FOREST RESEARCH REPORT

NOVA SCOTIA DEPARTMENT OF LANDS AND FORESTS
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SITE INDEX CURVES FOR HARDWOODS IN NOVA SCOTIA

INTRODUCTION

Hardwood stands cover 1,051,600 hectares and mixed hardwood/softwood stands cover 1,142,800 hectares in Nova Scotia to account for 55% of the total forested area. Hardwoods also account for 38% of Nova Scotia's total growing stock of 248,070,000 m^3 (Anon. 1987). To wisely manage this important resource, it is essential that information be available on site quality and its relationship to hardwood growth and yield. Site index curves have been commonly used as a convenient way to provide this information. More specifically these curves define a quantitative relationship between height, age and site index (defined here as height at 50 years). They, in turn, can be utilized to estimate yields at rotation age when used in conjunction with basal area growth estimates.

Site index (SI) curves have been derived and utilized for many years in Canada. For example, Plonski (1956) developed some of the earliest SI curves and associated volume tables for Ontario. He used graphical techniques to produce guide curves from mean stand height and age data. Later Payandeh (1973) and others fit mathematical functions to these type curves. This enabled users to predict SI without using graphical methods. In more recent times researchers (e.g. Carmean, 1981) have concentrated on building more flexible polymorphic SI curves via non-linear regression and other techniques.

Some of the problems associated with SI curves are:

1) They may be based on temporary sample plot data. This type of data is less accurate than data gathered from permanent sample plots or stem analysis.

2) Site index may be correlated with age in the data causing the SI curves to be biased.

3) The mathematical model and statistical methods used to fit height and age data do not have appropriate shapes and characteristics for SI analysis.

Refer to Smith (1984) for a more complete discussion of these problems.

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METHODS

To avoid many of the aforementioned SI curve inadequacies the Nova Scotia hardwood SI curves were derived using:

1) stem analysis data,
2) a simple, "sigmoid shaped" model to represent the height, age relationship,
3) a weighting procedure that utilized older stands in determining the height age relationship, and
4) a grouping procedure to give equal representation to as wide a range of sites as represented in the data.

Stem analysis was performed on 10 dominant free growing trees taken from each of 94 different stands.
Each tree was sectioned every 1.25 metres and the growth rings counted in the field. The stands were selected according to the following criteria:

1) fully stocked (100% crown cover),
2) even-aged,
3) pure (80% of basal area in one species),
4) on uniform sites, and
5) they must represent a range of sites (Land Capability classes of from three to five as designated by Bailey and Mailman, 1972).

Table 1. Breakdown of sampled stands by species, site index and age.

Species	SI Class (metres)							Total Stands
	<10	10-12	12-14	14-16	16-18	18-20	>20	
Largetooth Aspen (ltA)			1[a] (78)[b]	1 (91)	4 (56-73)	2 (57-64)		8
Red Maple (rM)			2 (67-86)	9 (45-77)	5 (47-57)	1 (46)		17
Red Oak (rO)	1 (73)	4 (41-72)	3 (71-73)	5 (53-79)	1 (57)			14
Sugar Maple (sM)		1 (61)	8 (49-83)	4 (47-59)	3 (49-52)	1 (49)		17
White Ash (wA)				4 (59-88)	4 (61-64)	2 (46-67)	2 (48)	12
White Birch (wB)			1 (59)	8 (52-66)	3 (47-61)			12
Yellow Birch (yB)		5 (63-76)	1 (81)	3 (54-58)	5 (50-55)			14
	1	10	16	34	25	6	2	94

a. number of stands

b. range of average stand ages in years at stump height

The following non-linear regression model introduced by Richards (1959) and Chapman (1961) was used to estimate a height versus age curve for each site.

$$HT = b_1 \ (1-e^{-b_2 \ AGE})^{b_3} \qquad [1]$$

where,
HT = dominant height in metres
AGE = dominant tree age in years (stump height)
b_1 = regression coefficient defining maximum height
b_2 = regression coefficient defining overall growth rate
b_3 = regression coefficient defining early growth rate
e = base of the natural logarithms

The curves derived for each species were grouped according to SI into at least three groups, representing lower, mid-range and higher SI. A guide curve was chosen for each group based on the stand age, SI and height growth pattern. In choosing a guide curve, priority was given to older stands to the extremes of the lower and higher site groups and the middle of the mid-range. Next, the mean value of the b_2 and b_3 coefficients, that partially define the shape of these guide curves, were calculated for each species. These mean values were in turn used to determine the b_1 coefficient associated with a range of SI heights by using Equation [1] and forcing the curve through the SI height at AGE = 50 years. For example the b_1 value for a white birch stand of SI = 13 metres is:

$$SI = b_1 \ (1-e^{-b_2 \ AGE})^{b_3}$$

$$b_1 = SI/(1-e^{-b_2 \ AGE})^{b_3}$$

$$b_1 = 13/(1-e^{-b_2 \ 50})^{b_3}$$

where b_2 and b_3 were determined as described above for white birch. The result is a series of b_1, SI data pairs for each species. The calculated b_1 values were readily regressed with SI resulting in the following expression for b_1 over a range of SI.

$$b_1 = c_1 \ SI + c_2 \qquad [2]$$

where,
b_1 = as previously defined
c_1 = linear regression coefficient (slope)
c_2 = linear regression coefficient (y - intercept)

By combining Equation [1] and [2] we get the following formula

$$HT = (c_1 \ SI + c_2) \ (1-e^{-b_2 \ AGE})^{b_3} \qquad [3]$$

This equation can be used to generate SI curves for each species and species group. This is accomplished by inserting c_1, c_2, b_2 and b_3 values specific to a species or species group into Equation [3] and generating heights over a range of ages for a particular SI. Table 2 defines these c_1, c_2, b_2 and b_3 values.

Table 2. Parameter values that define site-index curves for a particular species or species group.

Species	Parameters			
	c_1	c_2	b_2	b_3
1tA	1.54	0.065	0.0260	1.355
rM	1.54	0.035	0.0216	1.037
rO	2.06	0.040	0.0118	0.896
sM	1.70	0.000	0.0180	1.019
wA	1.33	0.001	0.0313	1.221
wB	1.60	-0.200	0.0221	1.145
yB	1.83	-0.003	0.0159	1.005
Intolerants (1tA,rM.wB)	1.56	-0.0333	0.0232	1.179
Tolerants (rO,sM,yB)	1.86	0.0122	0.0152	0.973
Intolerants & Tolerants	1.71	-0.0106	0.0192	1.076

RESULTS

Figure 1 shows the SI curves generated using Equation [3] for each species and species group. They also show the coefficient of determination (r^2), standard error of the estimate (S_{yx}) and the number of stem analysis data points used to test the SI curves (n). The r^2 values range from .962 to .972 and the standard error of the estimate from 0.88 to 1.06 metres.

The white ash SI curves appear to be the only curves appreciably different in shape. They show a quicker early growth rate and a slower growth rate in later years compared to the other species. It is therefore recommended, to simplify their use, that two SI curves be utilized. One combined curve for ltA, rM, rO, sM, wB and yB species and a separate curve for wA should be sufficient for most purposes.

Note that by transforming Equation [3] one can calcuate SI class given the height and age of a stand and the appropriate values for c_1, c_2, b_2 and b_3.

$$SI = [HT/(1-e^{-b_2\ AGE})^{b_3} - c_2]/c_1 \qquad [4]$$

To use these SI curves, five dominant, free growing undamaged trees should be measured for total height and age at .15 meters above mean ground level in each even-aged, uniform stand and site of interest. From the mean height and age of these five trees SI can be derived in one of two ways: a) Plot the height and age data on the appropriate set of SI curves. The line closest to the location of this point is considered the SI specified in two meter classes. b) Enter the mean height and age data into Equation [4] along with the appropriate coefficients.

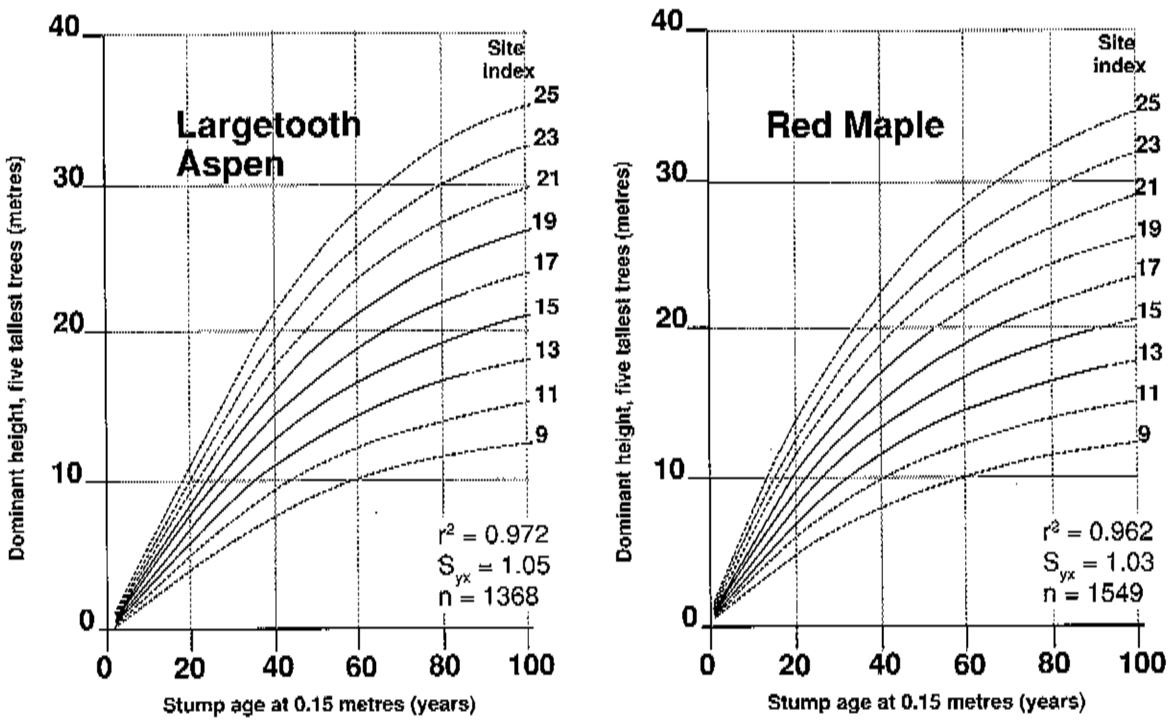
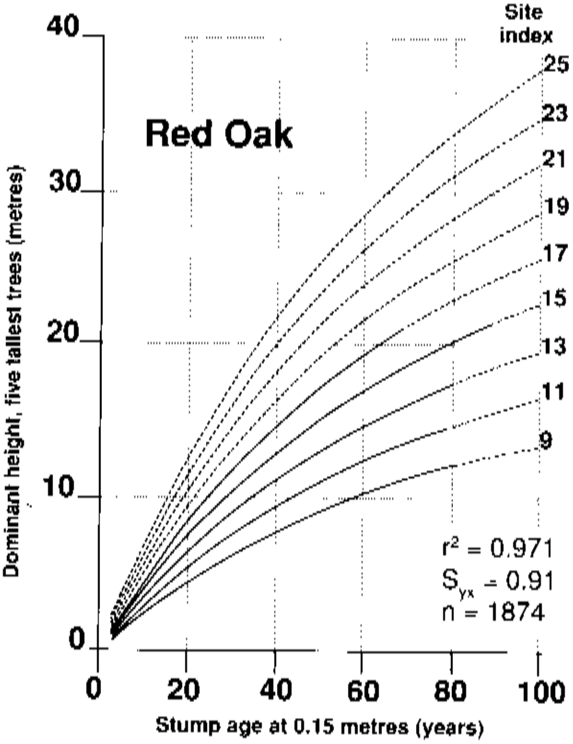
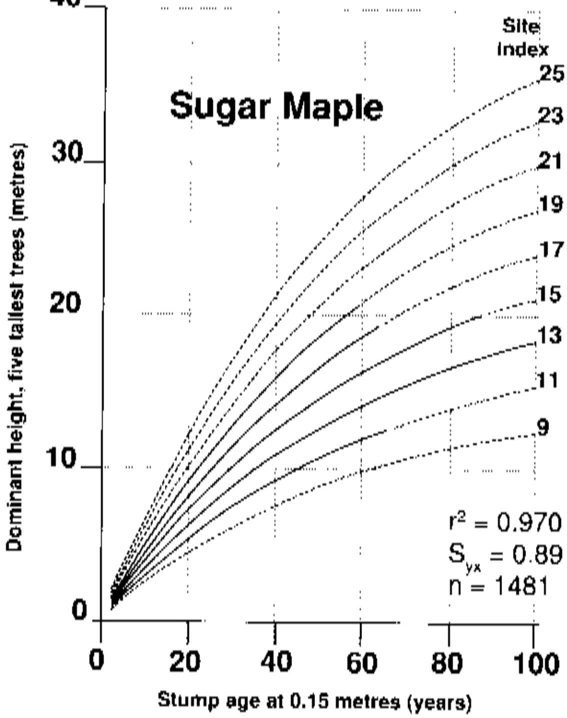
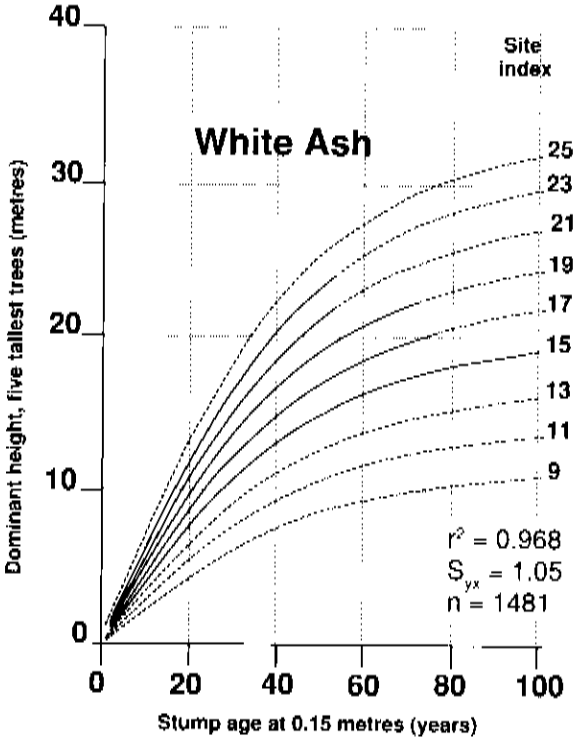


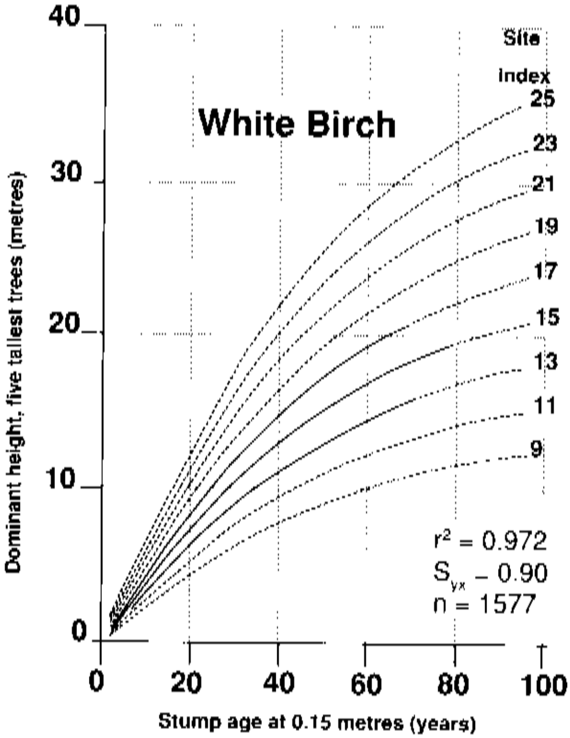
Figure 1. Site index curves for Largetooth Aspen, Red Oak, Red Maple, Sugar Maple, White Ash, White Birch, Yellow Birch, Intolerant, Tolerant, and Intolerant plus Tolerant Species.

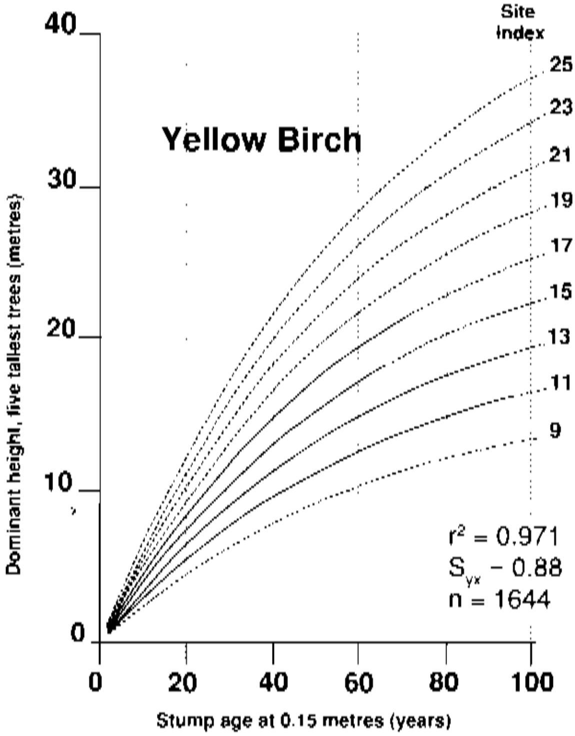
r^2 = Coefficient of determination
S_{yx} = Standard error of estimate
n = Number of stem analysis data points
— — — — — Outside range of data

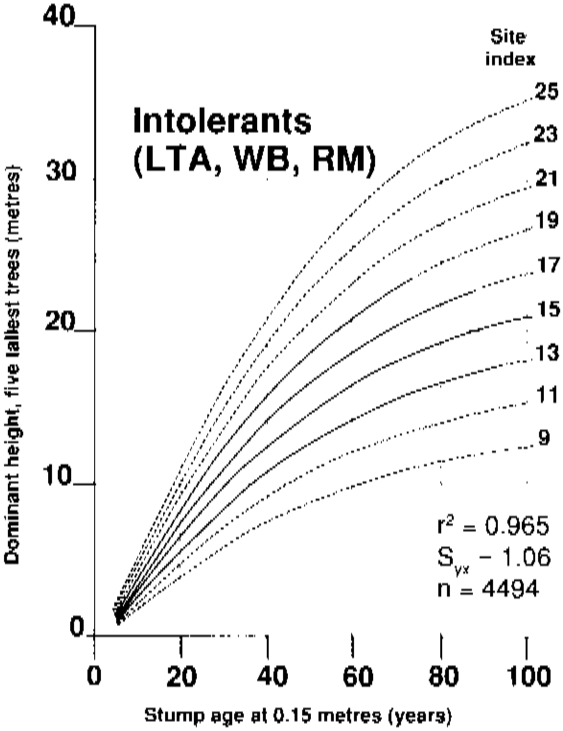

Red Oak
Site index
25
23
21
19
17
15
13
11
9
r² = 0.971
Syx = 0.91
n = 1874
Dominant height, five tallest trees (metres)
Stump age at 0.15 metres (years)
0
10
20
30
40
0
20
40
60
80
100

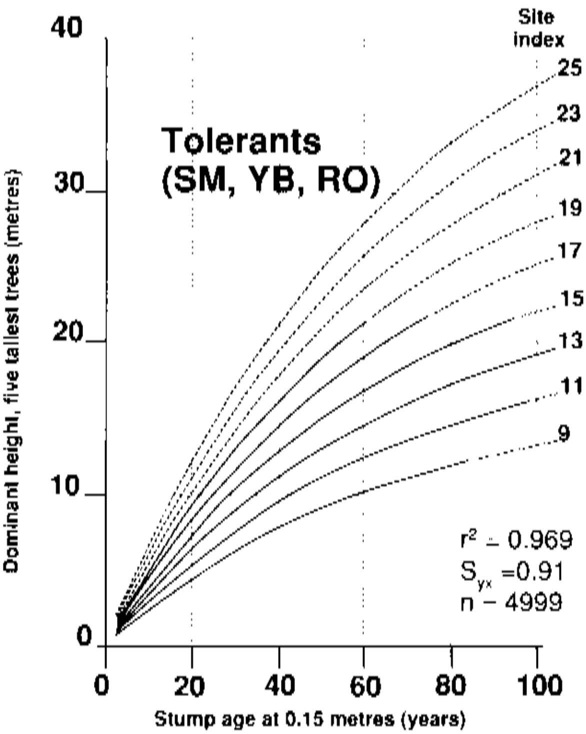

Sugar Maple
Site index
25
23
21
19
17
15
13
11
9
r² = 0.970
Syx = 0.89
n = 1481
Dominant height, five tallest trees (metres)
Stump age at 0.15 metres (years)
0
10
20
30
40
0
20
40
60
80
100

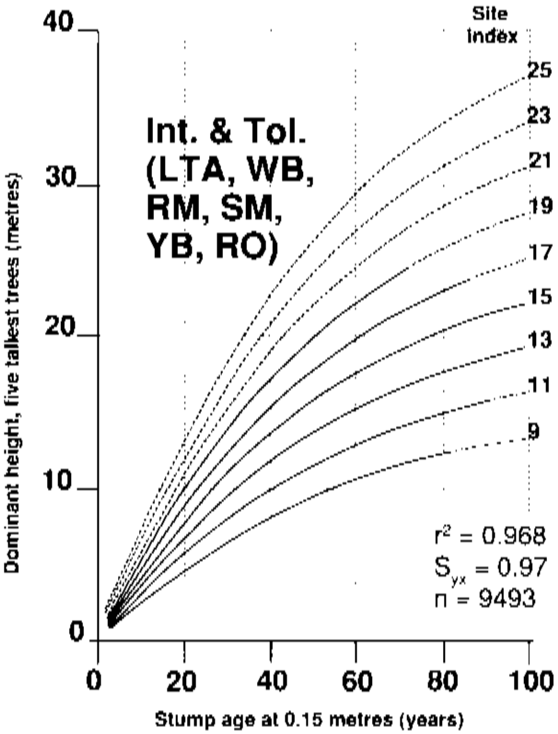

White Ash
Site index
25
23
21
19
17
15
13
11
9
r² = 0.968
Syx = 1.05
n = 1481
Dominant height, five tallest trees (metres)
Stump age at 0.15 metres (years)
0
10
20
30
40
0
20
40
60
80
100


White Birch
Site index
25
23
21
19
17
15
13
11
9
r² = 0.972
Syx – 0.90
n = 1577
Dominant height, five tallest trees (metres)
Stump age at 0.15 metres (years)
0
10
20
30
40
0
20
40
60
80
100


Yellow Birch
Site index
25
23
21
19
17
15
13
11
9
Dominant height, five tallest trees (metres)
Stump age at 0.15 metres (years)
r² = 0.971
Syx - 0.88
n = 1644


Intolerants (LTA, WB, RM)
Site index
25
23
21
19
17
15
13
11
9
Dominant height, five tallest trees (metres)
Stump age at 0.15 metres (years)
r² = 0.965
Syx - 1.06
n = 4494


Tolerants (SM, YB, RO)
Site index
25
23
21
19
17
15
13
11
9
Dominant height, five tallest trees (metres)
Stump age at 0.15 metres (years)
r² - 0.969
Syx =0.91
n - 4999


Int. & Tol. (LTA, WB, RM, SM, YB, RO)
Site index
25
23
21
19
17
15
13
11
9
Dominant height, five tallest trees (metres)
Stump age at 0.15 metres (years)
r² = 0.968
Syx = 0.97
n = 9493

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