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Silviculture for Acadian Spruce-Fir Forests

Soil-Site Relationships

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Silviculture for Acadian Spruce-Fir Forests No. 2

Introduction

Silviculture prescriptions and systems must be informed by the quality of the sites on which the stands are growing. In the Acadian spruce-fir forest, the importance of site is manifest in two ways: sites strongly influence the potential diversity of tree species composition, and sites control the inherent biomass and economic productivity of the stand, especially under intensive production silviculture.

Forest Type Associations

The glacier that melted about 9,000 years ago plastered an unsorted mixture of mineral material across northern New England's landscape. As the forest recolonized the barren landscape, soils began to form, driven by the process of weathering. Over millennia, biological activity and leaching converted raw parent material into recognizable horizons (layers) at different depths. By far the dominant parent material in the northern conifer region (84%, 4.2 million acres of Maine, Appendix 2A) is glacial till – unstratified, unsorted mineral particles ranging from fine silty textures to large boulders. Spatially variable deposition of these tills over undulating, resistant bedrock resulted in the characteristic landscape we see today, where distinct vegetation associations have developed in response to the underlying soil genesis.

The interaction of forest composition and soils is best understood using the concept of the soil catena - the variation in soils formed from the same parent material over a topographic gradient in soil drainage (Fig. 2.1). Red spruce and balsam fir occur over this entire topographic sequence, but tend to dominate stand composition only where poor or excessive soil drainage and limited nutrient availability limit the growth of northern hardwood species, at lowest and highest positions on the landscape. Prior to extensive human disturbance (largely harvesting), Westveld's (1928) described five distinct conditions: Spruce swamps support nearly pure stands of black spruce in mixture with tamarack and northern white-cedar on organic or very poorly drained mineral soils. About 7% of Maine's spruce-fir type (excluding cedar) occurs here, most of which are on organic parent material (Appendix 2A). ***Spruce flats*** occur on shallow glacial tills with impeded drainage (poorly and somewhat poorly drained) at low elevations; red spruce and balsam fir, in various mixtures, dominate these sites with minor components of paper birch and red maple. These

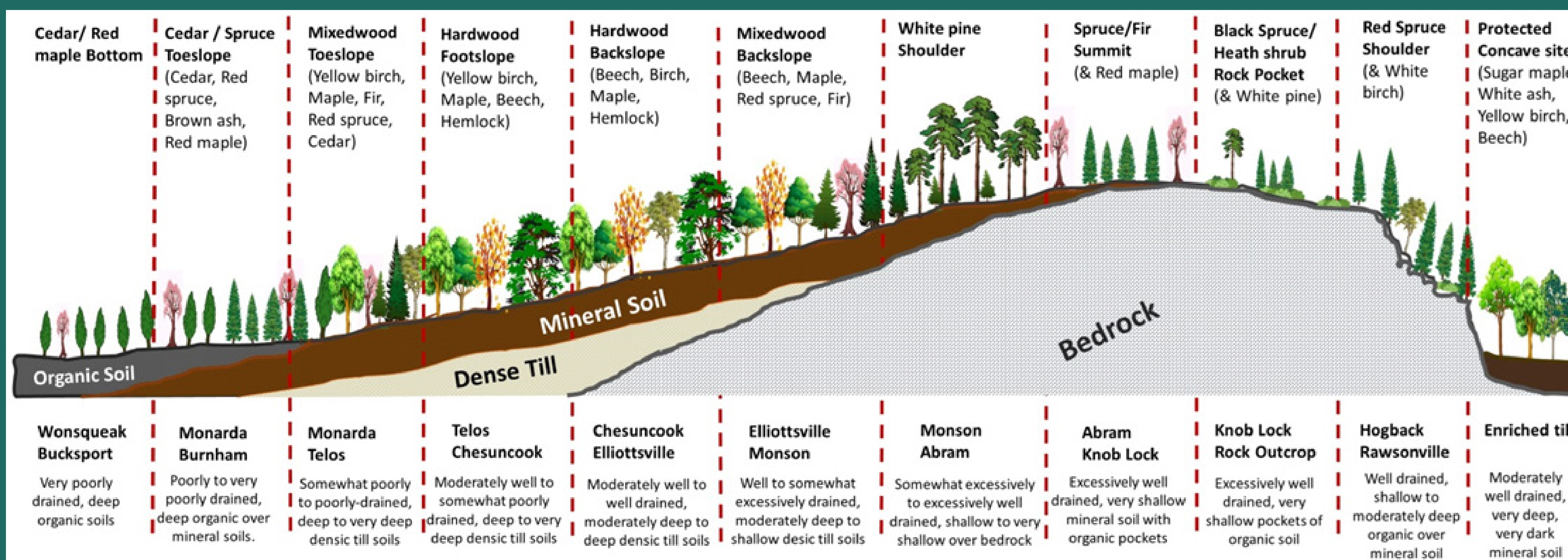

Figure 2.1 Diagram of the Chesuncook-Elliotsville catena in Maine, showing characteristic vegetation patterns in response to glacially driven soil-site gradients. Credit: Jamin Johansen, NRCS.

soils comprise 36% of Maine's spruce-fir type. ***Spruce slopes*** occur on mountainsides above an elevation of about 2,500 feet on shallow, very stony soils. Balsam fir and paper birch represented a minor component of the spruce slope type prior to human disturbance. Only 1.3% of Maine's spruce-fir forest occurs here.

In mid-slope landscape positions where soils are deeper with better drainage, red spruce and fir mix naturally with northern hardwoods (beech, yellow birch, maples) in the ***spruce-hardwood*** or mixedwood type. Westveld distinguished two variants: (1) the yellow birch-spruce subtype, also including red maple and paper birch, occupying lower slopes just above the spruce flats; and (2) the sugar maple-spruce subtype, where red spruce is a minority component in stands dominated by the long-lived, shade-tolerant sugar maple, beech and yellow birch. These mixedwood types on well and moderately well drained soils have been altered the most two from centuries of human disturbance, and it is difficult to estimate their present occurrence. However, 43% of Maine's spruce-fir type occurs on these soils, arguably the most productive sites in the resource as well as the most challenging to manage to maintain their spruce-fir stocking.

White spruce often forms a minor component of spruce-fir stands, especially those dominated by fir. Black spruce is naturally limited to poorly drained swamps, and is rarely found on upland sites. Red and black spruces hybridize extensively (Manley 1972); spruce hybrids are most prevalent on poorly drained sites with a frequent history of disturbance (Osawa 1989). In the southeastern part of Maine's spruce-fir forest in Washington, Hancock and southern Penobscot Counties, eastern hemlock becomes an important stand component on somewhat poorly and moderately well drained soils, often with a minor but economically important component of eastern white pine (Fajvan and Seymour 1993).

Although soils derived from glacial till dominate the landscape, spruce-fir forests do occur on other parent materials. About 6% of the resource in Maine grows on lacustrine-marine sediments, fine clay particles that settled out of glacial lakes or ocean embayments when sea level was much higher. Although inherently fertile, lacustrine soils are typically poorly drained and notable for poor windfirmness owing to shallow rooting depths. At the other extreme, about 5% of Maine's spruce-fir resource occurs as eskers and kame terraces on glacio-fluvial deposits or outwash, formed as coarse sandy and gravelly sediments in glacial meltwaters that carried finer particles out to the ocean. Outwash parent material is excessively drained and very low in nutrients; fir is not well adapted here, but sites can support mixed stands of spruce and pines.

Application

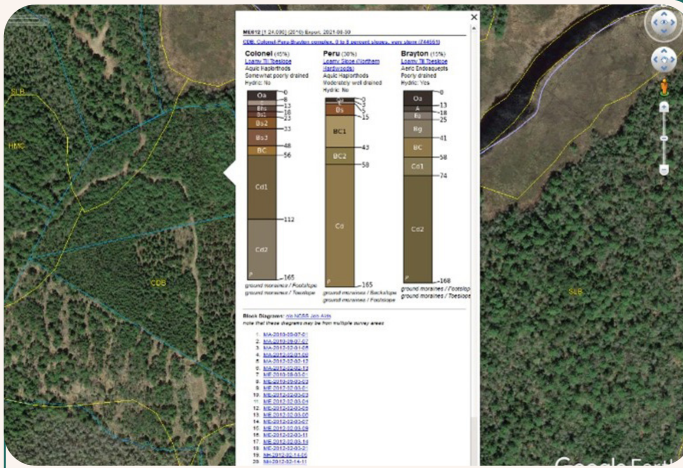

Figure 2.2. Example output from the SoilWeb smartphone application.

The Natural Resources Conservation Service is responsible for soils mapping in the United States and has developed useful web-based tools to facilitate their application. SoilWeb, developed at the University of California Davis (https://casoilresource.lawr.ucdavis.edu/gmap/) is a GPS-enabled mapping tool that shows soil polygons on an interactive web-based map. SoilWeb has a kml add-in for any PC-based Google Earth application, allowing the user to quickly identify soils for any area of interest. SoilWeb works on Android or iPhone smartphones using the phone's GPS capability to identify the soil at the user's current location. Mapped soil symbols are hyperlinked to detailed soil descriptions including profile diagrams (Fig. 2.2).

If you want to make and store custom maps of any property, either as stand-alone products or as layers in a geographic database, then the Web Soil Survey (WSS) is the tool of choice (https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm). WSS allows the user to upload an area of interest (AOI), either as a rectangle or polygon drawn on the zoomable web-based imagery, or precisely using an ESRI shape file. Output includes ESRI shape files for the soil polygons, and a custom soils report with maps and series descriptions as a pdf file.

To make the most of these and other available soil-mapping resources, the forester should place them in the landscape context of the relevant catena to which they belong. NRCS in Maine (2016) has developed the State of Maine Soils Catena Key (https://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/nrcs141p2_002105.pdf) which groups all soil series in Maine by parent material (tills, glacio-fluvial, glacio-lacustrine/marine, alluvium, organic) and drainage class. After identifying the series or association from the tools above, use its drainage class to locate it within the key to identify related soils in its catena. This 4-page pdf document hyperlinks every soil series with a detailed web-based description of its properties. Glacial till catenas are grouped by mineral composition of the bedrock which largely governs their fertility. Tills are further classed as either lodgement (highly compacted under the ice sheet against the bedrock) or supraglacial melt-out (uncompacted mineral materials on top of the ice that were deposited as moraines or terraces).

Although there are nearly 100 different forest soil series in the northern conifer forest, in practice relatively few dominate much of the managed landscape. To aid in learning the series names by parent material and drainage, we have compiled a complete list the more common catenas in the northern conifer forest in Appendix 2B.

Quantifying Site Quality for Growth Predictions

Over a century ago, forest scientists (Graves 1906; Frothingham 1918) chose site index – the height of free-growing dominant trees at a standard index age – over other methods, largely because height growth of dominant trees is largely unaffected by stand density. Site index also has obvious appeal because tree height is one of two variables that determine the volume of trees and stands. This convention has worked well for shade-intolerant species like Douglas-fir and loblolly pine but was once problematic for the northern conifer forest because dominant trees had developed in multi-aged stands experiencing growth suppression when small. McLintock and Bickford (1957) tried to overcome this drawback by constructing an index based on the height of a 14-inch dbh red spruce tree. Although this index showed that the upper asymptotic height of spruces was taller on well-drained uplands than in flats and swamps, it was not related quantitatively to any growth or yield and was never used in practice.

Beginning the in 1970s, literally millions of acres of dense, even-aged stands originating after heavy, repeated harvests from ca. 1880 through 1930, as well as the destructive spruce budworm outbreak of 1913-19, grew to merchantable size and came to dominate the resource (Seymour 1992). Ralph Griffin, silviculturist on the University of Maine forestry faculty, oversaw an extensive effort involving nine graduate students who installed 206 plots in dense, even-aged, pure stands throughout the spruce-fir region of Maine. Above-ground stand metrics were fully quantified, yields were calculated, and extensive analysis of the physical and chemical properties of the soils were completed. After careful screening of these data, Steinman (1992) fitted polymorphic height-development curves for red spruce and balsam fir, with corresponding equations to predict site index from height and breast-height age. Refitted versions of these curves were published as an appendix in Wilson et al (1999), who used these data to fit a density management diagram. Although other equations exist, experience shows that these curves are best suited to the current resource.

Equations are given in Appendix 3C, where curves are also plotted.

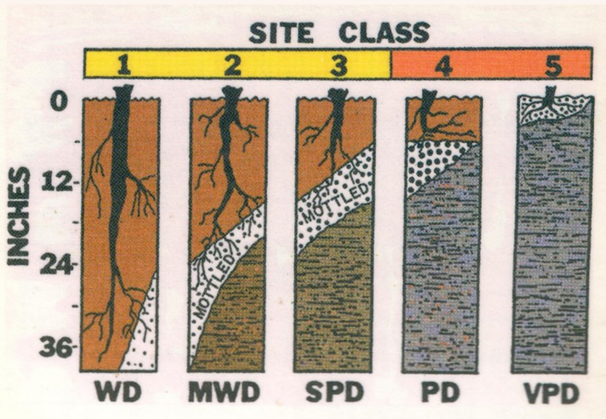

Figure 2.3 Spruce-fir site classes based on soil drainage and rooting depth (from Briggs 1994).

The high variability in soil drainage and depth of the solum across the archetype catena (Fig. 2.1) suggests that site index would vary in a similar fashion across this landscape. Working in fully stocked spruce-fir stands over a range of soil on the Chesuncook-Elliotsville catena, Schiltz and Grisi (1980) and Williams et al (1991) found some differences in site index of balsam fir, but little difference in red spruce, when comparing poorly drained Monarda, somewhat poorly drained Telos, and well drained Chesuncook-Elliotsville soils. In young recently regenerated even-aged stands on poorly and well drained soils on the same catena, Meng and Seymour (1992) found differences in height growth for fir but not for red spruce. Seymour and Fajvan (2001) sampled 698 dominant red spruce trees on 360 plots in eastern Maine, and found an average difference of only 2.6-foot difference in site index between well-drained and poorly drained soils. All these studies exhibited a very wide range in site index within drainage classes, however, showing conclusively that large productivity differences do exist that are only weakly related to soil drainage.

Briggs (1994) used drainage class, quantified as depth to mottling, to construct a site classification guide with five categories, one for each drainage class. Although this guide is widely used to describe sites in the northern conifer region, it has proven difficult to use the Briggs' site classes for any quantitative purpose. Steinman (1992) used the Griffin dataset to relate site index (based on his equations) to physical and chemical soil properties, but never explicitly tested for site index differences among drainage classes. Instead, multiple regressions were fitted using depth to mottling as a continuous variable, which showed only weak importance for spruce and none for fir.

To address this issue, the Griffin dataset was reanalyzed using a general linear model to predict Site Index from soil drainage class. Results showed absolutely no pattern for red spruce (Fig. 2.4) with an average statistically identical site index slightly below 50 for all drainage classes. In contrast, fir responds strongly to the drainage gradient, averaging 45 on the poorly drained end of the spectrum (4 feet lower than spruce) to nearly 55 on well drained sites (7 higher than spruce, Fig. 2.4).

All evidence supports the fact that height growth of red spruce is highly variable across the landscape, but is not related to variation in drainage class. Fir exhibits similar variability in height growth, but in contrast to spruce, is strongly related to soil drainage.

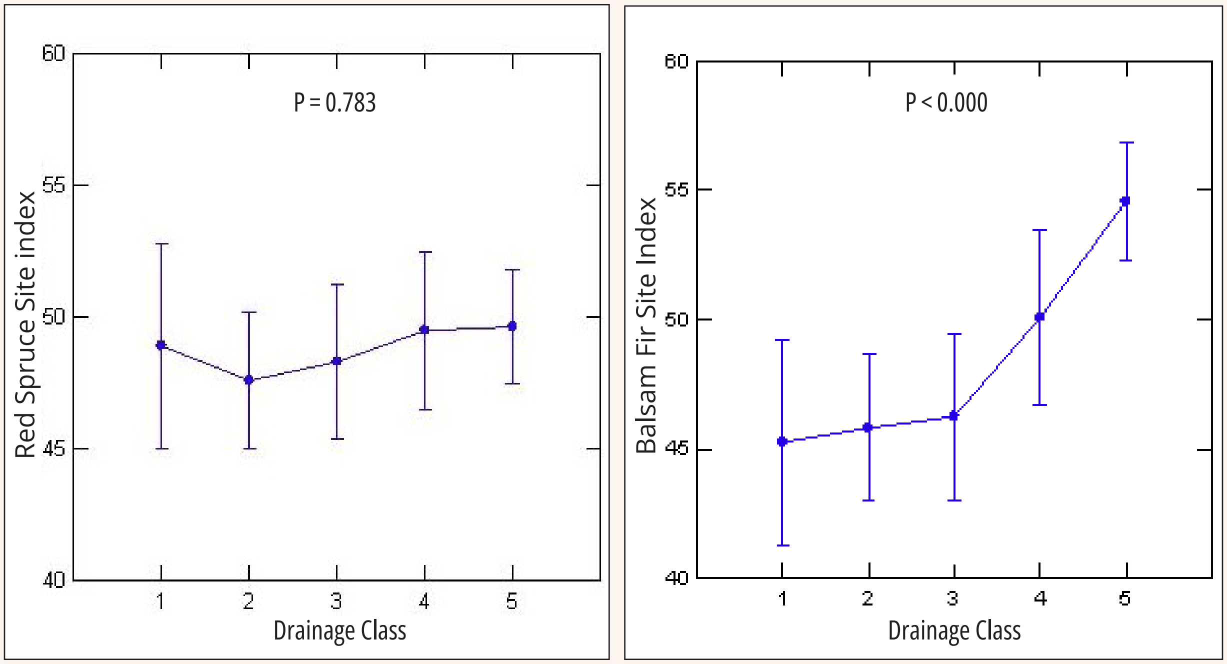

Figure 2.4 Relationship between site index (breast height age 50) with soil drainage class (1 = very poorly drained; 2 = poorly drained; 3 = somewhat poorly drained; 4 = moderately well drained; 5 = well drained) for red spruce and balsam fir, from the Griffin dataset. P values are the probably of no differences in the least-squares means. Bars are one standard error.

Application

The patterns described above have several strong ramifications for quantitative silviculture of northern conifers. First, to predict yields of red spruce stands, you must actually measure the site index; you cannot rely indirectly on any soil properties. This same advice also applies to balsam fir. Although fir site index is, on the average, somewhat higher on better drained soils, the actual within-soil variability is much higher, so accurate predictions require direct measurements.

Second, site indices of red spruce and balsam fir are far from identical, though they appear to converge in the middle of the drainage spectrum. Fir is an excellent candidate for estimating site index; it is ubiquitous throughout the resource; it is usually free-growing once it reaches breast height; and it is easy to core with an increment borer and read the rings to determine breast height age. If needed, red spruce site index can be accurately predicted from fir site index using the following equation derived from the Griffin dataset:

RS_SiteIndex = 19.5 = BF_SiteIndex * 0.605 + DC where DC depends on soil drainage, as follows:

Well drained soils = 0
Moderately well drained soils = -1.2
Somewhat poorly drained soils = 1.7
Poorly drained soils = 1.5, and
Very poorly drained soils = 6.2

For example, a measured balsam fir site index of 40 on very poorly drained soils would equal a red spruce site index of 19.5 + (.605*40) + 6.2 = 51.7 feet.

If you find that the best dominant site trees have periods of narrow rings near the pith, indicating they were suppressed when small, you must determine an equivalent free-growth age to use the site index curves using the procedures described by Seymour and Fajvan (2001; Fig. 2.5). Count all the rings outward from the last narrow ring; this gives the age since release.

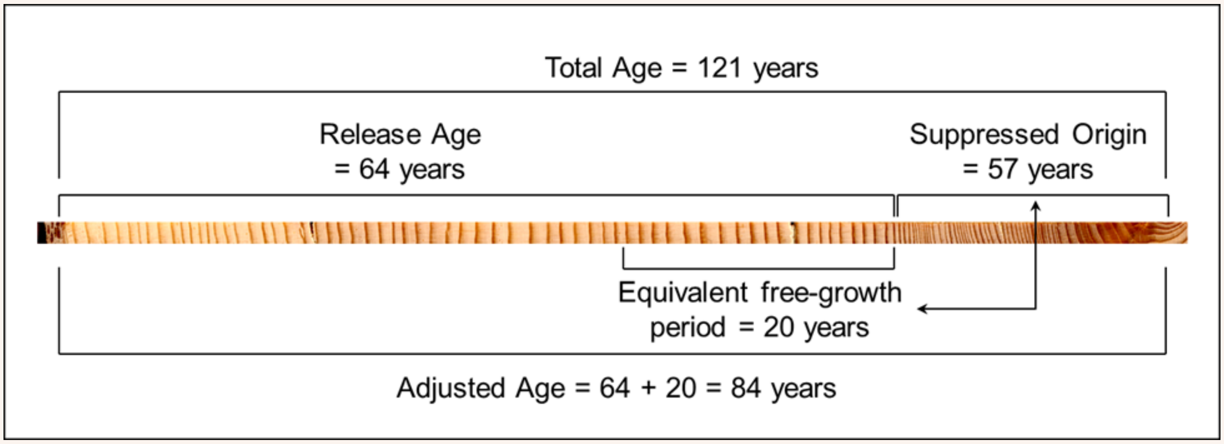

Figure 2.5 Adjusting for periods of growth reduction when determining effective age for site index calculation.

Then measure the length of the suppressed zone on the core, and mark a zone of equal length on the core starting at the first year of free growth. Count the number of rings in this distance outward from the first year of free growth, and add to the release age to obtain the best estimate of free-growth breast-height age.

Finally, the site differences between species on poorly drained soils suggest that spruce should be favored there because the trees will be at least 4 feet taller at the index age of 50. On well drained soils where firs are nearly 5 feet taller, spruces will be at a competitive disadvantage early in stand development, but should nevertheless be retained and favored to carry on longer rotations once the fir reaches maturity at an earlier age.

Do not generalize the soil-site patterns for red spruce to other spruces. White and black spruce, as boreal conifers with a different successional status, likely behave more like fir than red spruce, although that has not been formally quantified.

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Appendices

Appendix 2A. Area (acres) of Spruce-Fir Forest Types by Soil Parent Material and Drainage Class, Maine

Includes FIA codes 121 (balsam fir), 122 (white spruce), 123 (red spruce), 124 (red spruce-balsam fir) and 125 (black spruce). Soils data assembled by H. Lee Allen.

Drainage Class	Lodgement Till	Meltout Till	Glacial Outwash	Lacustrine/ Marine	Alluvial	Organic	Total	
Very poorly drained	109,147	-	11,489	11,489	11,489	201,060	344,675	7%
Poorly drained	608,925	34,467	74,680	80,424	34,467	-	832,964	17%
Somewhat poorly drained	769,773	57,446	5,745	126,381	-	-	959,345	19%
Moderately well drained	919,132	51,701	28,723	45,957	5,745	-	1,051,258	21%
Well drained	574,458	517,012	22,978	17,234	-	-	1,131,682	22%
Excessively drained	45,957	545,735	126,381	-	-	-	718,072	14%
Grand Total	3,027,393	1,206,361	269,995	281,484	51,701	201,060	5,037,995	100%
	60%	24%	5%	6%	1%	4%	100%	

Appendix 2B. Common Soil Catenas in the Acadian Spruce-Fir Forest, Grouped by Parent Material and Soil Drainage Class

Parent Material	Excessively drained	Somewhat Excessively drained	Well drained	Moderately well drained	Somewhat poorly drained	Poorly drained	Very poorly drained
Lodgement Till			Plaisted	Howland		Monarda	Burnham
			Becket	Skerry	Westbury		
			Marlow	Peru	Colonel	Brayton/Pillsbury	Peacham
		Monson	Elliotsville	Chesuncook	Telos	Monarda	Burnham
				Perham	Daigle	Aurelie	
		Success	Colrain	Buckland		Cabot	
			Potsdam/Mundal	Crary	Adirondack		
Meltout Till			Berkshire	Sunapee	Moosilauke	Lyme	
		Thorndike	Danforth	Shirley			
			Bangor/Penquis	Dixmont			
	Schoodic	Hermon/ Canaan	Monadnock	Waumbek		Naskeag	
			Hogback/ Rawsonville				
	Abram	Lyman	Tunbridge				
			Saddleback/Sisk	Surplus		Bemis	
Glacial Outwash	Colton	Adams		Croghan	Madawaska	Naumburg	Searsport
	Windsor			Deerfield		Walpole	
		Masardis	Stetson	Sheepscot			
Lacustrine/ Marine			Suffield	Buxton	Lamoine	Scantic	Biddeford
				Boothbay	Pushaw	Swanville	
Alluvial			Fryeburg	Lovewell	Cornish	Charles	Medomak
			Ondawa	Podunk		Rumney	
Organic		Ricker					Bucksport
		Knob Lock					Wonsqueak

Appendix 2C. Site Index Curves and Equations

Site index is defined as the height of dominant trees (the concept of top height, the average of the tallest 40 per acre) at a common base age of 50. For convenience and to avoid the effect of early suppression, age is often measured at breast height. As part of a Ph.D. dissertation, Steinman (1992) fit a site index equation to the Griffin data for spruce and fir combined. Subsequently, Steinman (unpublished) fit separate equations for spruce and fir, using two different 5-parameter Chapman-Richards models. To predict total Height from Site Index and Age:

$$H = 4.5 + (b_0 + b_1 S) * [1 - \exp(b_2 A)]^{(b_3 S^{b_4})} \qquad (1)$$

Where:

H = total height of dominants and codominants (feet); S = site index (total height at a breast height age of 50); and A = age at breast height.

To predict Site Index from Height and Age:

$$S = [b_0 (H - 4.5)^{b_1} * \; [1 - \exp(b_2 A)]^{(b_3 (H-4.5)^{b_4})} \qquad (2)$$

where bi are as follows:

	Equation 1 (Height)		Equation 2 (Site Index)	
b_i	spruce	balsam fir	spruce	balsam fir
b_0	54.08	11.18	7.8531	1.19373
b_1	1.6697	1.416	-0.62589	-0.77673
b_2	-0.009722	-0.021459	-0.00010125	-0.00000137
b_3	6.02251	7.75063	-0.22073	-0.29571
b_4	-0.42122	-0.43778	0.33689	0.22433

To apply these equations, collect a sample of heights and breast-height ages from representative dominant trees. Substitute into Eq. 2 to estimate S for each tree, and compute the mean for the stand. Substitute S into Eq. 1 along with a range of bh ages to generate a height development curve. To determine A when H is known, either graph Eq. 1 and estimate visually, or input the formula into a spreadsheet and increment A until the corresponding H is obtained. As a check on both equations, the H at A = 50 should be very close to the S, although the match is not exact.

Reference

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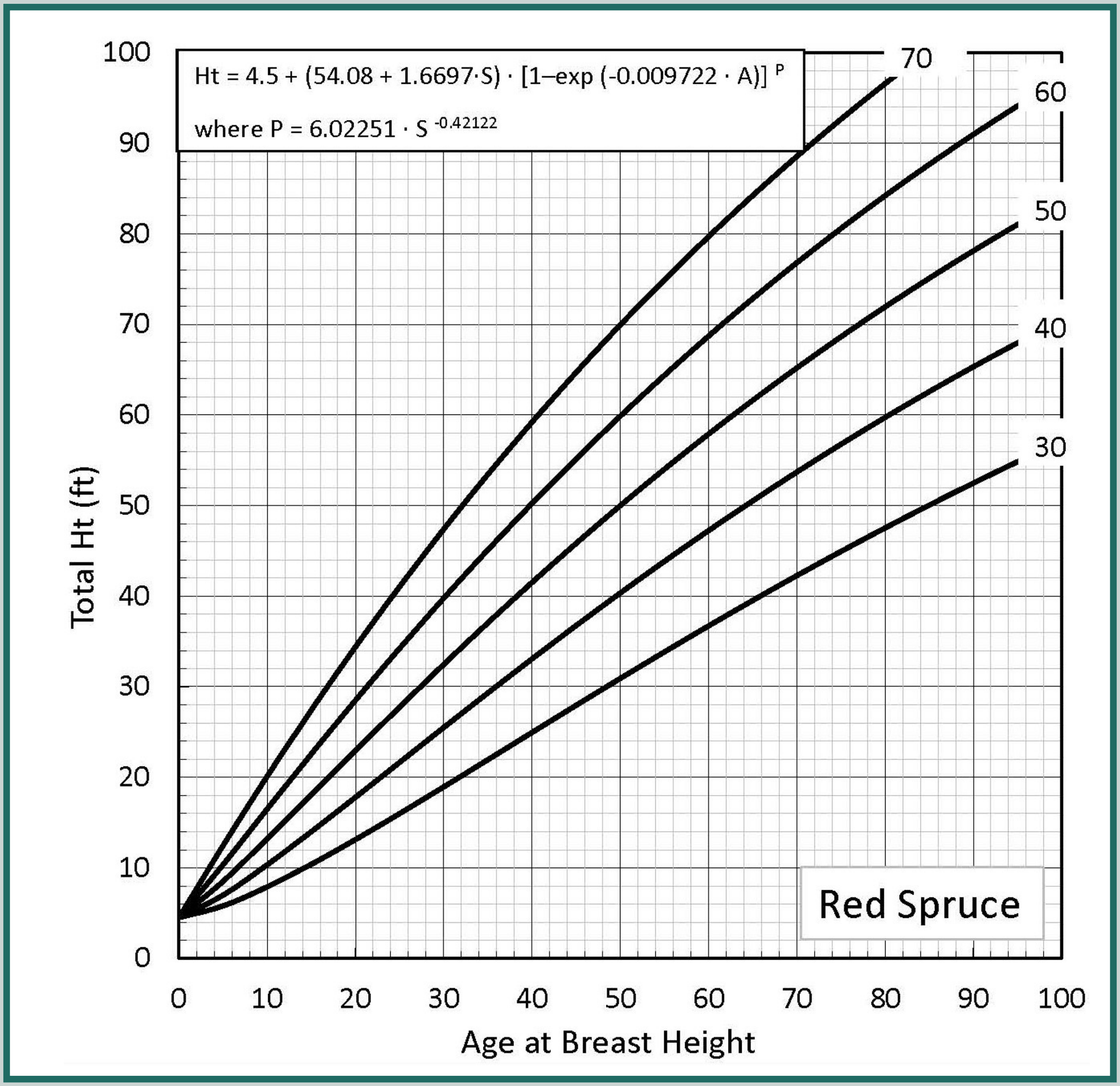
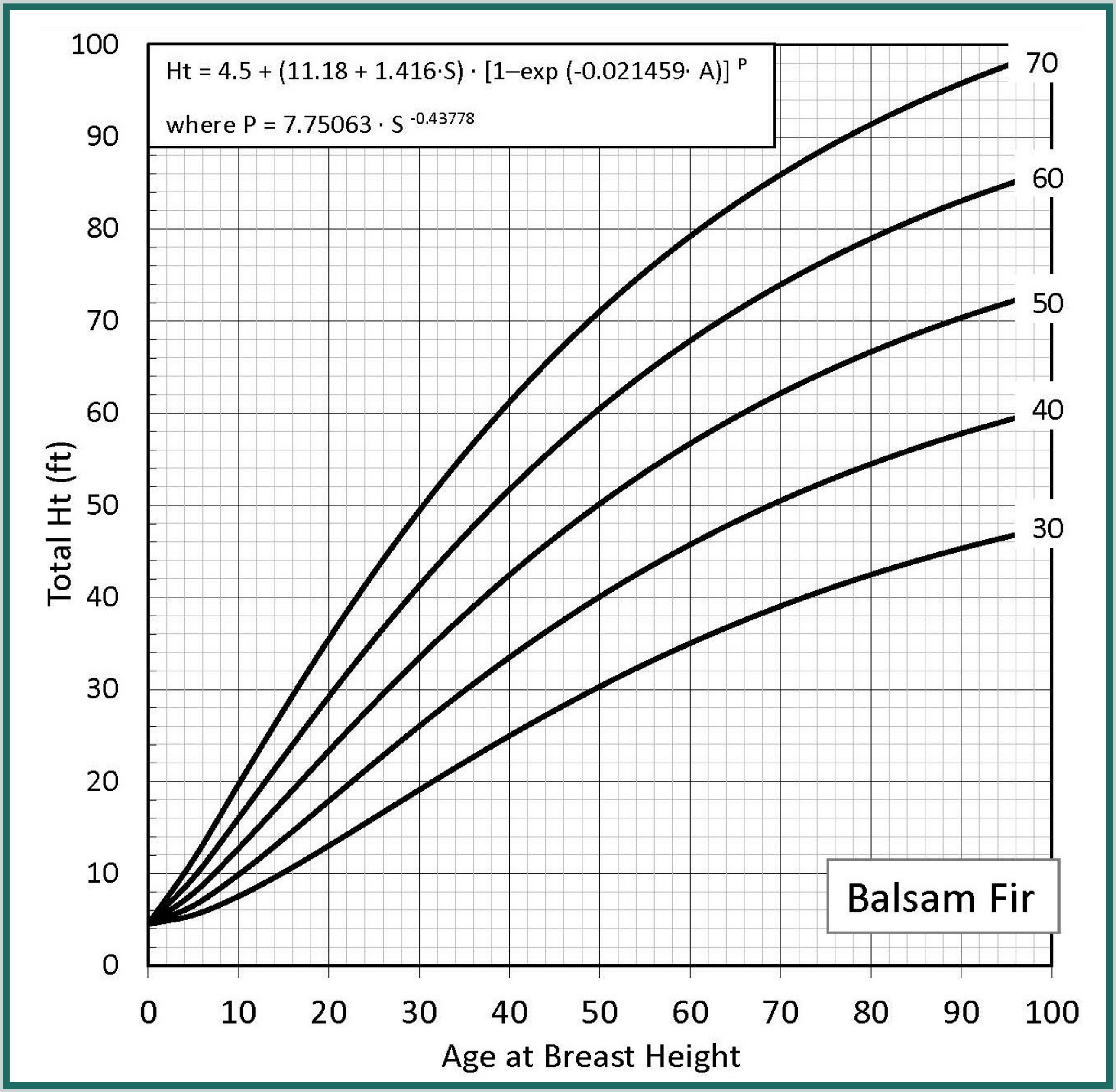
Site Index Curves for Red Spruce



Site Index Curves for Balsam Fir



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https://www.youtube.com/@tmimotf

https://www.researchgate.net/profile/Robert-Seymour

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