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Estimating Height and Volume of Nova Scotian Grown Norway Spruce

Introduction

Norway spruce (*Picea abies* (L.) Karst.) is native to Europe and one of its major commercial species. In Nova Scotia, the earliest recorded establishment of Norway spruce was around 1925. From that point onward, Norway spruce has been gaining popularity, especially since the early 90's. In 1994, 4.8 million Norway spruce seedlings were planted in Nova Scotia (37 % of all trees planted), compared to 1.5 million, five years previously. The increasing popularity of this exotic is attributable to its superior growth on a variety of sites. A previous study (NSDLF, 1990) found that the average Land Capability (LC) for Norway spruce was 10.4 m³/(ha · yr) compared to 6.6 m³/(ha · yr) for native softwoods growing on the same sites. This indicates that Norway spruce is capable of outgrowing most native conifers. However, a number of questions arise as to whether growth and yield information developed for native conifers in

Nova Scotia can be applied to Norway spruce. For example:

- Does Norway spruce have a height growth pattern similar to our native softwood species (Figure 1)?
- Can Nova Scotia's Forest Land Capability curves be used to estimate the site index of Norway spruce (Figure 1)?
- Can existing standard volume tables be used to estimate Norway spruce volume?

To provide preliminary answers to these questions, stem analysis studies were carried out in six older Norway spruce stands located on mainland Nova Scotia (Figure 2). All were plantations except for the direct seeded stand at Tanner Lake, Kings County. None of the stands were cleaned or thinned. The plantations varied in age from 33 to 57 years at stump height.
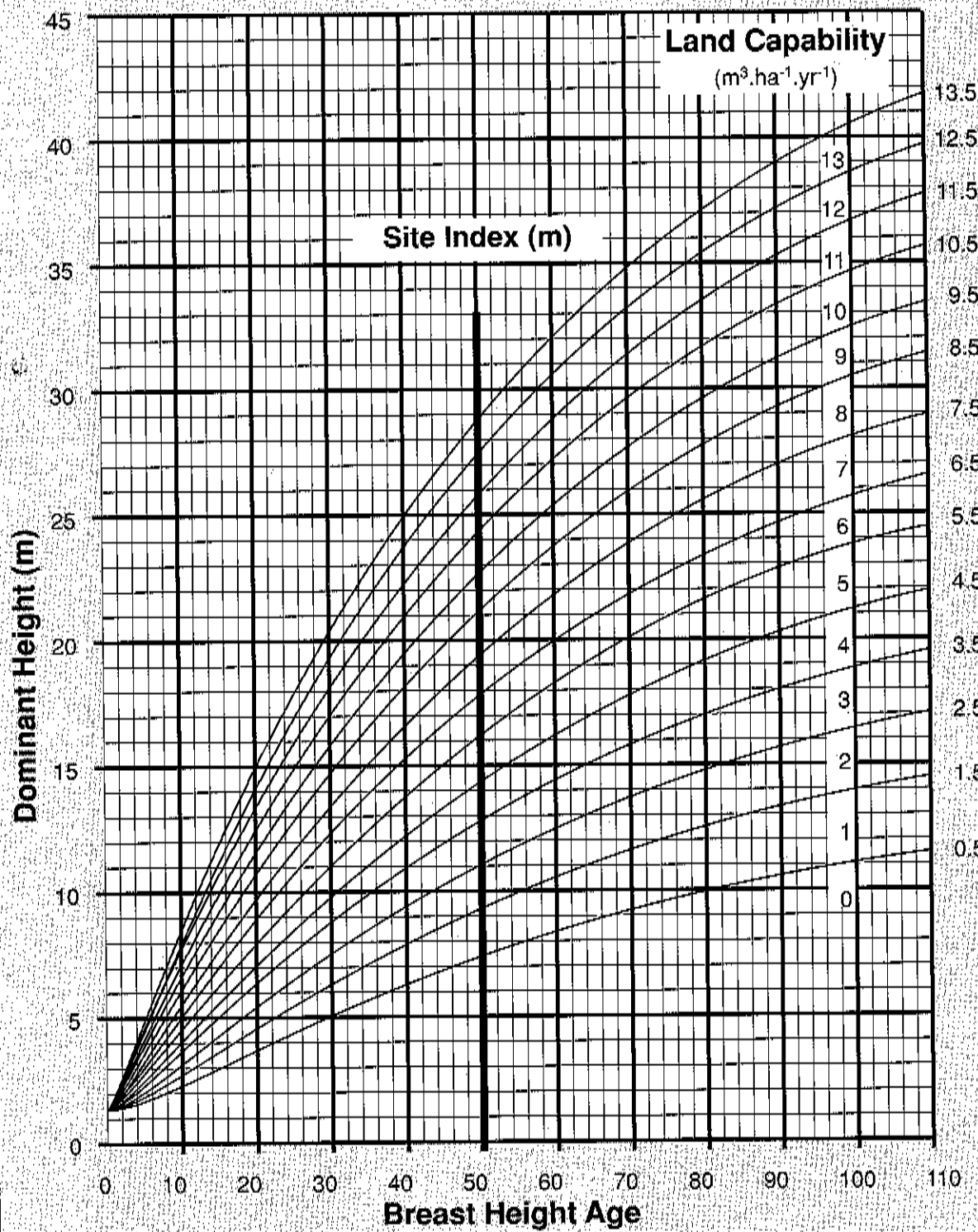
Canadä

Nova Scotia

Figure 1. Land capability and site index for Nova Scotia softwoods based on breast height age and dominant height.

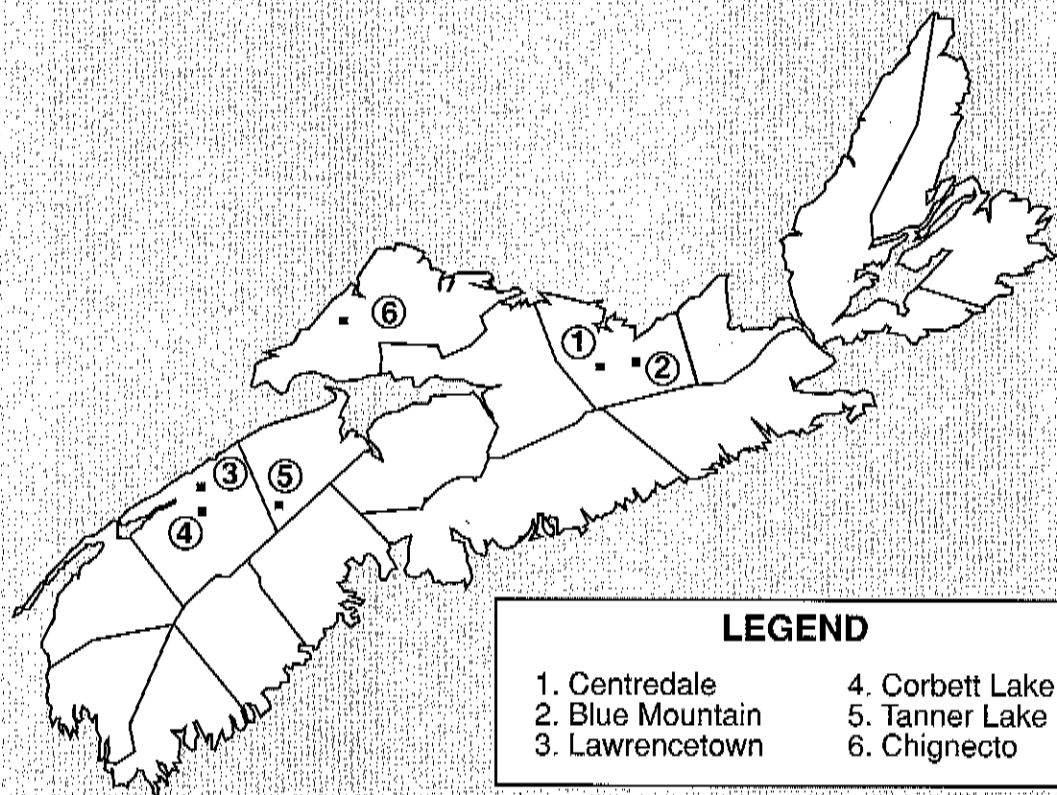**Figure 2. Location of Norway spruce study sites in Nova Scotia.**

LEGEND

1. Centredale
2. Blue Mountain
3. Lawrencetown
4. Corbett Lake
5. Tanner Lake
6. Chignecto

Methods

Height Growth Pattern

Stem analyses were performed on two domi-
nant, free-growing trees at each of the six sites
(12 trees in total). These trees were generally
growing in fully stocked areas. The procedures
used can be found in Appendix I. From the
stem analyses data, height versus age curves
were produced. These dominant height growth
patterns were then compared against those for
native softwoods as predicted by Nova Scotia's
Forest Land Capability (LC) curves (NSDNR,
1993). The purpose of this comparison was to
determine whether the Land Capability (LC)
curves can be used to accurately predict height
growth of Norway spruce.

Tree Volume

Individual tree volumes for Norway spruce,
derived from stem analyses, were compared
to corresponding volumes for various soft-
wood species, as predicted by Honer's
Standard Volume Tables (1983) (Appendix
II). The purpose of the comparison was to
determine which of Honer's species esti-
mates best predict the volume of Norway
spruce trees. For this test, three comparison
measures were used, total volume, mer-
chantable volume, and cylindrical form fac-
tor (Husch, Miller, and Beers, 1972)
(Appendix I).

Results and Discussion

Height Growth

By superimposing the height-age data for individual Norway spruce over the native softwood LC curves (Figure 3) it can be seen that the height growth patterns of Norway spruce are similar to native species. The height growth of all sampled Norway spruce fell between the LC 8.5 and 12.5 curves except at the Tanner Lake site, where the trees grew along the LC 6.5 curve.

The stem analyses data were then examined on an individual tree basis by comparing the height versus age relationship of each Norway spruce to the predicted height growth pattern curves for native softwood species of the same site index (NSDNR, 1993). Figure 4 indicates that the height growth of the twelve Norway spruce trees are very similar to that of native softwood species. Table 1 shows the average difference (expressed in percent) between predicted and actual height by age classes and location. The largest difference occurred in the 1-10 year age class where the predicted height averaged 7% higher than the actual height. The smallest difference occurred in the 31-40 and 41-50 year age classes where the differences averaged less than 1%. At all locations, over all age classes, differences in predicted versus actual height ranged from ±1% to ±3%, with the exception of Lawrencetown. On this site, the predicted height was approximately 18% greater than the actual Norway spruce height. On average, over all sites and age classes, the predicted heights were 3.4% higher than actual Norway spruce heights.
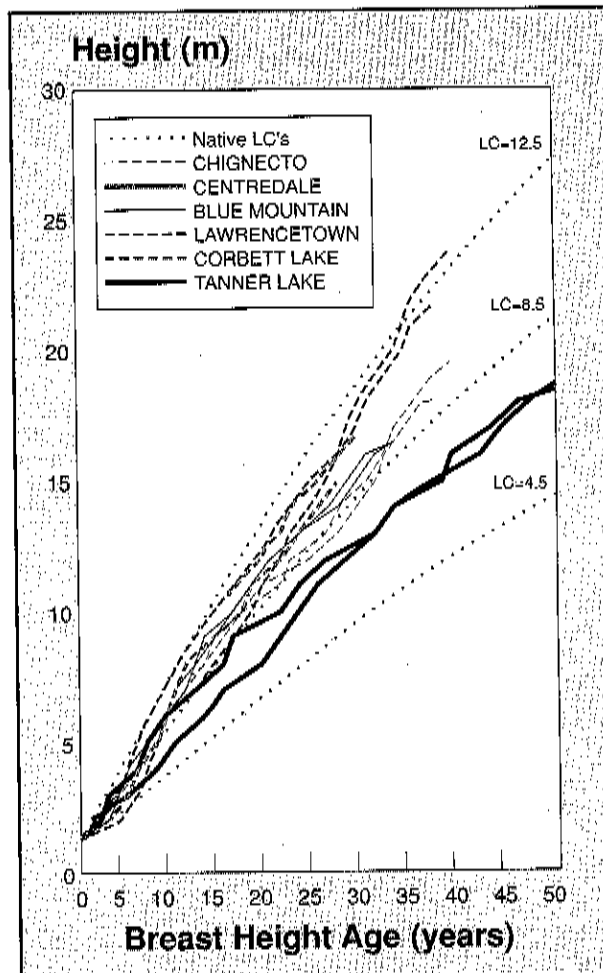
Figure 3. Comparison of the height growth patterns for individual Norway spruce with selected Forest Land Capability curves for native softwoods.
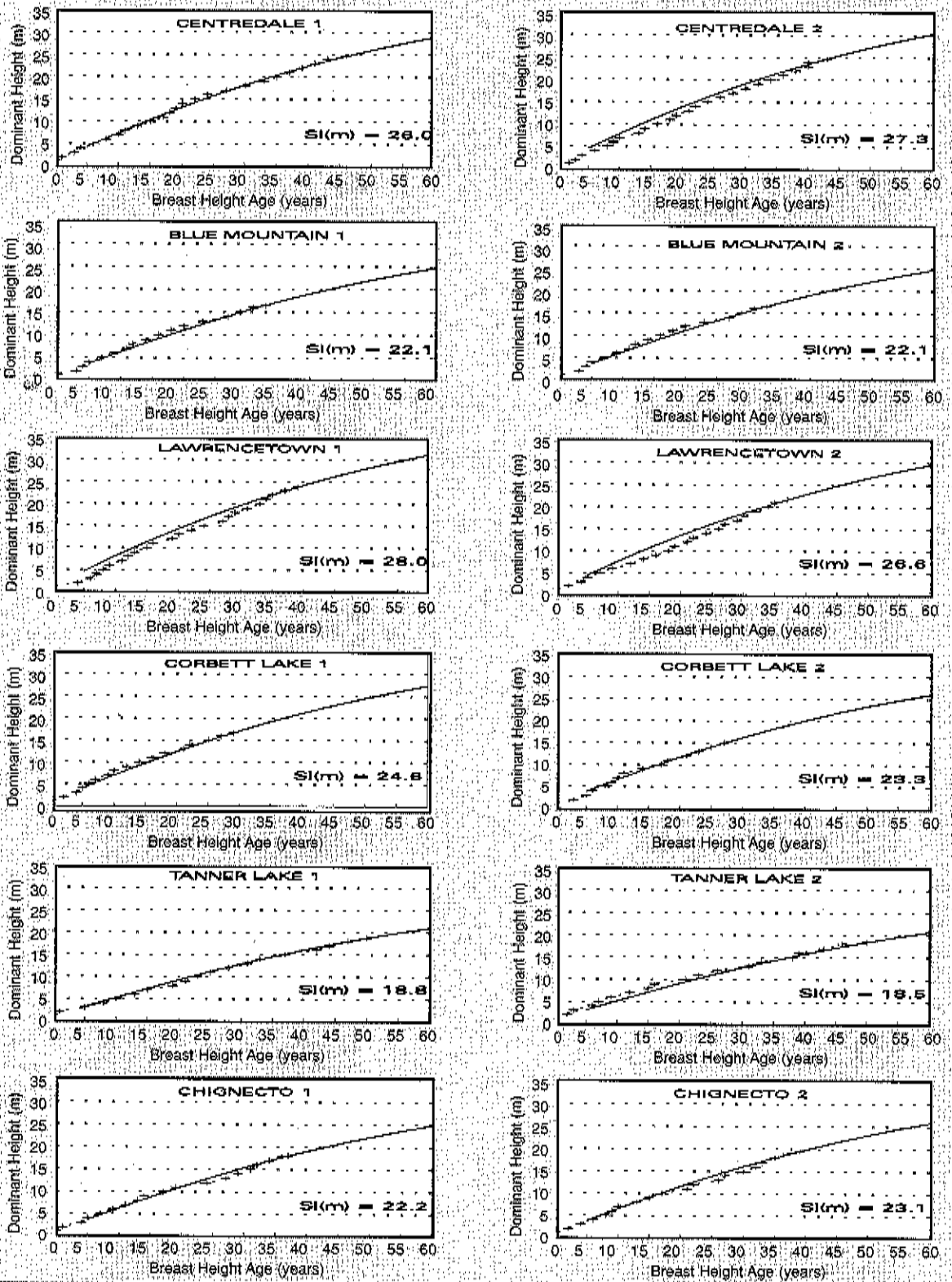
Figure 4. Actual height growth (+) of Norway spruce versus predicted height (-) based on native softwood species with the same site index. Site index (SI) is expressed as the height in metres of dominant trees at 50 years of age at breast height.

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Table 1. Average percent difference between actual and predicted[1] heights of Norway spruce.

Location		AVERAGE PERCENT (%) DIFFERENCE[2]											
		1-10 years		11-20 years		21-30 years		31-40 years		41-50 years		Overall (1-50)	
CENTREDALE	1	-0.20	3.57	0.65	2.52	-2.44	-0.38	1.51	0.27	-1.32	-1.32	-0.13	1.58
	2	6.79		5.15		0.99		-0.73		-		3.29	
BLUE MTN.	1	4.08	2.60	-7.74	-8.58	-1.41	-2.62	-1.72	-1.72	-	-	-2.13	-2.86
	2	1.36		-9.58		-3.52		-		-		-3.59	
LAWRENCE-TOWN	1	57.92	38.32	14.35	18.26	10.18	10.00	2.90	2.32	-	-	20.70	17.64
	2	18.72		23.73		9.87		1.36		-		14.27	
CORBETT LAKE	1	-0.39	6.34	-7.25	-5.36	-1.77	-0.55	-	-	-	-	-2.59	1.28
	2	14.19		-3.47		1.09		-		-		5.74	
TANNER LAKE	1	0.11	-8.85	7.37	-3.34	3.45	-0.64	0.64	-0.33	1.61	-0.10	2.54	-3.15
	2	-16.02		-14.04		-6.10		-1.06		-2.66		-8.83	
CHIGNECTO	1	-4.84	1.04	-4.21	-2.08	7.92	7.72	1.11	1.39	-	-	-1.00	1.93
	2	5.93		1.47		7.60		1.66		-		4.70	
ALL SITES		7.05		1.32		2.97		0.85		-0.45		3.37	

[1] Predicted height derived from Nova Scotia softwood LC curves for native species of the same site index.

[2] % DIFFERENCE = ((Predicted - Actual) + Actual) x 100%

Tree Volume

The total and merchantable volumes of Norway spruce (based on stem analyses) were compared to Honer's estimates for softwood species. Of the species included in Honer's tables; lodgepole pine (*Pinus contorta* Dougl. ex Loud.), red spruce (*Picea rubens* Sarg.) and red pine (*Pinus resinosa* Ait.) produced the closest estimates. Norway spruce generally had higher total volumes and less taper than the estimates for softwood species of the same height and diameter (Table 2, Appendix III) except for lodgepole pine. Similarly the merchantable volume for Norway spruce was underestimated by using Honer's estimates (Table 3, Appendix IV).

Table 2. Total volume, form factors, and differences[1] between actual and predicted total volumes for Norway spruce.

| | | | | STEM ANALYSES | | HONER'S ESTIMATE | | | |
| | | | | NORWAY SPRUCE | | LODGEPOLE PINE | | | |
Location	Tree #	DBH (cm)	HT (m)	Total Volume (m^3)	FF[2]	Total Volume (m^3)	FF[2]	Total Volume Difference[1] m^3	%
CENTREDALE	1	28.9	24.65	0.737	0.46	0.734	0.45	-0.003	-0.43
CENTREDALE	2	29.7	24.73	0.759	0.44	0.777	0.45	0.018	2.32
BLUE MOUNTAIN	1	27.0	16.50	0.417	0.48	0.449	0.48	0.033	7.87
BLUE MOUNTAIN	2	30.1	16.50	0.543	0.48	0.559	0.48	0.016	2.86
LAWRENCETOWN	1	28.2	23.80	0.666	0.45	0.678	0.46	0.011	1.68
LAWRENCETOWN	2	27.9	21.70	0.606	0.46	0.612	0.46	0.006	0.97
CORBETT LAKE	1	23.4	16.70	0.306	0.43	0.341	0.48	0.035	11.40
CORBETT LAKE	2	18.0	14.95	0.179	0.47	0.183	0.48	0.004	2.22
TANNER LAKE	1	22.4	18.75	0.372	0.50	0.347	0.47	-0.025	-6.64
TANNER LAKE	2	22.5	18.45	0.362	0.49	0.345	0.47	-0.017	-4.68
CHIGNECTO	1	25.5	18.05	0.453	0.49	0.434	0.47	-0.018	-4.00
CHIGNECTO	2	25.4	19.55	0.476	0.48	0.463	0.47	-0.013	-2.69
Average		-	-	-	0.46	-	0.47	0.004	0.91

[1] Differences obtained by subtracting Honer's estimate of total volume from the actual total volume of Norway spruce derived from stem analyses.

[2] Denotes cylindrical Form Factor.

Table 3. Differences[1] between actual and predicted merchantable volumes for Norway spruce.

Location	Tree #	DBH (cm)	HT (m)	STEM ANALYSIS		HONER'S ESTIMATE			
				NORWAY SPRUCE		LODGEPOLE PINE			
				Merchantable Volume (m³)	% Merch.	Merchantable Volume (m³)	% Merch.	Volume Difference	
								m³	%
CENTREDALE	1	28.9	24.65	0.716	97.2	0.699	95.3	-0.017	-2.40
CENTREDALE	2	29.7	24.73	0.735	96.8	0.742	95.6	0.007	1.00
BLUE MOUNTAIN	1	27.0	16.50	0.398	95.6	0.427	95.1	0.029	7.32
BLUE MOUNTAIN	2	30.1	16.50	0.523	96.3	0.534	95.6	0.011	2.11
LAWRENCETOWN	1	28.2	23.80	0.645	96.8	0.645	95.1	-0.001	-0.08
LAWRENCETOWN	2	27.9	21.70	0.586	96.6	0.582	95.1	-0.004	-0.63
CORBETT LAKE	1	23.4	16.70	0.290	94.6	0.320	93.8	0.030	10.42
CORBETT LAKE	2	18.0	14.95	0.167	93.2	0.167	91.2	0.000	-0.06
TANNER LAKE	1	22.4	18.75	0.355	95.7	0.323	93.1	-0.033	-9.16
TANNER LAKE	2	22.5	18.45	0.347	95.9	0.325	94.2	-0.022	-6.40
CHIGNECTO	1	25.5	18.05	0.435	96.1	0.411	94.7	-0.023	-5.37
CHIGNECTO	2	25.4	19.55	0.457	96.1	0.438	94.7	-0.019	-4.12
AVERAGE		-	-	0.471	95.9	0.468	94.4	-0.003	-0.61

[1] Differences obtained by subtracting Honers estimate of merchantable volume from the actual total volume of Norway spruce derived from stem analyses.

Total Volume

Lodgepole pine, the closest estimator, had an average total volume 0.9 percent (range of -6.6 to 11.4%) higher than Norway spruce (Table 2). Red spruce, the second closest estimator, had an average total volume difference of 1.0 percent (-8.2% to 10.6%) less than Norway spruce (Appendix III, IV). Red pine was the least accurate of the three closest softwood species, underestimating the total volume of Norway spruce by 2.6 percent (-9.9% to 7.5%) (Appendix III, IV).

The cylindrical form factors for Norway spruce were approximately the same as the predicted values according to Honer (Table 2, Appendix III). Norway spruce had an average form factor of 0.46. Predictions using lodgepole pine estimates averaged 0.47 while red spruce and red pine estimates resulted in form factors of 0.46 and 0.45 respectively. The form factors for individual Norway spruce varied from 0.43 to 0.50 but, with one exception, varied little for trees from the same location (Table 2).

Merchantable Volume

Honer's merchantable volume estimates are calculated as a product of the total volume estimate (as previously shown) and a merchantable to total volume ratio (Appendix II). Similar to the total volume results; Honer's lodgepole pine, red spruce and red pine estimates were closest to Norway spruce. For lodgepole pine, Honer's estimates averaged 0.6% (-9.2 to 10.4) low compared to 2.3% (-10.3 to 9.9) and 3.3% low (-11.5 to 7.6) for red spruce and red pine respectively. In terms of the merchantable ratio by itself, red pine estimates were slightly better than the other species averaging 0.7% low; compared to 1.3% and 1.5% low for red spruce and lodgepole pine respectively (Table 3).

SUMMARY / CONCLUSIONS

A stem analyses study of 12 dominant trees from six Norway spruce stands in Nova Scotia, indicated that:

1) Norway spruce has dominant height growth patterns similar to those predicted by LC curves for native softwood species. This indicates that these LC curves can be used to estimate site index for Norway spruce.

2) Norway spruce total and merchantable volumes can be closely estimated by Honer's (1983) volume tables.

3) Honer's lodgepole pine volume tables provide the closest estimates to actual Norway spruce total and merchantable volumes. For the sample of trees studied, lodgepole pine provided estimates within 1% of the actual merchantable and total volume of Norway spruce.

4) Until further estimates become available, Norway spruce volume can be predicted by using the Honer's estimates for lodgepole pine volume.

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Appendix I

STEM ANALYSES PROCEDURE

The stem analysis procedure required the tree to be felled, and cut into sections for further study. The first section, the stump, had a height of 0.15 metres. The second section was cut at breast height, 1.3 metres above ground level. All subsequent sections were cut at even one-metre intervals starting at 2 metres. The remaining length, the top of the tree, was less than or equal to one metre. The age was determined at the top of every section by counting growth rings, and the diameter outside bark was measured and recorded.

CALCULATION PROCEDURE

The bark thickness, and subsequently, the diameter inside bark (D_{ib}) was calculated using the following formula:

$$Y = a + bD + cD^2$$

where,

a,b,c = regression coefficients
(a=0.008887, b=0.056381, -0.000087)
D = diameter outside bark (inches)
Y = double bark thickness (inches)

D_{ib} was then used to calculate total volume (inside bark) and merchantable volume (inside bark), where merchantable volume excludes the stump (0.15 m) and top (7.6 cm D_{ib} limit). The formula for a cylinder was used for the stump, Smalian's formula was used for the bole, and the formula for a paraboloid was used for the top.

The form factor calculated is a measure of the total volume of a tree compared to the volume of a geometric solid and therefore, is one indicator of taper. In this case, the cylindrical form factor is used and the tree volume is compared to the volume of a cylinder (Husch, Millers, and Beers, 1972). The form factor was determined using measured values from the stem analysis. The equation is as

follows:

$$FF=TV_{ob} \div (g \times h)$$

where,

FF   = form factor
TV_{ob} = total tree volume outside bark (metres³)
g   = cross sectional area inside bark at breast height(metres²)
h   = height (metres)

Site Index (SI) is defined as the projected average height of the five tallest trees at age 50. It is used to numerically evaluate site quality for even-aged pure stands (Husch, Miller, and Beers, 1972). Some of the stem analysis trees were not yet 50 years old at breast height, necessitating their projection using the following native softwood SI curve equation:

$$H=4.5+(SI-4.5) \times [(1-e^{(-b_2 \times 50)})^{-b_3 \times SI^{b_4}}] \times [1-e^{(-b_2 \times BAGE)})^{b_3 \times SI^{b_4}}]$$

where,
H   = height (feet)
SI   = site index (feet)
e   = naperian constant (2.7182818)
BAGE = Breast Height Age
b_2 = 0.019070142,
b_3 = 3.063581805,
b_4 = -0.228589318

After the SI of the stem analysis tree was determined, the corresponding heights and ages (SI curve) for a tree of that Site Index were generated, using the formula shown above, and compared against actual height.

Appendix II

Honer's (1983) equations were used to determine the total and merchantable volume of native softwoods. Honer's equations used are as follows:

TOTAL VOLUME

$$TVOL = (0.0043891 \times DIAM^2 \times (1-0.04365 \times a)^2) \div (b+0.3048 \times c \div HT)$$

where,

TVOL = Total Volume inside bark(metres³)
DIAM = Diameter at breast height
outside bark (cm)
HT = Total height (metres)
a,b,c = regression coefficients
(species dependant)

Example for lodgepole pine:

a = 0.118, b = 0.694 and c = 343.896

MERCHANTABLE VOLUME

$$MVOL = TVOL \times (MVRAT)$$

$$MVRAT = (a+bX=cX^2)$$

where,

MVOL = Merchantable Volume inside bark
(metres³)
MVRAT = Ratio of Merchantable to
Total Volume
a,b,c,d = Regression coefficients
(species dependent)

Example for lodgepole pine:

a = 0.9658 , b = -0.1278 ,
c = -0.8108, d = 0.118

X is determined in the following equation:

$$X = TOPD^2_{ib} \div (DIAM^2 \times (1-.0.04365 \times d)^2) \times (1+STMPHT \div HT)$$

where,

TOPD$_{ib}$ = Top diameter inside bark (cm)   STMPHT = Stump height (metres)
DIAM = Diameter at breast height   HT = Total height (metres)
outside bark (cm)

APPENDIX III : Form factors and differences[1] between actual and predicted total volumes for Norway spruce.

Location	Tree #	STEM ANALYSIS NORWAY SPRUCE Total Volume (m³)	FF[2]	HONER'S ESTIMATES RED SPRUCE Total Volume (m³)	FF[2]	Volume Difference m³	%	RED PINE Total Volume (m³)	FF[2]	Volume Difference m³	%
CENTREDALE	1	0.737	0.46	0.704	0.44	-0.033	-4.45	0.708	0.44	-0.028	-3.85
CENTREDALE	2	0.759	0.44	0.745	0.43	-0.014	-1.84	0.750	0.44	-0.009	-1.19
BLUE MOUNTAIN	1	0.417	0.44	0.447	0.47	0.030	7.18	0.434	0.46	0.017	4.12
BLUE MOUNTAIN	2	0.543	0.46	0.555	0.47	0.012	2.20	0.539	0.46	-0.004	-0.72
LAWRENCETOWN	1	0.666	0.45	0.652	0.44	-0.014	-2.09	0.654	0.44	-0.012	-1.81
LAWRENCETOWN	2	0.606	0.46	0.595	0.45	-0.012	-1.93	0.591	0.45	-0.015	-2.51
CORBETT LAKE	1	0.306	0.43	0.339	0.47	0.032	10.59	0.329	0.46	0.023	7.53
CORBETT LAKE	2	0.179	0.47	0.183	0.48	0.004	2.29	0.176	0.46	-0.002	-1.35
TANNER LAKE	1	0.372	0.50	0.341	0.46	-0.030	-8.16	0.335	0.45	-0.037	-9.87
TANNER LAKE	2	0.362	0.49	0.340	0.46	-0.022	-6.12	0.333	0.45	-0.029	-7.99
CHIGNECTO	1	0.453	0.49	0.429	0.47	-0.024	-5.28	0.419	0.45	-0.033	-7.33
CHIGNECTO	2	0.476	0.48	0.454	0.46	-0.022	-4.61	0.447	0.45	-0.029	-6.06
Average		-	0.46	-	0.46	-0.014	-1.02		0.45	-0.013	-2.58

[1] Differences obtained by subtracting Honers estimate of merchantable volume from the actual total volume of Norway spruce derived from stem analysis.

[2] Cylindrical Form Factor.

APPENDIX IV: Differences[1] between actual and predicted merchantable volume for Norway spruce.

Location	Tree #	STEM ANALYSIS		HONER'S ESTIMATES							
		NORWAY SPRUCE		RED SPRUCE				RED PINE			
		Merchantable Volume (m³)	% Merch.	Merch. Volume (m³)	% Merch.	Volume Difference		Merch. Volume (m³)	% Merch.	Volume Difference	
						(m³)	%			(m³)	%
CENTREDALE	1	0.716	97.2	0.671	95.4	-0.045	-6.27	0.679	95.9	-0.037	-5.12
CENTREDALE	2	0.735	96.8	0.712	95.6	-0.023	-3.07	0.721	96.1	-0.014	-1.88
BLUE MOUNTAIN	1	0.398	95.6	0.425	95.2	0.027	6.75	0.415	95.7	0.017	4.34
BLUE MOUNTAIN	2	0.523	96.3	0.531	95.6	0.008	1.49	0.518	96.1	-0.004	-0.85
LAWRENCETOWN	1	0.645	96.8	0.621	95.2	-0.024	-3.69	0.627	95.8	-0.018	-2.83
LAWRENCETOWN	2	0.586	96.6	0.566	95.2	-0.020	-3.38	0.566	95.7	-0.020	-3.37
CORBETT LAKE	1	0.290	94.6	0.319	94.1	0.029	9.92	0.312	94.7	0.022	7.55
CORBETT LAKE	2	0.167	93.2	0.168	91.7	0.001	0.60	0.162	92.1	-0.004	-2.56
TANNER LAKE	1	0.355	95.7	0.319	93.4	-0.037	-10.32	0.315	94.0	-0.041	-11.46
TANNER LAKE	2	0.347	95.9	0.321	94.4	-0.026	-7.59	0.316	95.0	-0.031	-8.86
CHIGNECTO	1	0.435	96.1	0.407	94.8	-0.028	-6.48	0.400	95.4	-0.035	-7.93
CHIGNECTO	2	0.457	96.1	0.430	94.8	-0.027	-5.86	0.426	95.4	-0.031	-6.71
AVERAGE		-	95.9	-	94.6	-0.014	-2.32		95.2	-0.016	-3.31

[1] Differences obtained by subtracting Honer's estimate of merchantable volume from the actual total volume of Norway spruce derived from stem analysis. Percent calculated by dividing this difference by actual and multiplying by 100.

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