

Site Index Curves for Norway Spruce in Southern Ontario¹

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ABSTRACT. Four dominant or codominant Norway spruce trees from each of 55 sites were destructively sampled and the annual height growth determined by stem analysis. The sampled sites were stratified by soil textural class (coarse, medium, and fine) and depth to distinct mottling (0–16, 16–40, and 40 in.). Two sets of anamorphic site index curves were constructed using a total age of 30 years (SI30), and breast height age of 25 years (SIBH25) as base ages. The mean SI30 from Ontario (53 ft) was found to be 17.8% higher than the mean values published from Vermont (45 ft) and currently used in Ontario. SIBH25 values had a range of 34.6 to 74.8 ft with a mean of 55.3 ft. Analysis of variance showed significant differences in SIBH25 due to soil texture and drainage class, and in years to breast height (BH) due to drainage class. SIBH25 was highest on sites with loamy soils and distinct mottling at 16–40 in. It took an average of 6.5 years for seedlings to reach BH with a range of 3 to 12 years. Years to BH was lowest on sites with sandy soils and those with distinct mottling below 40 in.

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Norway spruce is a native European species that has been widely planted in eastern North America since the 1800s and in southern Ontario since the early 1900s. Norway spruce has been found to have excellent growth rates under a wide range of soil tex-

ture and moisture regimes in New York (Jokela et al. 1986), Ontario (Taylor and Jones 1986), and Quebec (MacArthur 1964). The latter suggested that Norway spruce be planted in favor of white spruce on old-field sites, and Jokela et al. (1986) suggested it as a replacement for red pine on imperfectly drained soils. Although Norway spruce grows well under southern Ontario conditions, red pine and white pine have been more commonly used in reforestation.

In recent years there has been concern over the viability of some of these red and white pine plantations in southern Ontario. For example, red pine growing on calcareous soils have been observed to exhibit symptoms similar to those found by Stone et al. (1954) associated with red pine on poorly drained sites. These symptoms are a decline in growth and vigor and frequent mortality, in severe cases, after 30 years of age. It is suspected that the presence of free carbonates in shallow C horizons are the causal factors (Carter 1981). Similar but less severe problems have also been observed in plantations of white pine on calcareous soils. White pine is also subject to attack by the white pine weevil (*Pissodes strobi* Peck), often resulting in multiple stems and limited merchantability. White pine blister rust (*Cronartium ribicola* Fisch.) is not a serious problem in southern Ontario; however, where it does occur, high mortality rates can result. Both pine species are susceptible to a variety of pathogens, notably, *Scleroderris* canker (*Gremmeniella abietina* (Lagerb.) Morelet.), *Fomes* sp., and *Armillaria* sp.

The problems associated with the viability of red and white pine plantations from pathogens and decline on calcareous soils have increased the need for reliable information on alternative species such as Norway spruce. Norway spruce tends to maintain a single leader after weevilling, is not susceptible to white pine blister rust, and is not severely affected by *scleroderris* canker. Although Norway spruce plantations have failed on swampy and extremely dry sites, the species is relatively tolerant of a va-

riety of soil conditions, including imperfectly drained soils (MacArthur 1964). Normal growth and vigor have also been observed in Norway spruce plantations established on soils derived from calcareous parent materials.

Until the present, there were no local site index curves and limited site quality information available for Norway spruce in this region. To facilitate management, Norway spruce site index curves generated in Vermont (Hannah 1972) and volume tables from the United Kingdom (Hamilton and Christie 1971) have been used. The objectives of this project were: (1) to develop site index curves for Norway spruce growing in southern Ontario, (2) to compare these new site index curves to those currently in use, and (3) to determine the influence of broad soil drainage and texture classes on the growth of Norway spruce in southern Ontario.

STUDY AREA

The study was conducted in central, southern Ontario, an area highly subject to glacial influence (Fig. 1). Most of the soils are depositional in nature, and the topography is gentle to rolling and highly amenable to agriculture. The soils tend to be sandy, but this varies, depending on the local parent material (Chapman and Putnam 1973). Much of the area is underlain by dolomitic bedrock, from which the calcareous parent material for many of the soils was derived.

The rural 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. Historically, forest plantations have been established on abandoned agricultural land and on windblown sands. Hardwood woodlots in the region are normally regenerated by natural means.

MATERIALS AND METHODS

Sample data were collected from unthinned Norway spruce plantations of normal stocking growing under a range of soil drainage and texture conditions within the study area (Fig. 1). Soil conditions were divided into nine categories (cells) consisting of all combinations of three soil drainage and textural classes. Depth to distinct mottling (DDM) was selected as the most readily identifiable diagnostic feature within the profile that inferred soil drainage. Soil drainage conditions were broken into three classes, by DDM (0–16, 16–40, and 40+ in.). In Ontario, these DDM ranges correspond to poorly to imperfectly drained, imperfectly to moderately

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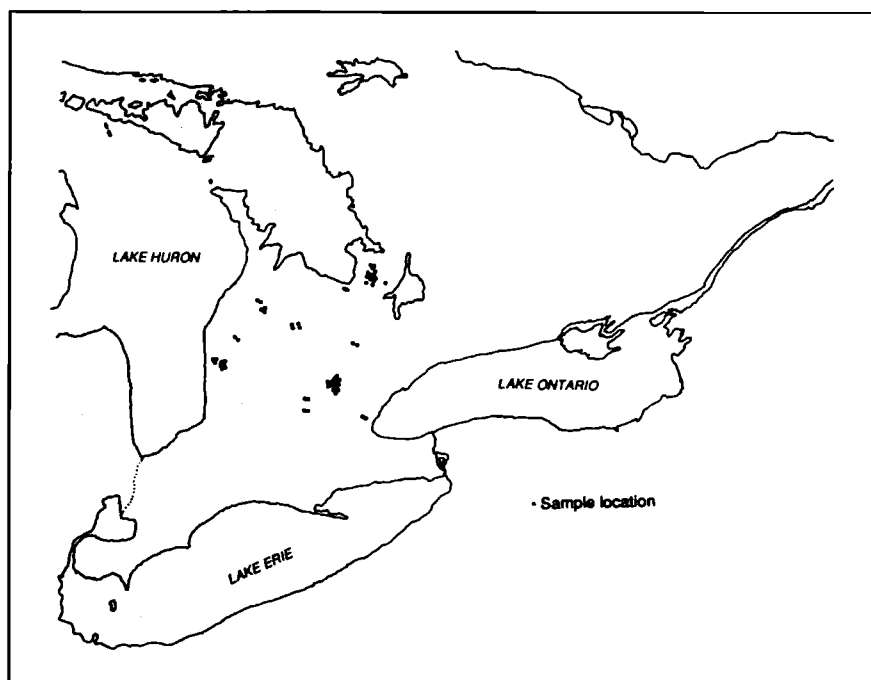


Fig. 1. Location of the study area. Each point represents a sampled stand.

well-drained and moderately well to rapidly drained soils, respectively (Ontario Inst. Pedol. 1985). To simplify discussion, these drainage classes will be referred to in this work as poorly, imperfectly, and well-drained.

The three soil texture classes were coarse (sandy), medium (loamy), and fine (clayey). Very coarse, rapidly drained (excessively dry) and very poorly drained (saturated) soils were not sampled in this study. It is not known whether attempts to establish plantations, with subsequent failure, occurred on these sites. A goal of eight sites per category was chosen; however, this was not always possible because of insufficient plantation area in some of the site categories. A total of 55 plots and 220 trees were sampled in well-established plantations; the stratification of these plots within the three drainage/texture classes is given in Table 1.

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 Jones et al. (1983) and Ontario Institute of Pedology (1985). At each sampling point four dominant or codominant trees were selected that were apparently free from defects. 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 at the University of Guelph until measured.

Annual rings were counted using the Tree Ring Increment Measurer (TRIM) (MacIver et al. 1985). The TRIM is a computer-aided system for collecting and analyzing stem analysis data. The system is based on APPLE computer technology and was developed by the Ontario Ministry of Natural Resources. Data were transferred from the APPLE to IBM compatible computers to facilitate analysis. 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). The height for 19 trees with BH age less than 25 and greater than 22 years was extrapolated by adding the average height growth increment for the last 5 years to the total height of the tree for each year less than 25. One tree with a BH age of 20 and six trees with height growth patterns

symptomatic of weevil damage were deleted from the data set.

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 contractual obligations and to facilitate comparison of the generated curves with those currently in use in Ontario (Hannah 1972). Hannah (1972) published harmonized curves that were derived from total height and plantation age data. In addition, the application of Heger's (1968) method to stem analysis data results in curves that more closely reflect tree growth than other anamorphic methods that result in harmonized curves.

Analysis of variance (ANOVA) was conducted using height growth data on an individual tree basis. 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 $\times$ texture interaction term and the plots within drainage $\times$ texture term, were also included in the model. Duncan's Multiple Range test was used to compare the means of each of the three soil drainage and texture classes. PCSAS General Linear Models Procedure (SAS Institute, Inc. 1985) was used to conduct the statistical analysis.

RESULTS AND DISCUSSION

Age

The total age of the sampled trees ranged from 27 to 58 years, and breast height age ranged from 20 to 54 years. It took an average of 6.5 years for the trees to reach breast height, with a range of 3 to 12 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

SI30 curve specific to southern Ontario are given in Figure 2, superimposed on the SI30 curves published by Hannah (1972). The average SI30 for the trees from Ontario was 53 ft (17.8% higher than Vermont), with a range of 32 to 68 ft (Table 2). SIBH25 curves were also constructed and are

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

Soil textural class	Depth to distinct mottling (in.)			Total
	0-16 (poorly drained)	16-40 (imperfectly drained)	40+ (well-drained)	
Coarse (sandy)	8	6	8	22
Medium (loamy)	8	8	10	26
Fine (clayey)	4	3	0	7
Total	20	17	18	55

Table 2. Average, minimum and maximum SI30 (ft) for Norway spruce in southern Ontario (this study), and Vermont (Hannah 1972).

	Vermont	Ontario	Difference (%)
Average SI30	45	53	17.8
Minimum SI30	27	32	18.5
Maximum SI30	62	68	9.7

(6.6 years). The mean for the clayey soil group was highest due to the long period of time (7.7 years) it took trees growing on poorly drained clays to reach breast height. The lowest site index values were also found on these sites.

ANOVA (Table 4) showed marginally significant differences in SIBH25 due to both soil texture and drainage ($P < 0.1$). Significant differences were also found in years to BH due to soil drainage ($P < 0.01$); however, differences in years to BH due to soil texture were not significant. The drainage $\times$ texture interaction term was not significant for SIBH25 or years to BH although significant differences were found among plots within soil drainage/texture cells for both variables.

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, resulting in some of the observed variation. Sampling under winter conditions may have also resulted in additional error in the assignment of inappropriate class levels to some of the sites with borderline characteristics. While these problems are typical to site classification and field operations in general, they serve to highlight the benefits of increased soils training to forestry personnel.

APPLICATIONS

Site index using breast height age is considered to give a better estimate of site potential because of differences in the number of years it takes a tree to reach breast height on different sites. In the present study, Norway spruce site index curves for unthinned plantations are presented for both breast height age (SIBH25 curves) and total age (SI30 curves). Where breast height age data is available, the SIBH25 curves should be employed. Where this data is lacking (e.g., when working from inventory data from harvested or heavily thinned plantations), the SI30 curves should be used.

The results of the soil-site data presented could prove helpful in the allocation of planting stock or cultural treatments to particular sites. In this study, trees from poorly drained sites had a significantly greater years to BH than trees from better drained sites. Nonetheless, height growth in the former still averaged greater than 2 ft/yr once breast height was reached. This suggests that Norway spruce is a good candidate for these wetter sites, but that extra measures such as competition control, large nursery stock, and greater care in planting might be helpful in getting the trees to breast height at an earlier age.

Norway spruce showed good site index values across the range of soil textures sampled in this study. Lower site index values were found on sandy soils, but the differences were relatively minor, especially considering that trees on these sites took the least time to reach breast height. Foresters might consider other species on poorly drained, clayey sites since this study showed that Norway spruce had the lowest site index and took the

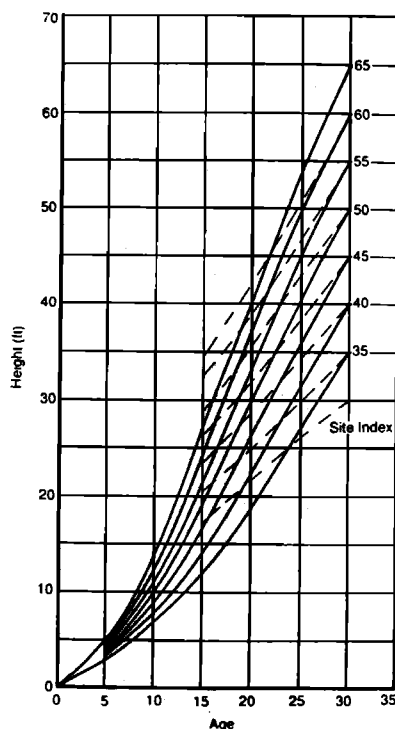


Fig. 2. SI30 curves for Norway spruce growing in southern Ontario (dark lines) superimposed on SI30 curves for Norway spruce in Vermont (dashed lines; Hannah 1972). The equation for the average SI30 line from Vermont is Total height = $7.85894 + 1.20478(\text{age}) + 0.00098(\text{age})^2$. For the Ontario curves, the equation is Total height = $1.15334 + 0.62006(\text{age}) + 0.00055(\text{age})^2$. Age units = years.

given in Figure 3. SIBH25 had a range of 35 to 75 ft with an average of 55.3 ft.

Soil-Site Factors

The number of years to BH and the SIBH25 are given in Table 3 for each of the nine soil drainage/texture class cells. Means by soil drainage and texture class are also presented. Years to BH decreased with increasing coarseness in soil texture and improving drainage. The highest SIBH25 were found in loamy soils; clayey, imperfectly drained soils; and sandy, well-drained soils.

Duncan's Multiple Range Test Duncan's showed that poorly drained sites had a significantly lower SIBH25 and a significantly greater number of years to BH than well or moderately well drained sites (Table 3). Significant differences were found in SIBH25 among the means of all three soil texture classes, with loamy soils supporting the highest site index, and sandy soils the lowest. Mean separation tests also showed that sites with sandy soils took significantly fewer years (6.1) to reach breast height. Trees on sites with clayey soils took the longest to reach breast height (6.9 years) but the time was not significantly longer than that for loamy soils

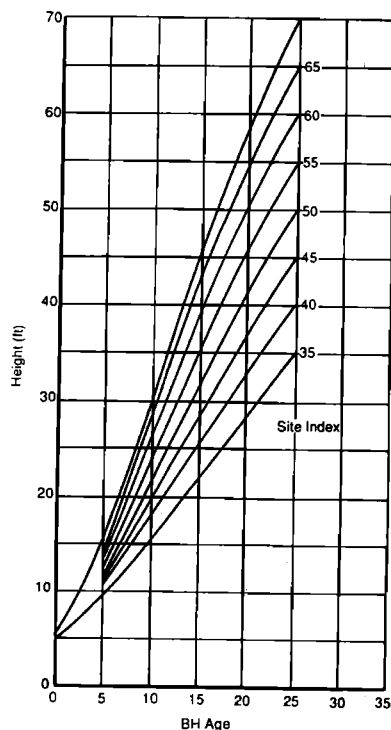


Fig. 3. SIBH25 curves for Norway spruce growing in southern Ontario. Age units = years.

Table 3. Average SIBH25 and the average number of years to reach breast height by soil drainage and texture class.

Dependent variable (by textural class)	Depth to distinct mottles (in.)			Mean
	0-16 (poorly drained) ¹	16-40 (imperfectly drained) ¹	40 + (well: drained) ¹	
SIBH25 (ft)				
Coarse (sandy)	52.3	51.5	54.8	53.0a
Medium (loamy)	54.1	60.0	58.2	57.5b
Fine (clayey)	49.6	61.2	—	54.6c
Mean	52.5d	57.2e	56.7e	55.3
Years to breast height				
Coarse (sandy)	7.2	5.9	5.3	6.1a
Medium (loamy)	7.2	6.6	6.3	6.6ab
Fine (clayey)	7.7	5.9	—	6.9b
Mean	7.2d	6.2e	5.8e	6.5

Means within texture and drainage classes followed by the same letter are not significantly different ($P < 0.05$)

¹ Poorly drained: poor to imperfectly drained, distinct mottles at 0-16 in. below surface, moist to very moist moisture regime.

Imperfectly drained: imperfectly to moderately well-drained, distinct mottles at 16-40 in. below surface, fresh to moderately moist moisture regime.

Well-drained: moderately well to rapidly drained, distinct mottles below 40 in. in depth, fresh to dry moisture regime.

(Ontario Inst. Pedol. 1985)

Table 4. Results of ANOVA for the effects of soil drainage and texture on SIBH25 and the number of years to breast height.

SIBH25				
Source	df	MS	F-value	p > F
Soil texture	2	506.2938	2.62	0.0837
Soil drainage	2	532.5151	2.75	0.0741
Texture × drainage	3	266.9056	1.38	0.2607
Plots (texture × drainage)	47	193.5158	21.73	0.0001
Years to breast height				
Source	df	MS	F-value	p > F
Soil texture	2	7.2669	1.44	0.2462
Soil drainage	2	43.0243	8.55	0.0008
Texture × drainage	3	5.4904	1.09	0.3622
Plots (texture × drainage)	47	5.0320	2.86	0.0001

longest to reach breast height in these areas.

CONCLUSIONS

The results of this study are in general agreement with other research findings regarding site quality and Norway spruce growth in eastern North America (MacArthur 1964, Jo-

kela et al. 1986, Taylor and Jones 1986). Comparisons of site index information for southern Ontario and previously used information from Vermont (Hannah 1972) showed that site index was substantially greater in southern Ontario. Given the magnitude of differences between the information from the two areas, upward adjustments of growth predictions for

Norway spruce in the study area are in order.

The excellent growth rate and resilience to insect and disease pests suggest that Norway spruce should be utilized more frequently as an alternative to red or white pine for plantation management in southern Ontario. □

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