a review USDA For Serv Gen Tech Rep NC-30 23 p
HEALY, W. M., R. T. BROOKS, AND R. M. DEGRAFF. 1989. Cavity trees in sawtimber-size oak stands in central Massachusetts. North. J. Appl. For. 6:61–65.
HUNTLEY, J. C. 1983. Squirrel den tree management: reducing incompatibility with timber production in upland hardwoods. P. 488–495 in Proc. Second biennial southern silvicultural research conference. GA. USDA For. Serv. Gen. Tech. Rep. SE-24.
LOWNEY, M. S., AND E. P. HILL. 1989. Wood duck nest sites in bottomland hardwood forests of Mississippi. J. Wildl. Manage. 53(2):378–382.
MCCOMB, W. C. 1982. Forestry and wildlife habitat management in central hardwoods. J. For. 80:490–492.
MCCOMB, W. C., S. A. BONNEY, R. M. SHEFFIELD, AND N. D. COST. 1986. Den tree characteristics and abundance in Florida and South Carolina J Wildl Manage 50 584–591
MILLER, M. R. 1981. Ecological land classification terrestrial subsystem, a basic inventory system for planning and management of the Mark Twain National Forest. USDA For. Serv. Resour. Planning and Manage., Rolla, MO. 56 p.
NIXON, C. M., AND L. P. HANSEN. 1987. Managing forests to maintain populations of gray and fox squirrels. Ill. Dep. Conserv. Tech. Bull. 5. 35 p.
SANDERSON, H. R., W. M. HEALY, J. C. PACK, J. D. GILL, AND J. W. THOMAS. 1975. Gray squirrel habitat and nest tree preference. Southeast Assoc. Game Fish Comm. Annu. Conf. Proc. 29:609–616.
SCHEFFER, T. C., G. H. ENGLERTH, AND C. G. DUNCAN. 1949. Decay resistance in seven native oaks. J. Agric. Res. 78:129–149.
SEDGWICK, J. A., AND F. L. KNOPF. 1986. Cavity-nesting birds and the cavity-tree resource in plains cottonwood bottomlands J Wildl Manage. 50:247–252.
SMITH, W. H. 1970. Tree pathology: a short introduction. Academic Press, New York. 309 p.
TUBBS, C. H., R. M. DEGRAAF, M. YAMASAKI, AND W. H. HEALY. 1987. Guide to wildlife tree management in New England northern hardwoods. USDA For. Serv. Gen. Tech. Rep. NE-118. 30 p.
VAN BALEN, J. H., C. J. H. BOOY, J. A. FRANEKER, AND E. R. OSIECK. 1982. Studies on hole-nesting birds in natural nest site 1. Availability and occupation of natural nest sites. Ardea 70:1–24.
WEIER, R. W. 1966. A survey of wood duck nest sites on Mingo National Wildlife Refuge in Southeast Missouri. P. 91–108 in Wood duck management and research: a symposium. Wildl. Manage. Inst., Wash., DC.

Site Index Curves and Site Factors Affecting the Growth of White Pine in Southern Ontario[1]

Peter A. Williams *and* **Andrew M. Gordon,** *Department of Environmental Biology, University of Guelph, Guelph, ON N1G 2W1; and* **Edward P. Taylor,** *Ontario Ministry of Agriculture and Food, Guelph Agriculture Centre, P.O. Box 1030, Guelph, ON N1H 6N1, Canada.*

ABSTRACT. The objectives of this project were to develop site index curves and provide soil-site information for southern Ontario white pine and to compare that information to similar information on white pine from other regions and to information on Norway spruce in the study area. Sampling points were selected in unthinned white pine plantations and classified by soil textural class (course, medium, and fine) and depth to distinct mottling (0–16, 16–40, and 40+ in.). Two sets of anamorphic site index curves were constructed from stem analysis data, using a total age of 30 years (SI30) and a breast height age of 25 years (SIBH25) as base ages. Significant differences due to soil factors were found in the number of years it took seedlings to reach breast height (BH) (mean = 6 5 years; range = 3 to 11 years) but not in SIBH25. Years to BH was significantly greater on clayey sites than those with loamy or sandy textures (6.1 vs. 5.0 and 4.9 years). White pine height growth in the study area compared favorably with white pine height growth in New England, Wisconsin, and Ohio. When white pine height growth was compared to the growth of Norway spruce in the study area, SIBH25 values were significantly higher for Norway spruce but years to BH were significantly lower for white pine. On poorly drained sites, site index values for white pine and Norway spruce were similar, but it took 2.2 years less for white pine to reach breast height (7.2 vs. 5.0 years). On imperfectly and well-drained sites, white pine seedlings took less time than Norway spruce to reach BH, but the site index of Norway spruce was much greater.

North. J. Appl. For. 7:183–186, December 1990.

[1] Funding for this project was provided under the Canada-Ontario Forest Resource Development Agreement, contract number 21005, the Ontario Ministry of Agriculture and Food, and by a grant-in-aid to the University of Guelph by Consolidated-Bathurst Inc., Montreal, PQ. We also thank Messrs. Rob Baldwin, Mike Kolentsis, and Paul McLennan for data collection in the field and help with stem analysis procedures. Appreciation is extended to Dr. Willard Carmean, Lakehead University, Thunder Bay, for his helpful comments.

White pine is historically one of the most important timber species in eastern North America. Although the great virgin stands of white pine that were once common had largely been logged out by the early 1900s, second-growth natural stands and plantations have maintained the species in forests in and beyond its original range. Two major pests, white pine blister rust and the white pine weevil, have threatened the commercial viability of many white pine stands. However, the high commercial value and rapid growth rate of white pine over a wide range of site conditions, along with the benefits of intensive silviculture to minimize these problems, have assured the continued use of white pine in eastern forest management activities (Gross 1985, Wray 1985).

Although some information is available on white pine growth in central Ontario (Smithers 1954), local site index curves for white pine in southern Ontario are lacking. Managers have used white pine site index curves generated in Vermont (Hannah 1971), yield tables based on broad geographic areas (Plonski 1971), and reconnaisance level information (Taylor and Jones 1986). Forest managers have expressed a need for more detailed local soils/site index information for white pine growing under local conditions including comparisons with alternative species such as Norway spruce. The objectives of this project were: (1) to develop site index curves for white pine growing in southern Ontario, (2) to determine the influence of broad soil drainage and texture classes on the growth of white pine in southern Ontario, and (3) to compare the resultant information to similar information from other regions and to Norway spruce growing in the study area.

STUDY AREA

The study was conducted in central, southern Ontario (Fig. 1). The entire study area was glaciated during the Wisconsinan advance with the resultant soils being depositional in nature. The topography is gentle to rolling and generally suitable for agriculture. The soils tend to be sandy, but texture varies with local parent material (Chapman and Putnam 1973). Much of the area is underlain by dolomitic

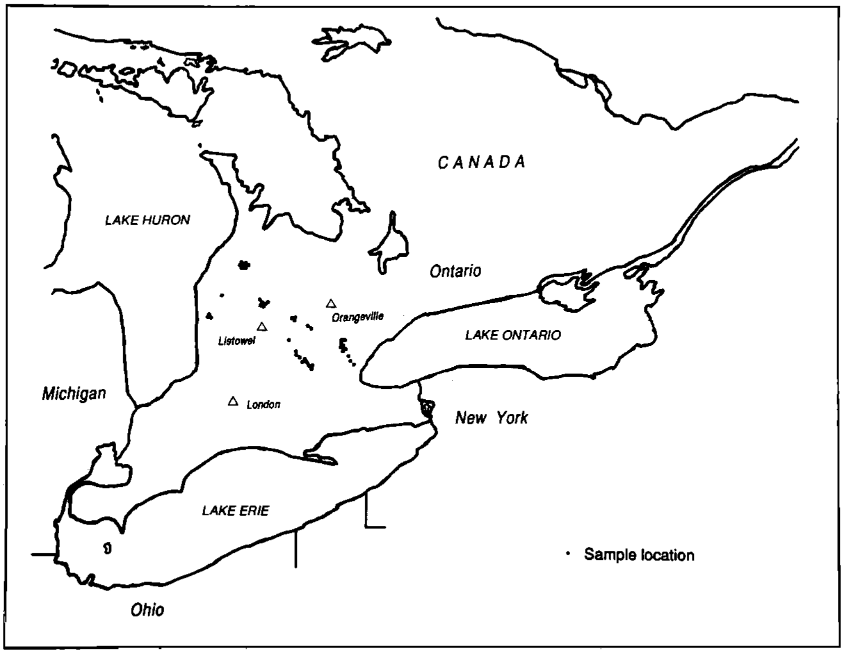

Figure 1. Location of the study area. Each point represents a sample stand.

bedrock, from which the calcareous parent material for many of the soils was derived.

The landscape in the study area is dominated by agriculture. Past tillage of marginal agricultural land in the region has often resulted in erosion, soil degradation, and land abandonment. Coniferous plantations have usually been established on marginal or degraded sites, often abandoned agricultural land or windblown sands.

MATERIALS AND METHODS

Sampling points were established in fully stocked, unthinned white pine plantations, representing a range of soil drainage and texture conditions. Soil conditions were classified into nine combinations of three soils drainage and textural classes. Soil drainage was classified by depth to distinct mottling (*DDM*) (<16, 16–40, and 40+ in). In Ontario, these *DDM* ranges correspond to poorly to imperfectly drained, imperfectly to moderately well-drained, and moderately well to rapidly drained soils, respectively (Ontario Institute of Pedology 1985). To simplify discussion, these drainage classes will be referred to as poorly, imperfectly, and well-drained.

The three soil texture classes were coarse (sandy), medium (loamy), and fine (clayey). Plantations growing on very coarse, rapidly drained (excessively dry) and very poorly drained (saturated) soils were not encountered during this study. Sampling to determine *DDM* and soil texture was conducted using a soil auger. Soil textures were determined in the field according to the methods of the Ontario Institute of Pedology (1985). A total of 40 points were sampled in well-established, unthinned plantations; the stratification of these points within the three drainage/texture classes is given in Table 1.

A total of 160 trees (four dominant or codominant from each sampling point) were selected. Care was taken to choose only defect-free trees, although several trees were later deleted from the data set when it was discovered that they were not. The selected trees were felled, and stump height, total tree height, and stump age were recorded. Discs were cut at 1 m intervals over the length of the tree, following stem analysis procedures described by Husch et al. (1982). The discs were placed in plastic bags, inside a burlap sack, and stored at 3°C until measured.

Annual rings were counted using The Tree Ring Increment Measurer (MacIver et al. 1985), a computer-aided system developed by the Ontario Ministry of Natural Resources for collecting and analyzing stem analysis data. No correction was used to compensate for dissections not coinciding with maximum height attained for a particular age.

Anamorphic site index curves at base age 30 (*SI30*) were constructed using total tree age and methods described in Heger (1968). Site index curves using a breast height (*BH* = 4.5 ft) age of 25 (*SIBH25*) were also calculated because of variability in the number of years it took for the trees to reach a free-to-grow state (breast height). Although sawlog production is not achieved by age 30, the relatively low base ages were used to produce the site index curves because the sampled plantations did not permit construction of curves more reflective of a sawtimber rotation. The height for 47 trees with *BH* age less than 25 and greater than 22 years was extrapolated by adding the average annual height growth increment for the last 5 years to the total height of the tree for each year less than 25. Five trees with *BH* age less than 22 or height growth patterns symptomatic of weevil damage were deleted from the analysis for site index.

While it is recognized that polymorphic site index curves yield better estimates of tree growth over a range of site conditions, anamorphic methods were used in this study because of time constraints and contractual obligations. In general, anamorphic methods give a better approximation of tree growth closer to the mean rather than at the highest or lowest site index values.

Analysis of variance (ANOVA) was performed using height growth data on an individual tree basis using PCSAS General Linear Models Procedure (SAS Institute 1985). *SIBH25* and years to *BH* were used as dependent variables, and soil texture class and soil drainage class were used as independent variables. The drainage*texture interaction term and the nested term, plots within drainage*texture class, were also included in the model A protected LSD test (PCSAS GLM Procedure, PDIFF option within LSMEANS) using adjusted means was used to compare the means of each of the three soil drainage and texture classes.

The growth data for white pine were compared to similar data for Norway spruce growing in the study area using a t-test (Little and Hills 1978). Comparisons were made be-

Table 1. Sampling points in each of nine soil drainage/texture cells for white pine in southern Ontario.

	Depth to distinct mottling			
Soil textural class	<16 in. (poorly drained)	16–40 in. (imperfectly drained)	40+ in. (well-drained)	Total
Coarse (sandy)	2	3	5	10
Medium (loamy)	6	11	6	23
Fine (clayey)	4	2	1	7
Total	12	16	12	40

tween species across the range of site conditions and for the individual soil drainage and texture classes.

RESULTS AND DISCUSSION

Age

The total age of the sampled trees ranged from 25 to 43 years, and breast height age ranged from 18 to 40 years. It took an average of 5.3 years for the trees to reach breast height, with a range of 3 to 11 years. The older plantings were found to be on sites with a lower site index, most likely because eroded farmland and blowsands received priority during early tree planting programs.

Site Index

*SIBH*25 curves specific to southern Ontario are given in Figure 2. The average *SIBH*25 for the trees was 52.1 ft with a range of 38 to 63 ft. *SI*30 curves were also constructed and are given in Figure 3. *SI*30 ranged from 33 to 65 ft with an average of 51.6 ft. The site index for white pine growing within the study area compared favorably with site index information published for many areas in eastern North America (Table 2). Beck (1971) shows that the site index for white pine is better in the southern Appalachians than in southern Ontario.

Soil-Site Factors

ANOVA indicated no significant differences in *SIBH*25 due to either soil texture, drainage, or their interaction. Significant differences were found in Years to *BH* due to soil texture ($P < 0.05$), but the effects of drainage and drainage∗texture interaction were not significant. Significant differences were found among plots within soil drainage/texture cells for both variables.

The highest *SIBH*25 were found in loamy soils, and clayey, imperfectly drained soils. Lower *SIBH*25 values were found at sites with well-drained soils, sandy textures, and poorly drained clayey soils.

Mean separation showed that white pine growing on clayey soils took significantly longer to reach breast height than those growing on sandy or loamy soils (6.4 vs 5.0 and 5.1 years respectively). White pine from poorly drained sites took the least number of years (5.0) to reach breast height although the difference when compared to the other two drainage classes (5.6 and 5.8) was not significant.

The variation among plots within drainage/texture cells could have resulted from several sources. Since the soil drainage and texture classes represent sections from continuous scales, there would likely have been extremes of drainage and texture within each class, accounting for some of the observed variation. Sampling under winter conditions may have also resulted in additional error in the classification of sites with borderline characteristics.

The comparison of the white pine growth data to similar data on Norway spruce in the study area (Gordon et al. 1989) (Table 3) showed that site index was significantly higher for Norway spruce for most texture and drainage classes. Site indices were greater in all cases for Norway spruce with significant differences found between species in imperfectly and well-drained soils and those with sandy and loamy textures. However, Norway spruce took longer to reach breast height in all cases and the differences were significant among sites with poorly drained or loamy soils.

APPLICATIONS

White pine site index curves for unthinned plantations are presented for both breast height age (*SIBH*25 curves) and total age (*SI*30 curves). Site index using breast height age rather than total age is considered to give a better estimate of site potential because of differences in the number of years it takes for seedlings to reach breast height. Where breast height age data are available, the *SIBH*25 curves should be employed; in instances where breast height age data are

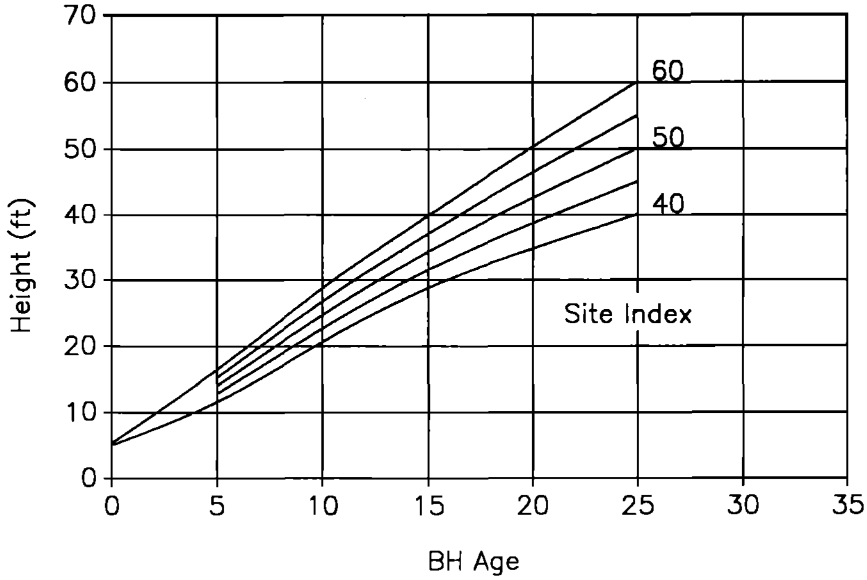

Figure 2. ***SIBH*25 curves for white pine growing in southern Ontario. The equation for the mean curve is: Total height = 4.72122 + 2.181472 (age) − 0.01103 (age)^2. Age units = years.**

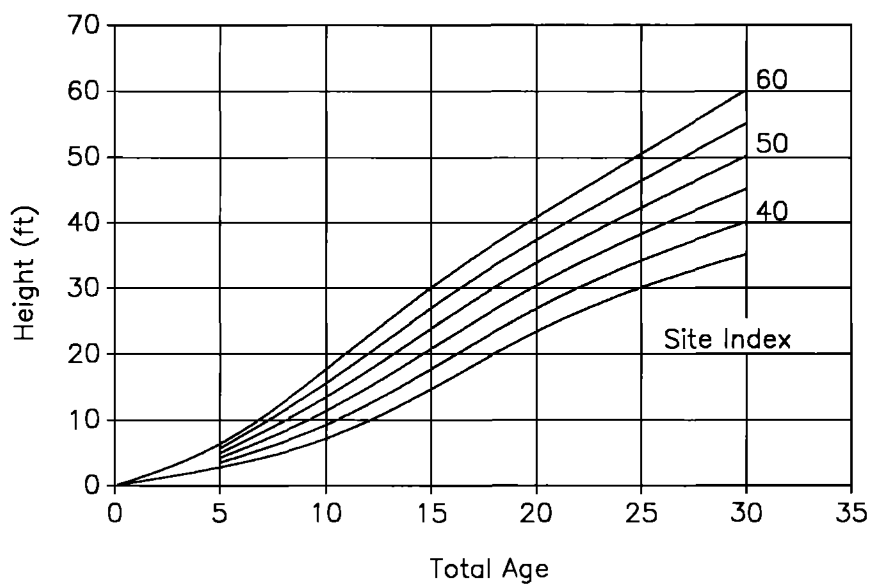

Figure 3. ***SI*30 curves for white pine growing in southern Ontario (dark). The equation for the mean curves is: Total height = −1.45446 + 1.63119 (age) + 0.00570 (age)^2. Age units = years.**

Table 2. Comparison of white pine site index values from different regions in eastern North America.

Region	Base age Total age	Base age BH age	Site index Range	Site index Mean	Source
Appalachians, southern[a]	50	—	71–122	93[c]	Beck 1971
New England, southern[b]	—	50	40–90[c]	69[c]	Leak, et al. 1970
New Hampshire, southern[b]	—	25	—	43[c]	Husch & Lyford 1956
Ohio[a]	—	35	58–84	69[c]	Brown & Stires 1984
Ontario, southern[a]	—	25	38–63	52.1	Current study
Ontario, southern[a]	30	—	33–65	51.6	Current study
Vermont[a]	30	—	33–64	50.9	Hannah 1971
Vermont[a]	50	—	42–100	69.5	Hannah 1971
Wisconsin[b]	50	—	45–75[c]	59[c]	Gevorkiantz & Zon 1930

[a] Plantations.
[b] Natural stands.
[c] Estimated from information in publication.

lacking (e.g., when using data from inventories), *SI*30 curves could be used.

The results of the soil-site data for white pine and Norway spruce could prove helpful in the allocation of planting stock or cultural treatments to particular sites. The results from this study suggest that on poorly drained sites, site index of white pine is similar to that of Norway spruce, but the faster early growth of the white pine could give that species an early advantage in overcoming competition. However, the long-term pest management problems associated with white pine compared with Norway spruce and the susceptibility of white pine to windthrow on poorly drained sites may offset early gains in reaching the "free to grow" state On better drained sites, the higher site index values for Norway spruce overshadow early seedling growth rates Other species such as white spruce may be better adapted to some poorly drained sites and red pine to drier sites, but this information is not yet available for the study area. □

Table 3. Comparison of arithmetic means for *SIBH*25 and Years to *BH* of white pine and Norway spruce in southern Ontario by soil drainage and texture class.

Texture/drainage class	White pine	Norway spruce[a]
*SIBH*25 (ft)		
Textural class		
Coarse (sandy)	50.4	50.3*
Medium (loamy)	53.2	57.5*
Fine (clayey)	51.3	54.6
Drainage class		
Poorly drained[b]	52.4	52.5
Imperfectly drained[c]	53.7	57.2*
Well-drained[d]	49.7	56.7*
Total	52.1	55.3*
Years to Breast Height		
Textural class		
Coarse (sandy)	4.9	6.1
Medium (loamy)	5.0	6.6*
Fine (clayey)	6.1	6.9
Drainage class		
Poorly drained[b]	5.0	7.2*
Imperfectly drained[c]	5.3	6.2
Well-drained[d]	5.3	5.8
Total	5.3	6.5*

* Difference between means for white pine and Norway spruce are significantly different (student's t-test at $P < .05$).
[a] from Gordon et al. (1989).
[b] poorly drained: poor to imperfectly drained, distinct mottles at <16 in below surface, moist to very moist moisture regime.
[c] imperfectly drained: imperfectly to moderately well-drained, distinct mottles at 16–40 in below surface, fresh to moderately moist moisture regime.
[d] well-drained: moderately well- to rapidly drained, distinct mottles below 40 in depth, fresh to dry moisture regime.
[b,c,d] from Ontario Institute of Pedology (1985).

LITERATURE CITED

BECK, D. E. 1971. Height growth patterns and site index of eastern white pine in the southern Appalachians. For. Sci. 17:252–260.

BROWN, J. H., AND J. L. STIRES. 1984. Growth of white pine in relation to soils and topography in southeastern Ohio. Ohio Agric. Res. and Dev. Ctr. Res. Bull. 1164. 14 p.

CHAPMAN, L. J., AND D. F. PUTNAM. 1973. The physiography of southern Ontario. Univ. of Toronto Press, Toronto, Ont. 386 p.

GEVORKIANTZ, S. R., AND R. ZON. 1930. Second-growth white pine in Wisconsin. Wis. Agric Exp. Stn. Bull. 98. 41 p.

GORDON, A. M., P. A. WILLIAMS, AND E. P TAYLOR. 1989. Site index curves for Norway spruce in southern Ontario. North. J. Appl For. 6:23–26.

GROSS, H. L. 1985. Impact of pests on the white pine resource of Ontario. Proc. Entomol. Soc Ont. 116:33–37.

HANNAH, P. R. 1971. Soil-site relationships for white scotch and red pine plantations in Vermont. Univ. of Vermont Agric. Exp. Stn. Bull 667. 25 p.

HEGER, L. 1968. A method of constructing site-index curves from stem analyses. For. Chron 44(4):11–15.

HUSCH, B., AND W. H. LYFORD. 1956. White pine growth and soil relationship in southeastern New Hampshire. Univ. of New Hampshire Agric. Exp. Stn. Stn. Tech. Bull. 95. 29 p.

HUSCH, B., C. I. MILLER, AND T. W. BEERS. 1982 Forest mensuration. Wiley, New York, 402 p.

LEAK, W. B., ET AL. 1970. Yields of eastern white pine in New England related to age, site, and stocking. USDA For. Serv. Res. Pap. NE-176 15 p.

LITTLE, T. M., AND F. J. HILLS. 1978. Agricultural experimentation, design and analysis. Wiley, Toronto, Ont. 350 p.

MACIVER, D. C., S. MASAROVICH, AND D. C FAYLE. 1985. Tree ring increment measurer For. Resour. Group, Min. Natur. Resour , Queen's Park, Toronto, Ont. 27 p.

ONTARIO INSTITUTE OF PEDOLOGY. 1985. Field manual for describing soils. Ed. 3. O.I.P , Guelph Agric. Cent. and Univ. of Guelph, Guelph, Ont. 33 p.

PLONSKI, W. L. 1971. Normal yield tables for black spruce, jack pine, aspen, white birch, tolerant hardwoods, white pine and red pine for Ontario. Ont. Dep. Lands and Forests, Queen's Park, Toronto. 39 p.

SAS INSTITUTE INC. 1985. SAS/STAT guide for personal computers, version 6 edition. SAS Institute Inc., Cary, NC 27511-8000, USA. 378 p

SMITHERS, L. A. 1954. Thinning in red and white pine stands at Petawawa Forest Experiment Station. Can. Dep. North. Aff. and Nation Res. Silv. Res. Note No. 105. Ottawa, Ont 52 p.

TAYLOR, E. P., AND R. K. JONES. 1986. Soil interpretation and training for forestry 1981–1985 in central and southwestern region 6e and 7e Ont. Inst. Pedol., Guelph, Ont. 66 p.

WRAY, D. O. 1985. Securing the future of white pine in Ontario. Proc. Entomol. Soc. Ont 116:109–110.