of replicated sample plots, which were measured three times in a five-year interval. Further, some selected trees were remeasured for 10 consecutive years to follow crown and stem growth patterns. It was too early in their development to recommend one particular spacing over another, but early estimates of stand volume were presented covering a range of spacing treatments.

553 Stiell, W.M.; Berry, A.B. 1985. Limiting white pine weevil attacks by side shade. For. Chron. 61:5–9.
A study made between 1964 and 1982 at Petawawa, Ontario, investigated approaches of limiting the damage caused by white pine weevil (*Pissodes strobi* (Peck)). Strip cuts to provide side shade were aligned north–south to control the hours of daily sunlight falling on the strips. The widths of the strips were in relation to the surrounding stand height and varied to admit 25, 50, 75, and 100% of full sunlight. When surrounded by a pine (*Pinus* spp.)–mixedwood stand, the number of trees attacked by the white pine weevil increased with the amount of light available. The 50 and 75% of full light treatments allowed adequate numbers of healthy eastern white pine (*Pinus strobus* L.) to reach the height of one log length (4.9 m). Surrounding hardwood stands did not provide enough side shade in early spring when adult white pine weevils were active.

554 Stiell, W.M.; Robinson, C.F.; Burgess, D. 1994. 20-year growth of white pine following commercial improvement cut in pine mixedwoods. For. Chron. 70:385–394.
An understory of eastern white pine (*Pinus stobus* L.) in mixedwood stands at Petawawa, Ontario, was released from an 80-year-old overstory of intolerant hardwood to increase the growth and yield of eastern white pine for sawlogs during the following 20–30 years. Growth of the released, healthy eastern white pine was assessed after logging for a range of stand densities (basal area of 6.9, 11.5, and 16.1 m^2/ha) by measuring both partially harvested and control plots in a randomized complete block design with five replicates. Plots were measured 10 and 20 years after the release treatment. Understory species diversity was assessed and not affected. When species abundance was taken into account, herb diversity was higher in treated stands compared with control, and browse potential was not affected. The improved growth of the released eastern white pine after 20 years showed similar trends to those after 10 years. The release treatment essentially increased the natural rate of succession in these stands. Further management activities or wildfire would be needed to regenerate the study area to eastern white pine.

555 Stiell, W.M.; Von Althen, F.W. 1964. Revised taper curves and volume tables for plantation red pine. Publication No. 1075. Department of Forestry, Ottawa. 19 p.
The taper curves and volume tables for red pine (*Pinus resinosa* Ait.) plantations presented in Stiell (1960) (see annotation 535) were updated and presented here. Measurements were taken in pure red pine 17–48-year-old plantations in eastern Ontario with an average spacing of 1.8 × 1.8 m and with low mortality rates. The diameters ranged from 7.6 to 25.4 cm and the height from 7.6 to 22.9 m. All measurements were taken on full-length trees. This revised version provided improved estimates for large trees.

556 Stone, E.L.; Leaf, A.L. 1967. Potassium deficiency and response in young conifer forests in eastern North America. Pages 217–229 *in* Proceedings of the colloquium on forest fertilization, Jyväskylä, Finland. International Potash Institute, Bern, Switzerland.
Potassium deficiencies and responses in young conifer forests were described on very sandy soils on which K deficiencies, alone or in combination with Mg deficiencies, are common. Stands were studied in Quebec, Ontario, New York, and Connecticut, and K deficiencies were widespread on sandy soils. Growth responses to K fertilization were positive and lasting. Relationships between soil K and leaf K were discussed as well as the response of conifer trees to fertilization. Where stands were treated with K, there were some negative consequences because white pine weevil (*Pissodes strobi* (Peck)) attacks increased and red pine (*Pinus resinosa* Ait.) trees were more severely browsed by snowshoe hares (*Lepus americanus* Erxleben).

557 Stone, R.J.; Harou, P.A.; Mader, D.L.; Hunt, F.M. 1986. Economics of heavy thinning in eastern white pine plantations. Pages 70–74 *in* D.T. Funk, comp. Eastern white pine: today and tomorrow. Symposium proceedings, Durham, NH, 12–14 June 1985. Gen. Tech. Rep. WO-51. USDA For. Serv., Northeastern For. Exp. Stn., Durham, NH. 124 p.
The financial methodology necessary to determine the optimum intensity of thinning in eastern white pine (*Pinus strobus* L.) plantations was discussed and used to analyze the results of a thinning study. The study involved two eastern white pine plantations in central Massachusetts, which were established in 1940 on moderately well drained soils. The thinning treatments consisted of heavy thinning, moderate thinning, or control. The financial analysis indicated that on a good site, a heavy thinning provided a slightly higher net present worth than control or moderate thinning. On a poorer quality site, the two thinning regimes had a similar net present worth, but this was substantially higher than the control alternative.

558 Stratton, K.G.; Safford, L.O.; Struchtemeyer, R.A. 1968. Two fertilizer studies with white pine in Maine. Res. Life Sci. 6 p.
After some promising earlier results from forest fertilization studies in other areas, eight different fertilization treatments were applied to two eastern white pine (*Pinus strobus* L.) plantations in Maine. One plantation was 28 years old on a droughty, loamy sand, and the other was 20 years old growing on a sandy loam soil. A randomized block design was applied with the eight fertilizer treatments replicated four times. Fertilization treatment responses were influenced greatly by soil type. Tree growth responded positively to potassium fertilization on the coarse-textured droughty soil. Nitrogen fertilization alone did not increase growth, and no significant growth responses were measured on the sandy loam soil. The soil conditions should be considered when conducting fertilizer studies.

559 Stratton, K.G.; Struchtemeyer, R.A.1968. Evaluation of soil sites for white pine in Maine. Tech. Bull. 32. University of Maine, Maine Agric. Exp. Stn., Orono, ME. 17 p.
To provide information for evaluation of soil–site quality for eastern white pine (*Pinus strobus* L.), 55 eastern white pine sites 20–85 years old were selected in Maine and

sampled twice in two consecutive years. Basic stand data and soil samples were collected and analyzed and a detailed soil profile description was made. Age at breast height was used as the main variable affecting height. Site productivity decreased as soil pH increased in surface mineral horizons. Highest productivity occurred on moderately well drained to well-drained sites.

560 Streit, M. 1991. Response to thinning in a 50 year old white pine stand. FGF ONLINE. OMNR, Brockville, ON. 2 p.

A portion of a 50-year-old stand of eastern white pine (*Pinus strobus* L.), red pine (*P. resinosa* Ait.), and poplar (*Populus* spp.) on a sandy loam till site was thinned, which stimulated crown and seed development by releasing crop trees on two sides. Two plots were established, one in the thinned area and one in the control, unthinned area. The thinned portion of the stand showed increases in diameter growth, but minimal change in total height. The average basal area of the thinned plot five years after thinning was 20 m^2/ha, compared with 30 m^2/ha for the unthinned plot.

561 Struik, H. 1978. Tending of white pine and red pine. Pages 123–129 *in* D.A. Cameron, comp. White and red pine symposium, Chalk River, ON, 20–22 September 1977. Symposium Proceedings O-P-6. Department of the Environment, Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. 178 p.

An analysis of eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.) tending practices and problems was presented. Stand dynamics should be evaluated before harvesting as well as determining the plan for tending. Preplanting and postplanting release methods were described including mechanical and chemical approaches. Timing of release treatments and the influence of the original stand composition and site productivity on tending treatments were discussed. An overview of specific tending recommendations for eastern white and red pine management was presented.

562 Struve, D.K.; Blazich, F.A. 1982. Comparison of three methods of auxin application on rooting of eastern white pine stem cuttings. For. Sci. 28:337–344.

Eastern white pine (*Pinus strobus* L.) cuttings received different treatments of an indolebutyric acid (IBA) solution to determine whether the toothpick method was more effective in rooting eastern white pine stem cuttings than that obtained with concentrated basal dips or application of rooting powders. Treatments consisted of a toothpick soaked in 1000, 4500, or 8000 ppm IBA solution and then inserted in the stem cutting or cuttings treated with an 8000-ppm IBA rooting powder. Another experiment compared cuttings treated with a 10 000-ppm IBA solution for 30 seconds and cuttings treated with toothpicks soaked in a 1000-ppm IBA solution. Stem cuttings were observed for 13 months after treatment. Toothpicks soaked in a 4500- or 8000-ppm IBA solution initiated more roots per cutting than a 1000-ppm IBA solution. The toothpick method also proved to increase percentage rooting and induced more roots during a longer time period. The terminal shoot growth during the 13 months following initial rooting showed little correlation with root system morphology.

563 Struve, D.K.; McKeand, S.E. 1990. Growth and development of eastern white pine rooted cuttings compared with seedlings through 8 years of age. Can. J. For. Res. 20:365–368.

Container-grown rooted stem cuttings from 13 eastern white pine (*Pinus strobus* L.) clones were paired with open-pollinated bare-root seedlings to compare growth for eight years, and determine the association between rooted cutting growth and initial differences in root system quality. Root system quality, the number of roots, and root distribution were measured before and after planting in a randomized block design with three replicates. Survival and height were recorded each year. Rooted cuttings showed a higher survival rate and slightly better growth during the first three years, but after four growing seasons, rooted cuttings were significantly shorter than seedlings. Root system quality was not considered a significant factor affecting initial survival and growth in this eight-year study.

564 Struve, D.K.; Talbert, J.T.; McKeand, S.E. 1984. Growth of rooted cuttings and seedlings in a 40-year-old plantation of eastern white pine. Can. J. For. Res. 14:462–464.

Although tree improvement programs based on sexual reproduction have demonstrated significant gains in some instances, the use of vegetative propagation offers even greater potential if the propagation method has no negative effects on field performance. In 1982, two 37-year-old (40 years from propagation) plantations of eastern white pine (*Pinus strobus* L.) in Dane and Wood Counties, Wisconsin, were examined to compare the long-term performance of trees from rooted cuttings to seed origin trees. Height, diameter at breast height, and wood specific gravity were compared using a *t*-test. Survival and growth of rooted-cutting origin trees at age 40 were either higher or comparable to seedling origin trees at both sites. These results supported earlier shorter term studies of vegetatively propagated conifers.

565 Sucoff, E.; Hong, S.G. 1974. Effects of thinning on needle water potential in red pine. For. Sci. 20:25–29.
This study was initiated to determine whether water stress of needles varied between thinned and unthinned stands. Soil moisture and needle water potential were measured on trees in thinned and unthinned plots in an almost pure 18-year-old red pine (*Pinus resinosa* Ait.) stand, the growing season following thinning. The thinned portion (0.06 ha) had a basal area of 22.5 m^2/ha and 2960 trees per hectare. The unthinned portion of the stand had a basal area of 36.7 m^2/ha and 4270 trees per hectare. Soil moisture was always higher in the thinned plots; needle water potential was usually higher in the thinned plots, but only significantly on 4 out of 10 measurement days. On those four days, soil moisture was more available to the trees in the thinned plots. The trees in the thinned plots grew on average 36% faster than the trees in the control, unthinned plots.

566 Sullivan, C.R. 1960. The effect of physical factors on the activity and development of adults and larvae of the white pine weevil, *Pissodes strobi* (Peck). Can. Entomol. 92:732–745.
The influence of weather on the activity and development of adults and larvae of the white pine weevil (*Pissodes strobi* (Peck)) were studied to determine the needs of the insect and how to limit white pine weevil activity in eastern white pine (*Pinus strobus* L.) stands. Adult white pine weevils have two active periods per year, in spring when they lay their eggs, and in fall before they enter hibernation. Young, open-growing eastern white pine plantations at Petawawa, Ontario, were used for periodic observations of white pine weevil during spring and fall. Temperature and atmospheric moisture were the important physical factors affecting spring adult white pine weevil activity. The maximum activity of adults was on relatively clear, warm days with temperatures between 26 and 31°C and relatively low humidity levels. Larvae were more active on warmer days as well; they consumed more food and moved down the stems more rapidly. Fall adult white pine weevils were influenced chiefly by temperature, and the insects were less affected by changes in atmospheric moisture and solar radiation.

567 Sutton, A.; Staniforth, R.J.; Tardif, J. 2002. Reproductive ecology and allometry of red pine (*Pinus resinosa*) at the northwestern limit of its distribution range in Manitoba, Canada. Can. J. Bot. 80:482–493.
The influences of some biotic factors on seed and cone production in red pine (*Pinus resinosa* Ait.) populations at the extreme northwest of the species' range were examined on Black Island in Lake Winnipeg, Manitoba. This is the most northerly and westerly occurrence of red pine. The main objective was to evaluate differences among trees and crown portions in terms of cone production and seed characteristics and germination. Sixty red pine trees were selected and height, diameter at breast height, age, and crown (divided into four portions) were measured and the number of cones counted for each tree. Mature cones were collected in September and seed was extracted. The total number of cones produced per tree was correlated positively with tree diameter, basal area increments, and crown area. Total number of cones per crown portion was increased with the longest living branch length, bole length, crown portion area, and nearest neighbor tree distance. Seed characteristics were influenced by cone characteristics; larger cones contained more and larger seeds than smaller cones.

568 Syme, P.D. 1985. Eastern white pine in Ontario: its entomological, pathological, physiological and other problems. Proc. Entomol. Soc. Ont. 116(Suppl.):21–31.
A total of 277 insects and 110 disease organisms have been identified that inhabit eastern white pine (*Pinus strobus* L.). Fifty-six of those organisms were reviewed in this report, although only 16 insects and 7 diseases caused serious injury or damage to eastern white pine. The insects and diseases were divided into groups depending on what portion of the tree they affected. Information on their life history and their effect on the tree form or health was presented. Surveys showed that white pine blister rust (*Cronartium ribicola* J.C. Fischer), white pine weevil (*Pissodes strobi* (Peck)), and armillaria root rot caused by the fungus *Armillaria mellea* (Vahl ex Fr.) Kummer were the three most important threats to eastern white pine in Ontario. Overall, eastern white pine in Ontario appeared to be in a healthy state.

569 Szuba, K.; Pinto, F. 1991. Natural history of the white pine weevil and strategies to decrease its damage to conifers in Ontario. COFTDU Tech. Rep. No. 13. OMNR, Central Ontario Forest Technology Development Unit, North Bay, ON. 60 p.
An extensive literature review on white pine weevil (*Pissodes strobi* (Peck)) was presented to combine detailed information on white pine weevil biology, the nature of its damage, and the strategies for control in a single reference document. A background on white pine weevil was provided including favorable host species (eastern white pine, *Pinus strobus* L.; Norway spruce, *Picea abies* (L.) Karst.; and jack pine, *Pinus banksiana* Lamb.) and effects on log volume and quality. Several methods of control were described with special attention on natural control and silvicultural control, but genetic improvement of planting stock and chemical control were also included. Possibly data collected in the annual forest insect and disease surveys could be used to develop a hazard rating system for the white pine weevil.

570 Tappeiner, J.C., II. 1971. Invasion and development of beaked hazel in red pine stands in northern Minnesota. Ecology 52:514–519.

Six red pine (*Pinus resinosa* Ait.) stands in northern Minnesota with a beaked hazel (*Corylus cornuta* Marsh.) understory were studied to assess how beaked hazel became established and developed a dense undergrowth. Litter and soil were removed in 12×12 m plots to expose underground stems. The expansion of beaked hazel distribution in the stands was occurring by seeding, and there was no evidence that seedlings had reproduced vegetatively. Dense undergrowths were formed by a coalescence of many individual clones. Underground beaked hazel stems did not spread far or rapidly.

571 Tester, J.R.; Starfield, A.M.; Frelich, L.E. 1997. Modeling for ecosystem management in Minnesota pine forests. Biol. Conserv. 80:313–324.

A model of forest succession was developed and examined to aid in the restoration of the pine (*Pinus* spp.) forest ecosystem in Itasca State Park in northwestern Minnesota. The model was based on the forests of northern Minnesota, which included eastern white pine (*Pinus strobus* L.) and northern hardwoods. Current understanding of seedling establishment, tree growth, competition, herbivory, and the effects of fire and high winds were described and used in model development. The overall simulation model consisted of five components corresponding to the key successional stages. The model was tested at three sites in northern Minnesota and proved useful for examining possible strategies for maintaining midsuccessional eastern white pine forests.

572 Thomas, P.A.; Wein, R.W. 1985a. The influence of shelter and the hypothetical effect of fire severity on the postfire establishment of conifers from seed. Can. J. For. Res. 15:148–155.

The influence of artificial and natural shelter on emergence of conifers was assessed at two clearcut sites near Fredericton, New Brunswick. Prescribed burnings were conducted and seven plots with four subplots were established on each site. Three subplots per plot were artificially sheltered (25, 50, and 75% cover) with wooden slatted screens, leaving the fourth subplot unsheltered. All subplots were sown with seed of jack pine (*Pinus banksiana* Lamb.), eastern white pine (*P. strobus* L.), balsam fir (*Abies balsamea* (L.) Mill.), and black spruce (*Picea mariana* (Mill.) BSP). On one site, randomly selected plots were naturally sheltered by shrubs and sown with seed of red pine (*Pinus resinosa* Ait.), balsam fir, and black spruce. The number of seedlings increased with the intensity of artificial shelter. Increased natural shelter did not affect red pine but increased the number of jack pine and black spruce seedlings. A hypothetical model was created in which fire severity was related to the establishment of the five tree species mentioned.

573 Thomas, P.A.; Wein, R.W. 1985b. Delayed emergence of four conifer species on postfire seedbeds in eastern Canada. Can. J. For. Res. 15:727–729.

The hypothesis that seeds of different conifer species differ in their ability to survive burial after several seasons was tested by comparing the emergence of jack pine (*Pinus banksiana* Lamb.), eastern white pine (*P. strobus* L.), black spruce (*Picea mariana* (Mill.) BSP), and balsam fir (*Abies balsamea* (L.) Mill.) for three seasons after sowing on two postfire seedbeds. The two study sites were near Fredericton, New Brunswick. A 3-ha area was burned on each site, and the sites lost their surface litter in the fire. On each burned area, twenty-eight 1-m^2 plots were established and 300 seeds of each of four conifer species were sown in each plot on separate 25×25 cm sowing areas. Less than 20% of all viable seeds produced emergent seedlings during the first season. Emergence continued in the second season, but no emergents were recorded in the third season. Both jack pine and black spruce emergents were abundant in the second season. Eastern white pine and balsam fir showed no delayed emergence, but they can produce and release seeds during most of their life span. Establishment of a new stand of eastern white pine or balsam fir does not depend on rapid colonization after only one catastrophic event.

574 Thor, E. 1965. Variation in some wood properties of eastern white pine. For. Sci. 11:451–455.

Earlier work on variations in wood properties of southern species had been done using mainly loblolly (*Pinus taeda* L.) or slash pine (*P. elliottii* Engelm.). This study investigated the wood properties of eastern white pine (*P. strobus* L.) using 31 sample trees growing in Morgan County, Tennessee. Selected trees were of good breeding type and all were considered superior in health, straightness, pruning, and branching habit. Sample trees ranged from 34 to 75 years old. Wood samples were taken at breast height using an increment borer and then were analyzed for their wood properties. Extractives accounted for 8.4% of the unextracted weight of young wood (10–20 years from the pith) and 7.2% of the older wood (20–30 years from the pith). Generally, the growth differences did not account for a large proportion of the variation in wood properties.

575 Tlusty, W.G. 1992. Visual and recreational values of white pine. Pages 84–97 *in* R.A. Stine and M.J. Baughman, eds. White pine symposium proceedings: history, ecology, policy and management, Duluth, MN,

16–18 September 1992. University of Minnesota, Extension Service Distribution Center, St. Paul, MN. 202 p.
Eastern white pine (*Pinus strobus* L.) for many people symbolizes the northwoods from a recreational and natural forest perspective. Current management practices for recreational forests were described here, and a new approach for managing the appearance of the forest was proposed. It consisted of a combination of previous approaches together with the incorporation of some new ideas. Some general management recommendations to increase aesthetics and recreational opportunties were made, which could be used as a recreational and visual value guide until additional research was completed.

576 Turnblom, E.C.; Burk, T.E. 2000. Modeling self-thinning of unthinned Lake States red pine stands using nonlinear simultaneous differential equations. Can. J. For. Res. 30:1410–1418.
A system of simultaneous differential equations incorporating logical, linked hypotheses regarding growth and mortality was proposed and data applied from red pine (*Pinus resinosa* Ait.) plantations in the Lake States. Data was used from a total of 28 plots that were situated in 10 different red pine plantations each measured between 4 and 11 times. Initial stand densities ranged from 1240 to 24 700 trees per hectare, and initial plot basal areas ranged from 1.38 to 75.31 m^2/ha. Stand ages ranged from 20 to 80 years. Stands with high initial densities exhibited lower self-thinning boundaries than stands with lower densities. Higher quality sites progressed through stand development at faster rates than lower quality sites.

577 Tworkoski, T.J.; Smith, D.W.; Parrish, D.J. 1986. Regeneration of red oak, white oak, and white pine by underplanting prior to canopy removal in the Virginia Piedmont. South. J. Appl. For. 10:206–210.
The effect of canopy removal was studied on survival and shoot growth of underplanted seedlings during the first three growing seasons after treatment. Red oak (*Quercus rubra* L.), white oak (*Q. alba* L.), and eastern white pine (*Pinus strobus* L.) were planted under a mixed-hardwood canopy in southern Virginia three years before canopy removal. There were three intensities of canopy removal: clear-felling, light shelterwood, and control. Each treatment covered at least one 0.4-ha area and was replicated four times. During the three years after treatment, all three tree species showed greater growth on the clearcut sites and slowest growth on control sites. Underplanting before harvest could be a viable tool for regenerating red and white oak or other midtolerant tree species. Eastern white pine was attacked heavily by white pine weevil (*Pissodes strobi* (Peck)) the first year after canopy removal, but no further attacks were recorded after the first year. Once eastern white pine became physiologically adapted to the new environmental conditions, white pine weevil attacks were expected to be less likely.

578 Ursic, M.; Peterson, R.L.; Husband, B. 1997. Relative abundance of mycorrhizal fungi and frequency of root rot on *Pinus strobus* seedlings in a southern Ontario nursery. Can. J. For. Res. 27:54–62.
The degree of mycorrhizal occurrence and the relative abundance of each mycorrhizal type on eastern white pine (*Pinus strobus* L.) seedlings were assessed at a nursery in southern Ontario. A secondary objective was to measure the frequency of root rot on eastern white pine seedlings and examine relationships between occurrence of root rot and (1) overall mycorrhizal density and (2) density of specific mycorrhizal types. Five compartments were examined with three containing three-year-old seedlings and two containing two-year-old seedlings. A total of thirty 4 × 1 m plots were established randomly. The soil was a fine sandy loam with poorly developed horizons. Seedlings were carefully excavated, and 5-cm root segments were observed under a dissecting microscope at 20–80 times magnification. Mean values of mycorrhizal colonization were high for June, July, and August ranging from 88 to 93%. Five mycorrhizal fungi were identified on the eastern white pine seedlings. Root rot frequencies were significantly different between the two- and three-year-old seedlings in July but differed only marginally in August. No correlations were found between overall mycorrhizal densities and root rot ratings. Possible solutions for protecting seedlings from root rot include creating less favorable conditions for the formation of E-strain mycorrhizal associations, and trial inoculations with some basidiomycete mycorrhizal fungi.

579 U.S. Department of Agriculture Forest Service. 1974. Seeds of woody plants in the United States. USDA For. Serv., Agriculture Handbook No. 450. Washington, DC. 883 p.
This book compiled information on seeds of forest species found in the United States. It was divided into two parts. Part one covered seed biology and also included seven chapters on the principles and general methods of producing and handling seeds. Part two was a compilation of seed data on 187 genera of woody plants including flowering and fruiting dates, seed processing methods, storage conditions, seed yields and weights, methods of breaking seed dormancy, germination tests, and a large collection of fruit and seed photographs. Both eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.) were included. Seed from the western part of the range of eastern white pine were lighter than seed from the eastern part, and seeds of southern origin required a longer stratification period than those of northern origin.

580 Van Arsdel, E.P. 1961. Growing white pine in the Lake States to avoid blister rust. Stn. Pap. 92. USDA For. Serv., Lake States For. Exp. Stn., St. Paul, MN. 11 p.
Procedures were presented for white pine blister rust (*Cronartium ribicola* J.C. Fischer) control that allowed for growing eastern white pine (*Pinus strobus* L.) with minimal losses to white pine blister rust at the lowest possible cost. Eradication of gooseberries and currants (*Ribes* spp.), alternate hosts of white pine blister rust, in the vicinity of eastern white pine was insufficient to control white pine blister rust in cool and wet areas. In addition, the selection of sites and manipulation of stands designed to make the stand environment unfavorable to the survival of the white pine blister rust fungus could be applied. Lack of moisture was a major limiting factor, but higher temperatures also limited infection. Some control methods that should have kept 95% of the trees rust free were presented and they included maintaining a closed canopy, pruning lower branches, and avoiding planting in small openings. The Lake States were divided into four hazard zones on the basis of their susceptibility to white pine blister rust, and a separate set of methods for controlling white pine blister rust were suggested for each zone.

581 Van Wagner, C.E. 1963. Prescribed burning experiments: red and white pine. Publication No. 1020. Department of Forestry, Ottawa. 27 p.
Procedures were examined for the further study of prescribed burning and to gather information about fire effects in red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.) stands. An 80-year-old red and eastern white pine stand near Petawawa, Ontario, was set up with eleven 0.1-ha plots, and they were burned in four series using different combinations of burning conditions. Fire behavior and intensity, and the effect of fire on trees in the stand were described as well as the effect of fire on shrubs, seedbed, and regeneration. Crown scorch of trees was a fair indicator of early mortality with overstory pines dying because of >75% crown scorch.

582 Van Wagner, C.E. 1968. Fire behaviour mechanisms in a red pine plantation: field and laboratory evidence. Publication No. 1229. Department of Forestry and Rural Development, Ottawa. 30 p.
Forest fire behavior was explored in red pine (*Pinus resinosa* Ait.) plantations near Petawawa, Ontario, through field experiments and laboratory trials. Plots, 0.05 and 0.13 ha, were set up, and nine experimental fires were started and observed under differing weather conditions. Three types of fires could be distinguished: surface fires burning against the wind, surface fires burning with the wind, and crown fires. Forty red pine needle fuel beds of various moisture contents and slopes were burned in the laboratory. The influence of several factors on fire spread was explored, and some predictive modeling for fire class behavior was developed. The general conclusion was that radiant heat was the primary means by which plantation fire spread. The main effect of fuel moisture content on fire behavior was one of delay, that is, the moister the fuel, the more time required to ignite it, and the slower the fire advanced.

583 Van Wagner, C.E.; Methven, I.R. 1978. Prescribed fire for site preparation in white and red pine. Pages 95–101 *in* D.A. Cameron, comp. White and red pine symposium, Chalk River, ON, 20–22 September 1977. Symposium Proceedings O-P-6. Department of the Environment, Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. 178 p.
The use of prescribed fire and its benefits were discussed on the basis of fire studies near Petawawa, Ontario. Prescribed fire seemed to be a successful method for preparing a seedbed not only for natural regeneration of red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.) but also for the control of competing vegetation. The fire should take place normally before leaf flush, when attempting to control hardwood competition. A fire before a good seed year was preferable, but waiting for a good seed year could severely complicate management scheduling. Prescribed fires could be applied at low cost, but it would be essential to plan and prepare for them well beforehand.

584 Von Althen, F.W. 1978. Artificial reforestation of a *Fomes annosus* infected red pine plantation. 1. Survival and early growth of natural and artificial hardwood and conifer regeneration. Department of the Environment, Canadian Forestry Service, Great Lakes Forest Research Centre, Sault Ste. Marie, ON. Information Rep. O-X-276. 12 p.
Reforesting harvested red pine (*Pinus resinosa* Ait.) plantations with a second generation of red pine was questioned because of losses caused by *Fomes annosus* (Fr. : Fr.) Cooke and *Gremmeniella abietina* (Lagerb.) Morelet. This study assessed their reforestation with hardwood species because of their low susceptibility to infections by *F. annosus* and their immunity to Gremmeniella canker. Six-year results were presented here. The study site was a 0.4-ha clearcut in a 59-year-old red pine plantation in Norfolk County, Ontario, that was infected by *F. annosus*. Natural regeneration of several hardwood species was recorded before and after logging in gaps created by red pine mortality. The spring following logging, red maple (*Acer rubrum* L.), sugar maple (*A. saccharum* Marsh.), tulip-tree (*Liriodendron tulipifera* L.), red oak (*Quercus*

rubra L.), white ash (*Fraxinus americana* L.), basswood (*Tilia americana* L.), black walnut (*Juglans nigra* L.), butternut (*J. cinerea* L.), eastern white pine (*Pinus strobus* L.), red pine (*P. resinosa* Ait.), and European larch (*Larix decidua* Mill.) were planted in a random mixture at an approximate spacing of 2.7 × 2.7 m. Logging killed 94% of the naturally regenerated eastern white pine seedlings. Six years after logging, natural regeneration of eastern white and red pine increased by 42 and 30 seedlings/0.04 ha, respectively. Planted eastern white pine grew well and had satisfactory survival, whereas red pine survived but grew poorly. Overall results showed that planting hardwood seedlings or a mixture of hardwood and coniferous seedlings could be a viable alternative to planting only coniferous seedlings in the reforestation of *F. annosus*-infected red pine plantations.

585 Von Althen, F.W.; Stiell, W.M. 1965. Twenty-three years of management in the Rockland red pine plantation. Publication No. 1123. Department of Forestry, Ottawa. 20 p.

Two 0.2-ha permanent sample plots were set up in a 6-ha red pine (*Pinus resinosa* Ait.) plantation near Rockland, Ontario, with an initial tree spacing of 1.8 × 1.8 m to serve as a demonstration forest. One plot received three thinning treatments and trees were pruned, whereas the other plot was left untreated as a control. Twenty-three years after planting, the plots were evaluated for survival, growth, form, development, and quality timber production. The thinned stand showed a lower basal area but an increase in diameter growth and a higher basal area growth per hectare. Height growth was not affected. Pruning and thinning had a positive effect on quality.

586 Von Althen, F.W.; Stiell, W.M. 1982. Update on the growth and yield of the Rockland red pine plantation. For. Chron. 58:211–212.

At age 67 from planting, the red pine (*Pinus resinosa* Ait.) plantation in Rockland in eastern Ontario was remeasured and the data analyzed and summarized. Average diameter in the thinned plot was 31.2 cm compared with an average diameter of 23.9 cm in the unthinned control plot. Height growth was similar in both plots. The mortality in the unthinned stand was high and stand quality was generally poor. Nevertheless, it still exceeded the merchantable volume estimate by 40% that was given for Plonski's site class 1 for natural red pine stands of the same age.

587 Von Althen, F.W.; Stiell, W.M. 1990. A red pine case history: development of the Rockland plantation from 1914 to 1986. For. Chron. 66:606–610.

Part of a 72-year-old red pine (*Pinus resinosa* Ait.) plantation near Rockland, Ontario, was thinned four times with a portion left unthinned. Development of the plantation was recorded for 48 years, and this publication summarized growth and yield during this time. Height growth essentially stopped between stand ages 67 and 72 years. The thinned part was a healthy stand with adequate growth (gross periodic increment of 38.6 m^3/ha), whereas the unthinned part had passed its optimal rotation age because mortality exceeded growth. The results confirmed earlier findings that thinning could salvage mortality and thereby increase net yield, but it could not increase the total volume production of a fully stocked stand.

588 Von Althen, F.W.; Stiell, W.M.; Forster, R.B. 1978. Effects of four thinnings on the growth, yields and financial returns of a 62-year-old red pine plantation. For. Chron. 54:253–260.

A 62-year-old plantation at Rockland, Ontario, was partly thinned four times between 1935 and 1972. Growth data were presented together with associated product yields and economic implications of alternative treatments. When based on current costs at the time of thinning, it was not proven that the thinning program would be profitable compared with planting and clearcutting. If the first thinning, which occurred during the 24th year, could have been delayed until it became less expensive or even paid for itself, a thinning program would have been more attractive. But differences between the two approaches of management were minimal.

589 Vose, J.M.; Swank, W.T. 1990. Assessing seasonal leaf area dynamics and vertical leaf area distribution in eastern white pine (*Pinus strobus* L.) with a portable light meter. Tree Physiol. 7:125–134.

The ability of a portable light meter (the Sunfleck Ceptometer) was evaluated to quantify seasonal photosynthetically active radiation (PAR) interception, projected stand leaf area index (LAI), and vertical LAI distribution in a 32-year-old eastern white pine (*Pinus strobus* L.) plantation. The ceptometer was sensitive to changes in PAR transmittance resulting from foliage growth, and predicted LAI values were within 9% of the values determined from destructive sampling. Because of interception by dead branches and stems, published canopy extinction coefficients were inadequate for converting PAR transmittance data to stand LAI. The ceptometer was also sensitive to seasonal changes in PAR transmittance in the canopy, although the relationship between proportional PAR transmittance and cumulative LAI in the canopy was linear.

590 Vose, J.M.; Swank, W.T. 1994. Effects of long-term drought on the hydrology and growth of a white pine plantation in the southern Appalachians. For. Ecol. Manag. 64:25–39.

Impacts of drought on an eastern white pine (*Pinus strobus* L.) stand and individual tree growth were assessed. A

significant drought effect occurred on the basal area increment of cored trees. Most growth occurred in spring and early summer during the drought, whereas growth was more uniform throughout the entire spring and summer during a wet year. Amounts of eastern white pine foliage litterfall were similar during the dry and wet periods, indicating little change between foliage production and senescence. The stand appeared well buffered against severe drought conditions. Precipitation–runoff relationships indicated less variation in evapotranspiration during the drought period than predicted by simulation modeling.

591 Wade, D.D.; DeBarr, G.L.; Barber, L.R.; Manchester, E. 1989. Prescribed fire—a cost effective control for white pine cone beetle. Pages 117–121 *in* D.C. MacIver, H. Auld, and R. Whitewood, eds. Proceedings of the 10th conference on fire and forest meteorology, Ottawa, ON, 17–21 April 1989. Forestry Canada and Environment Canada, Ottawa. 471 p.

The white pine cone beetle (*Conophthorus coniperda* (Schwarz)) is one of the most destructive seed and cone insects in North America. This study tested the effectiveness of prescribed fire at controlling the white pine cone beetle (WPCB) in a seed orchard in western North Carolina. A pilot burn and an operational burn were conducted in the spring of two consecutive years. The fires were effective at controlling the pest at considerably less cost than chemical alternatives. There was some damage to trees but no mortality the year after treatment. A list of guidelines for future WPCB-control burns was generated.

592 Wagner, R.G.; Mohammed, G.H.; Noland, T.L. 1999. Critical period of interspecific competition for northern conifers associated with herbaceous vegetation. Can. J. For. Res. 29:890–897.

Different tolerance levels were assessed by analyzing the time during which interspecific competition reduced tree growth to test the hypothesis that intolerant conifer species would have a higher growth rate and benefit more from early control of herbaceous vegetation. The effects of vegetation control were examined five years after planting four conifers on a sandy soil near Sault Ste. Marie, Ontario, which was clearcut and planted with jack (*Pinus banksiana* Lamb.), red (*P. resinosa* Ait.), and eastern white pine (*P. strobus* L.), and black spruce (*Picea mariana* (Mill.) BSP). A split-plot design was used with 10 different vegetation treatments and four replicates. Survival and growth of each tree were recorded each October. Growth responses were mainly differences in diameter and stem volume index (stem diameter^2 × height). The vegetation control did not influence survival and only partly influenced height growth.

593 Wagner, R.G.; Noland, T.L.; Mohammed, G.H. 1996. Timing and duration of herbaceous vegetation control around four northern coniferous species. N.Z. J. For. Sci. 26:39–52.

The purpose of the study was to find the optimum timing and duration of herbaceous vegetation control during the first three years after planting. A complete block, split-plot design with 10 treatments and four replicates was established 50 km north of Sault Ste Marie, Ontario, to test six patterns of herbaceous control on planted black spruce (*Picea mariana* (Mill.) BSP), and jack (*Pinus banksiana* Lamb.), eastern white (*P. strobus* L.), and red pine (*P. resinosa* Ait.). Survival and seedling growth were measured, and composition and abundance of all herbaceous vegetation recorded. Analysis of height and stem data showed that herbaceous control was important immediately after planting for all four conifer species. The critical-period approach provided an analytical method for quantifying the optimum timing and duration of vegetation management in newly planted forests as well as for examining the temporal effect of plant interference.

594 Wagner, R.G.; Robinson, A.P. 2006. Critical period of interspecific competition for four northern conifers: 10-year growth response and associated vegetation dynamics. Can. J. For. Res. 36:2474–2485.

The critical period of interspecific competition was assessed for four conifer species, jack (*Pinus banksiana* Lamb.), red (*P. resinosa* Ait.), and eastern white pine (*P. strobus* L.), and black spruce (*Picea mariana* (Mill.) BSP), in northern Ontario. The 10-year results were reported here for a clearcut site near Sault Ste. Marie, Ontario, which was planted using a randomized complete block, split-plot design with 10 treatments and four replicates. Vegetation control treatments were none (control); annual control; one, two, three, and four years after planting; and delaying for one, two, three, and four years after planting before annual control was initiated. A broadcast application of glyphosate herbicide was applied when scheduled. Survival and growth of all trees were assessed for the first 5 years after planting and after the 10th year. Stem diameter and volume were the most sensitive variables to all levels of vegetation control with 99, 210, 227, and 289% higher volumes for jack, red, and eastern white pine, and black spruce, respectively, with five years of vegetation control compared with no vegetation control. Parameter estimates provided quantitative estimates for the start of the critical period of interspecific competition, length of the critical period, and time of equal interference. Overall vegetation control during the first few years after planting had a substantial influence on the productivity of young conifer stands.

595 Wagner, R.G.; Ter-Mikaelian, M.T. 1999. Comparison of biomass component equations for four species of northern coniferous tree seedlings. Ann. For. Sci. 56:193–199.

Equations predicting the biomass components for seedlings of four coniferous species, jack (*Pinus banksiana* Lamb.), eastern white (*P. strobus* L.), and red pine (*P. resinosa* Ait.), and black spruce (*Picea mariana* (Mill.) BSP), were developed and compared. A randomized complete block, split-plot design with six treatments and four replicates was used to plant seedlings on a site 50 km north of Sault Ste. Marie, Ontario. After three years, 48 sample trees of each species were randomly selected for analysis, and the biomass of the components was determined. Pooled data were used to compare the biomass equations among species. The biomass component equations could not be combined for any of the four conifer species. All relationships between biomass components were species specific.

596 Wallace, D.R.; Sullivan, C.R. 1985. The white pine weevil, *Pissodes strobi* (Coleoptera: Curculionidae): a review emphasizing behavior and development in relation to physical factors. Proc. Entomol. Soc. Ont. 116(Suppl.):39–62.

This extensive literature review provided a background of general biological information and a more detailed description of the behavior of the white pine weevil (*Pissodes strobi* (Peck)), especially in relation to its physical environment. Life stages, development, and history of the white pine weevil were described. Shaded and cool environments were discussed more intensively because these conditions were less favorable for the insect.

597 Walter, R.; Epperson, B.K. 2005. Geographic pattern of genetic diversity in *Pinus resinosa*: contact zone between descendants of glacial refugia. Am. J. Bot. 92:92–100.

Red pine (*Pinus resinosa* Ait.) has a relatively low level of genetic variation, but there is a narrow, sharply bounded, and band-shaped pocket of higher diversity in northeastern New England. This pocket was evaluated to determine whether it had the characteristics of an admixture zone. Ten chloroplast microsatellites from 19 red pine populations from Nova Scotia to Ontario were compared with similar information from 10 previously studied populations. Red pine possibly has a more complex postglacial history than was typically assumed. The area of high diversity is a stable transition zone between descendants of two distinct refugia, one in the southern Appalachians and another near the North Atlantic coastline of the Wisconsinian glacial period.

598 Wang, B.; D'Eon, S. 2003. A brief review of germination testing requirements for eastern white pine (*Pinus strobus* L.) seeds. Canadian Tree Improvement Association, Tree Seed Working Group, Surrey, BC. News Bull. 38:13–16.

Requirements for pre-chilling, germination temperature, and photoperiod of eastern white pine (*Pinus strobus* L.) seeds were presented and briefly discussed using published and previously unpublished information. Seedlots were from eastern Ontario, Minnesota, southern Ohio, North Carolina, and Germany. Eastern white pine seeds required 28 days pre-chilling, a germination condition with an alternating temperature of 20–30°C, and an 8-hour photoperiod for laboratory testing. When seeds were stored at subfreezing temperatures for some time, an extended pre-chilling period was required.

599 Wang, B.S.P. 1982. Long-term storage of *Abies*, *Betula*, *Larix*, *Picea*, *Pinus* and *Populus* seeds. Pages 212–218 *in* B.S.P. Wang and J.A. Pitel, eds. Proceedings of the international symposium on forest tree seed storage, Petawawa National Forestry Institute, Chalk River, ON, 23–27 September 1980. Department of the Environment, Canadian Forestry Service, Ottawa. 243 p.

Previous studies on storage of seeds suggested good initial seed quality with low moisture content (<10%), storage temperatures between 5 and −18°C, and storage in airtight containers. This study tested the effectiveness of two storage temperatures (2 and −18°C) at Petawawa, Ontario, for various eastern and western Canadian tree seeds, cones, and fruits involving 41 seedlots and storage times of 1–13 years. Four replicates of 100 seeds were germinated for each seedlot. Cones of red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.) were kiln-dried at 50–60°C for 16 hours. Eastern white pine seed stored better at −18°C, whereas red pine seed could be stored equally well at 2 and −18°C. Eastern white pine seed with lower moisture content showed greater losses of germinability, indicating that it might have a higher limit of critical moisture content for long-term storage. Both plastic and glass containers were found suitable for the long-term storage of pine seed at −18°C.

600 Ward, J.S.; Gent, M.P.N.; Stephens, G.R. 2000. Effects of planting stock quality and browse protection-type on height growth of northern red oak and eastern white pine. For. Ecol. Manag. 127:205–216.

Methods of browse protection and initial seedling characteristics were assessed for their effects on seven-year survival and growth of northern red oak (preferred common name is red oak, *Quercus rubra* L.) and eastern white pine (*Pinus strobus* L.). Seedlings were planted at several sites in northern and southern Connecticut where white-tailed deer (*Odocoileus virginianus* (Zimmermann)) densities averaged

between 18 and 21 deer per square kilometre. Browse protection was applied and it included a mesh or fabric sleeve, a 120-cm or 180-cm-tall tan-colored tree shelter, a 120-cm white tree shelter, or control. Seedlings were measured before planting and for seven consecutive years after each growing season. A browse protection device, especially a tree shelter, significantly reduced browse damage to the terminal bud of both species. Tree shelters increased early growth of eastern white pine but not tree height in the seventh year. This was related to record snowfall and subsequent severe deer browsing. Larger, unprotected seedlings recovered better after damage from browsing than smaller seedlings, most likely due to more reserves.

601 Watwood, M.E.; Fitzgerald, J.W. 1988. Sulfur transformations in forest litter and soil: results of laboratory and field incubations. Soil Sci. Soc. Am. J. 52:1478–1483.
Little detailed work had been conducted earlier to document the importance of organic sulfate formation as a nutrient retention mechanism under field conditions. Field and laboratory incubations were conducted using ^{35}S-labeled inorganic sulfate with forest litter and A horizon mineral soil in both an eastern white pine (*Pinus strobus* L.) and hardwood stand. The amounts of sulfate adsorption and organic S formation in the field were determined and compared with the results from the laboratory incubations. Laboratory-determined S retention potentials accurately reflected capacities existing in the field at least during the summer. Organic forms dominated the total S pool in litter layers and A horizon mineral soils in the watersheds studied here.

602 Wazih Ullah, A.K.M. 1989. Financial analysis of red pine plantation management in the West Virginia University Forest. Indian J. For. 12:280–284.
A thinned and an unthinned red pine (*Pinus resinosa* Ait.) plantation, both 45 years old, at the West Virginia University Forest, West Virginia, were compared, and a financial analysis of red pine plantation management was done. The sawtimber and pulpwood volume estimates per hectare in the thinned stand were slightly lower than in the unthinned stand, but it was predicted that volume would be slightly higher in the thinned stand in 10 years. All the investment-criterion models indicated that the unthinned stand was more profitable at the time of measurement, but the opposite was true when an additional 10 years of production was evaluated.

603 Webb, D.T.; Flinn, B.S.; Georgis, W. 1988. Micropropagation of eastern white pine (*Pinus strobus* L.). Can. J. For. Res. 18:1570–1580.
This study expanded on earlier work to investigate the factors influencing caulogenesis from embryo-derived explants including the conditions needed for shoot elongation and rooting in vitro. Cotyledons, epicotyls, and hypocotyls from embryos and seedlings of eastern white pine (*Pinus strobus* L.) formed shoots after exposure to cytokinin on a Schenk and Hildebrandt medium. Benzyladenine concentrations of 0.5–1.0 mg/l gave consistently good results with cotyledons. About 80% of microshoots rooted in vitro on quarter-strength basal medium without any hormone application. An auxin pulse had little effect on rooting, and applying a rooting powder containing indolebutyric acid increased the number of roots formed but had little effect on the frequency of rooting.

604 Weber, M.G. 1990. Selected ecosystem processes in a *Pinus resinosa* Ait. forest in relation to other fire-affected eastern North American forest ecosystems. Pages 137–156 *in* J.G. Goldammer and M.J. Jenkins, eds. Fire in ecosystem dynamics. Third international symposium on fire ecology, Freiburg, FRG, May 1989. SPB Academic Publishing bv, The Hague, The Netherlands.
This study was initiated to place a particular red pine (*Pinus resinosa* Ait.) forest in eastern Ontario in perspective regarding other fire-affected forest ecosystems in eastern North America, and to compare ecosystem processes in fire-dependent forests. Litterfall, decomposition, organic matter turnover, and soil respiration rates in this mature red pine ecosystem near Petawawa, Ontario, were compared with results from other studies on similar eastern North American fire-affected forest types. Decomposition was determined using the litterbag technique, and forest soil respiration was estimated in situ with soda lime. Understory litter decomposed more readily than overstory litter, and nutrient inputs through litterfall followed a mass input pattern. Organic matter turnover rates were between 19 and 16 years and represented intermediate values when compared with other ecosystems.

605 Welsh, D.A.; Clark, T.; Clark, K. 1992. Fauna of red and white pine old-growth forests in Ontario: issues and recommendations for research. Rep. No. 3. OMNR, OFRI, Forest Landscape Ecology Program, Sault Ste. Marie, ON. 56 p.
The recommendations of 32 scientists were summarized on the direction that future research should take on the fauna in old-growth red (*Pinus resinosa* Ait.) and eastern white pine (*P. strobus* L.) forests in Ontario. The surveys used two questionnaires to attempt to identify the issues scientists thought were the most pressing and how they thought studies should be designed to address these issues. The respondents worked for government, universities, museums, or private organizations and most had expertise in vertebrate or invertebrate ecology. Their

recommendations were presented along with additional suggestions by the authors regarding future research scope and coordination.

606 Wendel, G.W. 1971. Converting hardwoods on poor sites to white pine by planting and direct seeding. Res. Pap. NE-188. USDA For. Serv., Northeastern For. Exp. Stn., Upper Darby, PA. 8 p.

An attempt was made to introduce eastern white pine (*Pinus strobus* L.) on poor hardwood sites in West Virginia, and the resulting studies completed between 1965 and 1971 were summarized. A study of underplanted eastern white pine on an oak (*Quercus* spp.) site revealed excellent survival if underplanted eastern white pine could be maintained for at least 15 years, and seedlings reached an average height between 1.2 and 1.8 m without overstory treatment. When an overstory was removed at the time of planting, 40% of the seedlings were free to grow after 15 years on a site with a site index of 45. Direct seeding did not show a consistent level of success. Even though some seedlings survived, they would require release before they could be considered free to grow. For successful conversion of poor hardwood sites to eastern white pine, it was recommended to plant 250–1000 stems per hectare under the canopy and then remove the overstory 5–10 years after planting.

607 Wendel, G.W.; Clay Smith, H. 1990. *Pinus strobus* L., eastern white pine. Pages 476–478 *in* R.M. Burns and B.H. Honkala, tech. coords. Silvics of North America. Vol. 1. Conifers. USDA For. Serv., Agriculture Handbook No. 654. Washington, DC.

An extensive literature on eastern white pine (*Pinus strobus* L.) was presented and it included studies throughout the species' natural range. The authors summarized the silvics of eastern white pine and described its habitat and associated forest cover types, life history, reproduction, and growth. Several regeneration methods were described as well as challenges when regenerating eastern white pine, such as control of the competing vegetation. Damaging agents were discussed as well, with white pine weevil (*Pissodes strobi* (Peck)), white pine blister rust (*Cronartium ribicola* J.C. Fischer), and the fungus *Armillaria mellea* (Vahl ex Fr.) Kummer being the most important species.

608 Wendel, G.W.; Della Bianca, L.; Russell, J.; Lancaster, K.F. 1983. Eastern white pine including eastern hemlock. Pages 131–134 *in* R.M. Burns, tech. comp. Silvicultural systems for the major forest types of the United States. USDA For. Serv., Agriculture Handbook No. 445. Washington, DC.

A thorough review was presented of the silvicultural systems applied in the management of eastern white pine (*Pinus strobus* L.) and its common associates. Suitable sites for eastern white pine were discussed as well as the requirements for successfully regenerating eastern white pine within its range. Partial shade, mechanical scarification, and burning improved seedbeds. The most versatile silvicultural system for regenerating eastern white pine was the shelterwood system. White pine weevil (*Pissodes strobi* (Peck)) and white pine blister rust (*Cronartium ribicola* J.C. Fischer) were the two most damaging pests when trying to regenerate eastern white pine. In the northwestern part of its range, eastern white pine was no longer managed commercially because of extremely high seedling and sapling mortality from white pine blister rust.

609 Westing, A.H. 1960. Peroxidase distribution in the leaders of erect and inclined *Pinus strobus* seedlings. Am. J. Bot. 47:609–612.

Peroxidases might be involved in both lignin genesis and auxin level and thus might be an important factor in the formation of compression wood. Therefore a study to investigate the longitudinal distribution of peroxidase activity in the leaders of eastern white pine (*Pinus strobus* L.) seedlings was initiated. Seedlings 8–12 years old from Yale Forest, New Hampshire, were selected for vigor, straightness, vertical growth, and uniformity. Treatments included weekly bending of the seedlings so that the leader was displaced to a horizontal position. Peroxidases were extracted but not linked to the formation of compression wood. Mutilation did have a marked effect on peroxidase activity.

610 Wetzel, S.; Burgess, D. 1994. Current understanding of white and red pine physiology. For. Chron. 70:420–426.

A review of eastern white (*Pinus strobus* L.) and red pine (*P. resinosa* Ait.) literature related to their physiology was summarized as well as new data on eastern white pine seedling response to nutrient supply. The effects of light and moisture on seedlings were described, and eastern white and red pine nutrition was discussed in some detail. Future efforts to elucidate the physiology of eastern white and red pine were encouraged and recommended to aid understanding and development of improved techniques to regenerate and grow red and eastern white pine forests and plantations more successfully under a variety of environmental conditions.

611 Wetzel, S.; Burgess, D. 2001. Understorey environment and vegetation response after partial cutting and site preparation in *Pinus strobus* L. stands. For. Ecol. Manag. 151:43–59.

Three natural, 110-year-old eastern white pine (*Pinus strobus* L.) stands near Petawawa, Ontario, were studied

to investigate understory vegetation response to thinning, site preparation, and underplanting. A split-plot, randomized block design was used with four replicates, and three thinning treatments (one-crown spacing, two-crown spacing, and control) and four preparation treatments (scarification, brush control, scarification and brush control, or control) were applied. With increased thinning intensity, the diversity of tree species decreased and shrub species increased. Light was the most crucial factor for successful seedling growth. But at 50% light, brush control and site preparation treatments increased growth and improved seedling nutrition because light was no longer the limiting factor.

612 Weyenberg, S.A.; Frelich, L.E.; Reich, P.B. 2004. Logging versus fire: how does disturbance type influence the abundance of *Pinus strobus* regeneration? Silva Fenn. 38:179–194.

A comparison was made of eastern white pine (*Pinus strobus* L.) regeneration success to test the hypothesis that the absence of fire was the limiting factor for eastern white pine regeneration in the Great Lakes region. Seed sources, soil conditions, and competition were the main factors explored that influence eastern white pine regeneration. Fire disturbances that were sufficiently severe were more favorable to eastern white pine regeneration than logging disturbances because fire removes competition and exposes mineral soil (promoting seed germination), whereas logging actually promoted competing shrub growth. Acceptable stocking of eastern white pine was obtained at 80 m from the edge of mature eastern white pine stands in fire-disturbed areas, and 20 m from the edge in logged areas, which demonstrated the importance of considering seed sources when managing for eastern white pine regeneration after a disturbance. Three to four times as many patches of mature eastern white pine were needed for retention after logging than after fire to achieve a similar level of eastern white pine regeneration stocking.

613 Wharton, E.H.; Powell, D.S. 1986. Eastern white pine: inventory and dynamics. Pages 16–21 *in* D.T. Funk, comp. Eastern white pine: today and tomorrow. Symposium proceedings, Durham, NH, 12–14 June 1985. Gen. Tech. Rep. WO-51. USDA For. Serv., Northeastern For. Exp. Stn., Durham, NH. 124 p.

Past and current data from several states, which were taken from several published and unpublished Forest Service resource bulletins, were used to evaluate the supply of eastern white pine (*Pinus strobus* L.) and how this resource has changed. Analysis showed that there was a considerable amount of eastern white pine potentially available and that this resource was maturing. Eastern white pine was growing twice as much compared with what was being removed for an increasingly wider range of forest products. The decline in small-diameter eastern white pine trees might create a future decrease in sawtimber volume in several decades.

614 White, E.H.; Jokela, E.J. 1980. Variation in red pine (*Pinus resinosa*) foliar nutrient concentrations as influenced by sampling procedure. Can. J. For. Res. 10:233–237.

Paired foliar samples were collected by shooting them from the crown with a shotgun versus climbing and clipping near-terminal foliage in 40-year-old red pine (*Pinus resinosa* Ait.) trees. Shot samples consistently and significantly resulted in lower estimates of foliar concentrations of N, P, and K than did the cut samples. Shot samples were significantly higher in Ca concentrations than cut samples. The shot samples tended to be from mid- to lower-crown positions, whereas the cut ones were more representative of near-terminal, current years' foliage. No significant correlation existed between the foliar nutrient concentrations of shot and cut samples, and therefore there was little possibility of using the shot samples to predict the near-terminal foliar nutrient concentrations with regression techniques.

615 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, U.S.A. Can. J. For. Res. 32:1639–1650.

A spatial model linking spatial environmental data with white pine blister rust (*Cronartium ribicola* J.C. Fischer) occurrence was applied to develop a map of eastern white pine (*Pinus strobus* L.) blister rust hazard in Minnesota. Inventory data was from either field inventory or aerial photograph interpretation, and a total of 9741 polygons in which eastern white pine occurred were used in map development. The new map was more fine-grained and showed spatial variability within broad white pine blister rust hazard zones, which were not on the original map. The electivity analysis, an index initially used to determine herbivores plant food choice given the food's overall abundance, was used for analyzing data. Analyses showed that climate, topographic characteristics, and distance from water bodies and wetlands strongly influence the white pine blister rust infection hazard. Areas previously classified as high hazard areas contained significant acreages of low hazard areas where eastern white pine regeneration might be possible.

616 Whitney, G.G. 1982. A demographic analysis of the leaves of open- and shade-grown *Pinus strobus* L. and *Tsuga canadensis* (L.) Carr. New Phytol. 90:447–453.

The demographic characteristics of the leaf formation of open- and shade-grown eastern white pine (*Pinus strobus*

L.) and eastern hemlock (*Tsuga canadensis* (L.) Carrière) were explored in Pennsylvania with eight hemlocks and eight eastern white pines (four from an open field and four from a closed forest) ranging from saplings to small trees. Eastern white pine grown in the shade kept their leaves for an average of 1.5–2 years, whereas open-grown eastern white pine trees kept their leaves for an average of 3.5 years. Open-grown trees were characterized by the production of large numbers of lateral branches and relatively dense crowns.

617 Whitney, G.G. 1984. Fifty years of change in the arboreal vegetation of Heart's Content, an old-growth hemlock–white pine–northern hardwood stand. Ecology 65:403–408.

The changing composition of an old-growth eastern hemlock (*Tsuga canadensis* (L.) Carrière)–eastern white pine (*Pinus strobus* L.)–northern hardwood stand in northwestern Pennsylvania was presented as well as an analysis of some of the factors responsible for the stand's current status and development. A total of 163 plots each 0.04 ha were set up on a 50-ha study area. Diameters of trees >9 cm were recorded, and seedlings and saplings were measured in 0.004-ha subplots. Heavy browsing by white-tailed deer (*Odocoileus virginianus* (Zimmermann)) during the past 40 years dramatically altered the stand structure and almost eliminated the small-sapling size class of all species. Browsing might be responsible for the increase of several more light-demanding species such as eastern white pine in the seedling and small sprout stages. Eastern white pine in the overstory was expected to continue to decline and might be completely eliminated from the stand.

618 Whitney, G.G. 1986. Relation of Michigan's presettlement pine forests to substrate and disturbance history. Ecology 67:1548–1559.

An attempt was made to reconstruct the original vegetation of two counties in Michigan and to specify the factors responsible for the development and maintenance of the pine (*Pinus* spp.) forest. Early Government Land Office survey records of both counties were examined to determine the tree composition and disturbance history. The abundance of pine was correlated with the presence of coarse-textured soils derived from outwash and ice-contact deposits. These soils promoted a vegetation type that was extremely susceptible to fire. The average return time for severe crown fires depended on the forest type: about every 80 years for a jack pine (*Pinus banksiana* Lamb.) forest type, 120–240 years for a mixed pine forest type, and up to 1400 years for an eastern hemlock (*Tsuga canadensis* (L.) Carrière)–eastern white pine (*P. strobus* L.)–northern hardwoods forest type.

619 Whitney, R.D. 1991. Quality of eastern white pine 10 years after damage by logging. For. Chron. 67:23–26.

A 130–ha eastern white pine (*Pinus strobus* L.) stand near Petawawa, Ontario, was logged in October 1981. Eight kinds of logging wounds (four made by skidders and four made by falling trees) on a total of 32 eastern white pine trees were assessed 10 years after logging. Of all the wounds examined, 40% had advanced decay and 90% were stained, which was slightly higher than at five years after thinning (30 and 63%, respectively). Felling wounds caused the greatest proportion of gross merchantable volume affected by decay. Only 14% of the residual trees that were wounded during the logging operation had significant defects resulting in cull and lower lumber grades.

620 Whitney, R.D.; Brace, L.G. 1979. Internal defect resulting from logging wounds in residual white pine trees. For. Chron. 55:8–12.

A careful logging operation near Petawawa, Ontario, left 20% of the 55–80-year-old residual eastern white pine (*Pinus strobus* L.) trees wounded. Five years after the harvest, the logging wounds were surveyed for decay and stain. The size, position, depth, and proportion of each wound that was healed were noted. An average of <1% of the gross tree volume was decayed or stained. A total of 13 decay-causing basidiomycetes were isolated from the decayed and stained tissues. Some of these decay fungi were capable of causing extensive decay in mature eastern white pine or other conifers. Logging procedure modifications were suggested to reduce the damage on residual trees and they included careful selection and training of crews, and temporarily leaving noncrop trees at critical points along skid trails to protect and minimize the damage to residual crop trees.

621 Wilkinson, R.C. 1983. Leader and growth characteristics of eastern white pine associated with white pine weevil attack susceptibility. Can. J. For. Res. 13:78–84.

Morphological and growth characteristics of eastern white pine (*Pinus strobus* L.) leaders were studied in relation to susceptibility to white pine weevil (*Pissodes strobi* (Peck)) attack. Seven leader characteristics were assessed as well as height and diameter growth of 208 eastern white pine trees in a plantation near Alfred, Maine. The plantation consisted of 27 geographic seed sources from throughout the natural range of eastern white pine. Each seed source was represented by 1-tree plots located in 24 randomized blocks, and the trees were planted in 15 rows of 44 trees each. At age 22, after 11 years of exposure to white pine weevil attack, every other tree in each row was harvested and used for analysis. White pine weevils successfully attacked between 15 and 70% of the trees each year with

on average 4.3 attacks per tree. Only four trees were not attacked. Repeated white pine weevil attacks severely reduced height growth. Diameter and early tree height were more strongly related to the number of white pine weevil attacks than leader characteristics. Of all leader characteristics, bark thickness was most closely related to susceptibility. Tree size and leader morphology were closely related and it was difficult to separate their relative contribution. It remained difficult to explain the susceptibility of eastern white pine to white pine weevil attack.

622 Williams, J. 1994. Planning and executing a commercial stand improvement experiment in pine mixedwoods. For. Chron. 70:382–384.

Thinning in eastern white pine (*Pinus strobus* L.) mixedwood stands near Petawawa, Ontario, was applied to possibly increase the yield of pine (*Pinus* spp.) sawlogs in the current rotation. A commercial thinning in two-storied pine mixedwoods was completed. Details of planning and executing the harvest were described. Planning processes consisted of conducting a detailed and accurate inventory of the stands, prescription marking, and the development of a logging plan. After the partial harvesting, a damage assessment was completed. A total of 80% of residual trees had no significant damage, which was considered an acceptable level of damage for tree-length skidder operations.

623 Wilson, F.G. 1979. Thinning as an orderly discipline: a graphic spacing schedule for red pine. J. For. 77:483–486.

A formula that correlated stem count with height was applied in a thinning study to design an appropriate thinning procedure and definitive treatment. The first thinning of a red pine (*Pinus resinosa* Ait.) plantation in Wisconsin left a residual spacing of 20.6% of height and an equal number of trees per hectare. This guide was followed with each subsequent thinning. Waiting for new height growth development of 2.4 m was suggested as a reasonable time interval between subsequent thinning treatments. The general thinning procedure was replicated through time with parameters appropriate to species, site, products, and markets.

624 Wilson, R.W., Jr.; Hough, A.F., comps. 1966. A selected and annotated bibliography of eastern white pine (*Pinus strobus* L.), 1890–1954. Res. Pap. NE-44. USDA For. Serv., Northeastern For. Exp. Stn., Upper Darby, PA. 166 p.

An annotated bibliography on eastern white pine (*Pinus strobus* L.) was prepared that contained 944 references published between 1890 and 1954. Most of the references were publications on silvics, phytosociology, silviculture, protection, and management of eastern white pine. But a significant number dealt with eastern white pine taxonomy, morphology, physiology, genetics, wood anatomy, wood technology, logging, manufacturing, end uses and marketing, and resource and economic statistics.

625 Wittwer, R.F.; Leaf, A.L.; Bickelhaupt, D.H. 1975. Biomass and chemical composition of fertilized and/or irrigated *Pinus resinosa* Ait. plantations. Plant Soil 42:629–651.

Few earlier studies had quantified the response of fertilizer additions and hence this study was initiated in 40-year-old red pine (*Pinus resinosa* Ait.) plantations on K-deficient sandy soils in New York State. They were fertilized and/or irrigated and the growth response in biomass and nutrient contents of N, P, K, Ca, Mg, Na, Al, Mn, Fe, Zn, and Cu were assessed. Regression equations were developed from sample-tree data. After fertilization, K contents increased by 140%, Mn by 70%, and N by 50% compared with nonfertilized trees. Biomass increased by 22% after fertilization, and the increases in the nutrient elements were closely related to this biomass increase. The influence of irrigation on biomass production and nutrient composition was minimal.

626 Woods, M.E.; Miller, R.J. 1996. Red pine and white pine site index curves and tables for South Central region. Tech. Note No. 02. OMNR, North Bay, ON. 11 p.

Growth predictions of individual forest stands help forest managers select the most appropriate silvicultural treatments and provide input to long-term wood supply modeling and wildlife habitat analysis. A total of 100 dominant and codominant trees were sampled in this study from sites varying from shallow soil to moderately deep sands in south central Ontario. Growth estimations were made using data from detailed stem analysis of the sampled trees. The new site index models provided better predictions of the height growth patterns than earlier published curves.

627 Wray, D. 1986. Managing white pine in Ontario. Pages 67–69 *in* D.T. Funk, comp. Eastern white pine: today and tomorrow. Symposium proceedings, Durham, NH, 12–14 June 1985. Gen. Tech. Rep.WO-51. USDA For. Serv., Northeastern For. Exp. Stn., Durham, NH. 124 p.

The two primary silvicultural systems applied in eastern white pine (*Pinus strobus* L.) management in Ontario, clearcutting with seed trees and uniform shelterwood, were reviewed. The seed tree system usually results in a sporadic regeneration success mainly because of hardwood competition and white pine weevil (*Pissodes strobi* (Peck)) damage. The shelterwood system typically was more difficult and expensive to implement, but it

better protected eastern white pine regeneration from competing hardwoods and lowered the incidence of white pine weevil attacks.

628 Wright, J.W.; Amiel, R.J.; Cech, F.C.; Kriebel, H.B.; Jokela, J.J.; Lemmien, W.A.; Matheson, A.C.; Merritt, C.; Read, R.A.; Roth, P.; Thor, E.; Thulin, I.J. 1978. Performance of eastern white pine from the southern Appalachians in eastern United States, New Zealand, and Australia. Pages 203–216 *in* Proceedings of the 26th northeastern forest tree improvement conference, University Park, PA, 25–26 July 1978. School of Forest Resources, The Pennsylvania State University, University Park, PA.

Eastern white pine (*Pinus strobus* L.) seeds obtained from 177 native trees in 49 stands between Maryland and Georgia were germinated and the seedlings planted in 15 plantations in 6 eastern or midwestern States, and in Australia and New Zealand. Trees were measured at 7–11 years old. Although average temperatures during the coldest month varied from −7 to +8°C at the 15 test sites, results were remarkably similar. The same seedlots recommended for southern Michigan or Nebraska would also be best to plant in New Zealand. There was insignificant pest damage at all of the test sites.

629 Wright, J.W.; Lemmien, W.L.; Bright, J.N. 1970. Genetic variability in eastern white pine from Michigan: six-year results. Silvae Genet. 19:146–149.

The genetic variability in native stands of eastern white pine (*Pinus strobus* L.) in Michigan was examined using open-pollinated seed collected from 123 trees located in 17 stands from 15 counties and 4 test plantations in Michigan. There was a strong correlation between height at age two and height at age six. Furthermore, trees from the west central Lower Peninsula grew 15% taller than those from the northeastern Lower Peninsula, and they in turn were 12% taller than those from the Upper Peninsula. Given the distinct height differences among regions, it was suggested to consider the populations from these three regions to be separate pine (*Pinus* spp.) ecotypes.

630 Wu, T.; Kabir, Z.; Koide, R.T. 2005. A possible role for saprotrophic microfungi in the N nutrition of ectomycorrhizal *Pinus resinosa*. Soil Biol. Biochem. 37:965–975.

This study investigated the accessibility of organic sources of nitrogen to red pine (*Pinus resinosa* Ait.) and ectomycorrhizal and saprotrophic microfungi. A vector analysis of plantation red pine demonstrated nitrogen limitations, and laboratory experiments assessed potential nitrogen sources for red pine seedlings, ectomycorrhizal fungi, and saprotrophic fungi. Red pine acquired simple forms of nitrogen and phosphorus indirectly through ectomycorrhizal fungi. Saprotrophic fungi might make complex organic nitrogen available to ectomycorrhizal fungi, which then could allow red pine to access organic nitrogen indirectly through the ectomycorrhizal fungi.

631 Yawney, H.W. 1961. Introducing white pine into poor-site hardwood stands in West Virginia. Stn. Pap. No. 154. USDA For. Serv., Northeastern For. Exp. Stn., Upper Darby, PA. 10 p.

Establishing eastern white pine (*Pinus strobus* L.) on poor sites in West Virginia was difficult due to hardwood competition. The overall objective was to determine which hardwood sites could be underplanted with eastern white pine at minimum expense but with reasonable regeneration success to obtain a mixed pine (*Pinus* spp.)–hardwood forest where pine could be maintained indefinitely. The study area in Tucker County, West Virginia, had a range of a site index from 40 to 70 and was composed of low-grade hardwoods. Six 0.12-ha plots were set up in pairs on three sites of different site index (lower, middle, and upper slopes). A total of 160 eastern white pine seedlings were planted per plot at a 2.7×2.7 m spacing. On one of the paired plots, all trees with a diameter at breast height >10 cm were girdled, and four growing seasons after planting, competing vegetation was cut on half of the treated plots. Survival was high on all plots. After six growing seasons, seedlings on the released plots were more than twice as tall as control seedlings. Pine seedlings that received the second release treatment were in the best competitive position. Eastern white pine could be planted with reasonable success on poor hardwood sites with a site index of 40–50 for oak (*Quercus* spp.), as long as all hardwoods were removed. Some release tending might be needed to increase pine survival and growth.

632 Young, H.E.; Dyer, R.F.; Dube, G.F. 1967. Nutrient distribution in the crown of pole size red spruce and white pine. Maine Farm Res. April 1967:30–34.

Nutrient distribution was assessed in the crown of pole-sized red spruce (*Picea rubens* Sarg.) and eastern white pine (*Pinus strobus* L.) to begin determining deficiency and normal nutrient levels for these major forest tree species. One eastern white pine and one red spruce were felled, and needle samples were collected. Needle samples were dried and then analyzed in a spectrograph for Ca, Mg, P, K, Fe, Mo, Zn, B, Cu, Mn, and Al. In the eastern white pine tree, the greatest concentration of 10 of the elements was in the lower section of the crown. In the red spruce, the greatest concentration of most elements was in the top section. There were few significant differences among the cardinal directions for the nutrients tested.

633 Zastrow, D.E. 1992. Big tree silviculture. Pages 179–185 *in* R.A. Stine and M.J. Baughman, eds. White pine symposium proceedings: history, ecology, policy and management, Duluth, MN, 16–18 September 1992. University of Minnesota, Extension Service Distribution Center, St. Paul, MN. 202 p.

Big tree silviculture (extended rotation) was described for the management of Wisconsin State forests and it focused on the aesthetic and recreation values and benefits of growing large-diameter trees. Big tree silviculture was limited to several forest cover types and corresponding forest sites that support old, large trees. The habitat type classification system, characterized by specific plant associations, was used to ecologically quantify forest communities suitable for big tree silviculture.

634 Zeleznik, J.D.; Dickmann, D.I. 2004. Effects of high temperatures on fine roots of mature red pine (*Pinus resinosa*) trees. For. Ecol. Manag. 199:395–409.

The tolerance of fine roots of mature red pine (*Pinus resinosa* Ait.) to high temperatures was discussed. Two experiments were initiated in the W.K. Kellogg Experimental Forest near Augusta, Michigan. The first study investigated a low-intensity burn in a red pine plantation to observe the effect of fire on fine roots. A second experiment tested root injury from high temperatures when hot water was applied directly to fine roots for 0.5, 1, 2, or 4 minutes. Root mortality was assessed during three weeks after treatment. Heat-induced mortality was apparent within one week after being exposed to temperatures >52.5ºC. A direct relationship was observed between mortality and the length of time of heat exposure. Low-intensity fires that have low-exposure times did not produce temperatures lethal to red pine root systems.

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

The growth response of naturally regenerated eastern white pine (*Pinus strobus* L.) was studied after pathological pruning and overstory release. Nine plots were set up near Duluth, Minnesota, and randomly assigned various partial release intensity treatments. Thirty-two eastern white pine seedlings of various heights were selected randomly in each plot, and half of these trees received pruning. Eastern white pine seedling response to release and pruning depended strongly on pretreatment seedling size. Eastern white pine <190 cm tall were reduced significantly in number by increased aspen (*Populus* spp.) densities and pruning, whereas eastern white pine >190 cm tall were not affected by either treatment.

636 Zhang, Y.; Reed, D.D.; Cattelino, P.J.; Gale, M.R.; Jones, E.A.; Liechty, H.O.; Mroz, G.D. 1994. A process-based growth model for young red pine. For. Ecol. Manag. 69:21–40.

A carbon-balance, process-based model was developed to simulate effects of environmental conditions on individual young red pine (*Pinus resinosa* Ait.) trees. The basic physiological processes of photosynthesis, respiration allocation and translocation of assimilate, and mortality of organs were modeled using tissue dry weights and measures of solar radiation, air temperature, leaf and soil water potential, and leaf age. Data from three young red pine plantations growing in the Upper Peninsula of Michigan were used for evaluating the model. The model performed well when predicted data were compared with observed values from the three plantations.

637 Ziegler, S.S. 1994. Relict eastern white pine (*Pinus strobus* L.) stands in southwestern Wisconsin. Am. Midl. Nat. 133:88–100.

The stand dynamics of eastern white pine (*Pinus strobus* L.) were investigated in a selection of stands in southwestern Wisconsin, which is close to the southern limit of eastern white pine's range. These stands were examined 45 years earlier as well. Eight of these stands were chosen for further quantitative analysis. Trees were sampled at a minimum of 20 locations in each stand, and environmental conditions were noted. Eastern white pine continued to be self-replacing in six of the eight stands in spite of competition by hardwood species that dominated the better-developed soils. Logging, grazing, and browsing have altered site conditions and replaced fire, which in the past was the major form of disturbance.

638 Zsuffa, L. 1978. Poplar and white pine breeding at Maple in 1975 and 1976. Contribution No. 1025. OMNR, Forest Research Branch, Maple, ON. 4 p.

This report provided an overview of poplar (*Populus* spp.) and eastern white pine (*Pinus strobus* L.) genetic research in Ontario. Research activities were focused on tree selection and progeny testing, field testing of progenies resistant to white pine blister rust (*Cronartium ribicola* J.C. Fischer), clonal propagation and testing of superior and white pine blister rust-resistant types, and the introduction of exotics. Progeny trials of selected white pine blister rust-resistant eastern white pine showed significant variation in height growth after five years.

639 Zsuffa, L. 1985. The genetic improvement of eastern white pine in Ontario. Proc. Entomol. Soc. Ont. 116(Suppl.):91–94.

Eastern white pine (*Pinus strobus* L.) breeding research in Ontario was focused on the development of varieties

resistant to white pine blister rust (*Cronartium ribicola* J.C. Fischer). Breeding for white pine weevil (*Pissodes strobi* (Peck)) resistance started early. Breeding research presented here focused on developing genetically improved seed sources to meet the needs of an expanding reforestation program. It concentrated on interspecific breeding with most attention focused on eastern white pine crosses with blue pine (*P. wallichiana* A.B. Jacks.) with the goal of producing fast-growing white pine weevil-resistant hybrids.

640 **Zsuffa, L. 1986. The genetic improvement of eastern white pine. Pages 32–39 *in* D.T. Funk, comp. Eastern white pine: today and tomorrow. Symposium proceedings, Durham, NH, 12–14 June 1985. Gen. Tech. Rep. WO-51. USDA For. Serv., Northeastern For. Exp. Stn., Durham, NH. 124 p.**

Reviews of genetic improvement studies in eastern white pine (*Pinus strobus* L.) showed a focus on the following topics: species hybridization, white pine blister rust (*Cronartium ribicola* J. C. Fischer) and white pine weevil (*Pissodes strobi* (Peck)) resistance, provenance studies, vegetative propagation and cloning, and plus tree progeny studies. The potential of breeding for pest resistance, growth, and improved lumber quality was discussed. Significant genetic gains in all the discussed areas could be achieved as long as adequate funding for genetic improvement research was maintained.

Subject Index

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