SOIL-SITE RELATIONSHIPS FOR EUROPEAN LARCH (*LARIX DECIDUA* MILLER) PLANTATIONS IN MAINE

By

Daniel W. Gilmore

A.A.S. Paul Smith's College, 1978
A.S. North Country Community College, 1986
B.S. State University of New York,
Empire State College, 1988

A THESIS

Submitted in Partial Fulfillment of the
Requirements for the Degree of
Master of Science
(in Forestry)

The Graduate School
University of Maine
May 1992

Advisory Committee:

Russell D. Briggs, Assistant Research Professor of Forest Resources, Thesis Advisor and Co-Chair
Robert S. Seymour, Curtis Hutchins Associate Professor of Forest Resources, Co-Chair
Katherine K. Carter, Associate Professor of Forest Resources
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By Daniel W. Gilmore

Thesis Advisor: Russell D. Briggs

An Abstract of the Thesis Presented in Partial
Fulfillment of the Requirements of the Degree of
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May, 1992

This study examined the relationship between the height development of European larch and soil-site factors. Stem analysis data were collected from 101 trees, in 31 plots located in 12 plantations, varying in age from 8 to 60 years.

These data were used to develop volume equations, site index curves and prediction equations for site index using early height growth information. A nonlinear model (incorporating average plot growth curves generated using the Richards function) was used to generate site index curves from the subset of these data attaining the index age of 20 years at breast height. Equations were developed and used to extrapolate site indices for plots in the younger plantations.

Three data sets were constructed utilizing soil-site information collected at three levels requiring successively more laboratory analyses (no laboratory analysis, laboratory analysis of the B horizon and, laboratory analysis of the solum). Using stepwise regression, 53% of the variability in site index was explained by 4 variables from the B

horizon: clay (%), concentration of K, the combined concentration of Al and H, and the solum thickness.

A stepwise discriminant analysis was used to select variables from each data set to develop a discriminant function (evaluated using a jackknife cross-validation procedure) to classify sites into low, medium, and high groupings of site indices, and into poor and good groupings of site indices (determined by cluster analysis).

While no strong relationship between soil drainage class and height development was observed, these results suggest that solum thickness has an important influence upon the site potential for European larch.

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I would like to thank the following landowners for their allowing the destructive sampling of portions of their European larch plantations: Boise-Cascade Corporation, James River Timber Company, S.D. Warren Company, a wholly owned subsidiary of Scott Paper Company, and the University of Maine.

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INTRODUCTION

Wood supply shortages are projected in New Brunswick (Baskerville 1983), Maine (Greenwood *et al.* 1988; Seymour and Lemin 1989), and in the Lake States (Einspahr *et al.* 1984) if the passive forest management practices presently being implemented in northeastern North America continue. These projected wood supply shortages have created an impetus for research pertaining to the incorporation of fast growing exotic larch species into the wood supply of pulp mills located in this region (Hatton 1987; Lawford 1987).

For over two and a half centuries, European larch (*Larix decidua* Miller) has been recognized as a fast growing, exotic species exhibiting impressive volume growth (Michie 1885; Cook 1969). Its superior early height and volume performance over native species has been demonstrated in numerous provenance tests and plantation trials. Early height, volume and yield information for exotic larches extracted from selected provenance tests throughout northeastern North America are summarized in Tables 1 and 2.

European larch appears to outperform Japanese larch (*L. leptolepis* Sieb. and Zucc.) in both early height and volume growth as well as percent survival when comparing plantations located in a frigid soil temperature regime (i.e., Maine, Ontario, Wisconsin and Michigan). Japanese larch exhibits superior early height and volume growth and percent survival when comparing plantations located in a

Table 1. Summary of early height growth data for European larch (*Larix decidua*), Japanese larch (*Larix leptolepis*), and the Dunkeld hybrid larch (*Larix X eurolepis*) from selected provenance tests in northeastern North America.

Source	Species	Age	Tot. Ht.	Avg. ht/yr
			m	m/yr
Carter *et al.* (1981) north-central ME	*L. decidua*	3	0.92	0.31
	L. leptolepis	3	0.91	0.30
	L. X eurolepis	3	1.09	0.36
northern ME	*L. decidua*	3	0.66	0.22
	L. leptolepis	3	0.59	0.20
	L. X eurolepis	3	0.65	0.22
Carter (1989)[a] north-central ME	*L. decidua*	6	5.64	0.94
	L. leptolepis	6	4.94	0.82
	L. X eurolepis	6	6.19	1.03
Einspahr *et al.* (1984)[a] Wisconsin	*L. decidua*	4	2.65	0.66
	L. leptolepis	4	2.16	0.54
	L. X eurolepis	4	2.96	0.74
Park & Fowler (1983) New Brunswick	*L. decidua*	4	1.04	0.26
	L. leptolepis	4	1.30	0.32
	L. decidua	8	3.28	0.41
	L. leptolepis	8	3.91	0.49
Boyle *et al.* (1989) Ontario	*L. decidua*	15	7.8	0.52
	L. leptolepis	15	6.8	0.45

[a] Indicates that published data were in feet and converted to meters.

Table 2. Summary of early volume growth for European larch (*Larix decidua*) and Japanese larch (*Larix leptolepis*) in northeastern North America.

Source, Location	Species	Age	Merch. Vol.	MAI
			m^3/ha	m^3/ha/yr
Park & Fowler (1983) New Brunswick	*L. decidua*	19	63.7	3.35
	L. leptolepis	19	120.4	6.34
Mroz *et al.* (1988)[a] Michigan	*L. decidua*	16	224.4	14.02
Fowler *et al.* (1988) New Brunswick	*L. decidua*	25	79.0	3.16
	L. leptolepis	25	202.9	8.12
Einspahr *et al.* (1984)[a] Wisconsin	*L. decidua*	19	183.5	9.66
Turner & Meyers (1972)[a] Vermont	*L. leptolepis*	14	35.1	2.51
	L. leptolepis	19	107.7	5.67
	L. leptolepis	24	191.0	7.96
	L. leptolepis	29	267.8	9.23

[a] Indicates that published data were in English units and converted to metric units.

mesic soil temperature regime or under coastal climatic influences (i.e., New York, Pennsylvania and the Maritime Provinces of Canada). It is important to note that not all of the above cited studies involved direct comparisons of different species of larch. It should also be noted that other factors may have contributed to the superior performance of European larch growing on soils characterized by a frigid soil temperature regime. Japanese larch may equal or exceed the performance of European larch in much of Maine provided that care is taken to avoid frost-susceptible planting sites[1].

During the latter half of the 20th century, several research studies focused on the height development and volume production of exotic larches (Aird and Stone 1955; James 1955; Adams and Hutchison 1961; Hamilton and Christie 1971; Turner and Myers 1972; Edwards and Christie 1981; Bolghari and Bertrand 1984; Parsonage 1989; Shipman and Fairweather 1986 and 1989). However, in the Northeast, only two studies evaluating the relationship between soil-site variables and productivity of exotic larches have been reported. Aird and Stone (1955) examined the effects of soil-site variables on the productivity of European and Japanese larch in the uplands of southern New York and southern New England. In addition to developing site index curves, they reported a linear relationship between free

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[1] Personal communication, Carl Haag, Research Forester
S.D. Warren Company, Fairfield, ME.

rooting depth and site index (base age 25) for both European and Japanese larch. Their site index curves were included in those compiled by Carmean *et al.* (1989).

Parsonage (1989) examined soil-site relationships for Japanese larch in 52 thinned and unthinned plantations in Pennsylvania. Using stepwise regression, 50% of the variation in site index was accounted for by three variables: surface soil percent silt, drainage class, and the free rooting depth X subsoil percent sand interaction term. Parsonage (1989) suggested that sites could be classified into three groups for Japanese larch productivity (poor, moderate and high).

In summary, there is a lack of information regarding the impact of soil-site variables on the growth and development of larch in Maine. Although several volume equations and site index curves have been reported, their applicability for use in Maine is unknown. As the emphasis on larch species in planting programs increases, this information will become more essential.

European larch was selected for study for two reasons: 1) it has greater frost hardiness than Japanese larch (Carter *et al.* 1981; Lee and Schabel 1989) and thus may be better suited to the climatic conditions of Maine, and 2) more European larch plantations were immediately available for study.

Objectives

The primary objective of this study was to evaluate the relationship between soil-site characteristics and site productivity of European larch. More specifically, this study utilized site index as a phytometer of site and examined its relationship to physical and chemical soil properties. The secondary objectives were to: 1) construct a volume equation, 2) develop site index curves, 3) develop a model for predicting site index from early height growth information, and 4) examine the effect of soil drainage class upon early height growth for European larch in Maine.

LITERATURE REVIEW

European Larch

The genus *Larix* is represented by ten species distributed throughout the northern hemisphere (Genys 1960; Dallimore *et al.* 1967; Cook 1969; MacGillivray 1969; Boyle *et al.* 1989). However, Morgenstern (1987) and Boyle *et al.* (1989) recognized work published by Soviet taxonomists which divided Siberian larch into two separate species, thereby including an eleventh species in the genus *Larix*. A list of these species is provided in Table 3.

The natural range of European larch, *Larix decidua* (Miller), which is also known as *Larix europaea* (De Candolle), is noncontinuous and is represented by four geographically isolated races (McComb 1955; Genys 1960; Boyle *et al.* 1989). A map of the natural range of European larch is provided in Figure 1.

The relatively small natural range of this species has been increased substantially as a result of plantation establishment throughout Europe (McComb 1955; Genys 1960), Great Britain (Michie 1885; Dallimore *et al.* 1967) and northeastern North America (Cook 1939; Aird and Stone 1955; Nyland 1965; Bailey and Neily 1987; Carter and Selin 1987; Parsonage 1989). Silvical characteristics common to the four races of European larch are provided in Table 4.

Table 3. Continental distribution of the genus *Larix*[a].

Continent	Species Scientific Name	 Common Name
North America	*L. laricina* (Du Roi) K. Koch	Tamarack
	L. occidentalis Nutt.	Western Larch
	L. lyallii Parl.	Alpine Larch
Europe	*L. decidua* Miller	European Larch
Europe & Asia	*L. sukaczewii* Dyl.	Western Siberian Larch
	L. sibirica Ledeb.	Siberian Larch
Asia	*L. gmelini* (Rupr.) Ledeb.	Dahurian Larch
	L. potaninii Batal	Chinese Larch
	L. mastersiana Rehd. & Wils.	Masters Larch
	L. griffithii Hook.	Himalayan Larch
	L. leptolepis (Sieb. & Zucc.) Gord	Japanese Larch

[a] Adapted from MacGillivray (1969), Morgenstern (1987) and Boyle *et al.* (1989)

Figure 1. Natural range of the four races of European larch (*Larix decidua* Miller). Adapted from Boyle *et al.* (1989).

Table 4. Silvical characteristics of European larch (*Larix decidua* Miller)[a].

Bark- Greenish grey-brown and smooth at first, later brown fissured vertically and exfoliating.

Crown- Narrow-conic, main branches whorled with minor branches between on young trees; irregular in open-growing old trees.

Twigs- Shoots pale yellow or pale pinkish, glabrous, grooved from leaf-bases.

Buds- Small, about 2 mm in diameter, terminal buds resinous.

Foliage- Deciduous. Leaf 2-3 cm long, but can be 6 cm long on vigorous trees, width is less than 1 mm. Always light green, 30-40 in clusters, soft, flattened and spirally arranged. Leaves turn yellow in late-October or early-November before shedding.

Flowers- Monoecious. Borne on short shoots appearing before the leaves. Males on underside of weak shoots or on hanging shoots opening in late-March as whitish discs, often pale purple around edges becoming yellow as pollen is shed approximately one week later. Females found towards ends of strong shoots, 1-6 per shoot, rosy-red, pale green or white; erect, length to 1 cm on a 0.5 cm scaly stalk; open two weeks before male flowers.

Cones- Brown, bluntly rounded, or pointed ovoid-conic 2-4 cm long by 2-3 cm wide. Scales rounded, tips turn slightly inwards, rarely slightly outwards, 40-50 seed scales. Dead cones can be retained for ten years or more.

Seeds- Small, 3.5 mm long, 2.5 mm broad, brown. Borne beginning at age 10 to 30. Good seed crops every 3 to 10 years.

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[a] From Hunt (1932), Genys (1960), Mitchell (1974), USDA Forest Service (1974), Krussmann (1985).

Within its natural range, European larch is a species component in two mixed forest types of the European Alps: 1) the spruce-fir-larch-beech type (*Picea excelsa* Link., *Abies pectinata* D.C., *L. europaea* D.C., *Fagus sylvatica* L., with or without, *Pinus sylvestris* L.) and 2) the spruce-larch type. Within their respective natural ranges, each race of European larch is exceptionally disease resistant and healthy (McComb 1955). Early planting failures resulted from plantations being established on sites unsuitable for the species or race planted (Michie 1885; McComb 1955; Genys 1960). The four recognized geographic races of European larch and their natural ranges are provided in Table 5.

The morphological variability within the Alpine race of European larch is apparent in the literature. Giertych (1979) reported a high proportion of straight stemmed trees from Alpine populations included in the 1944 International Union of Forest Research Organizations (IUFRO) provenance test. In contrast, Boyle *et al.* (1989) observed that stems from the Alpine race were crooked. McComb (1955) suggested that the introduction of the Alpine race into the natural range of the Sudeten race was a cause of the stem crookedness found in the Sudeten race of European larch. Evidence from provenance tests in Europe suggests a lack of genetic uniformity within the Alpine race (McComb 1955).

Table 5. Natural range of the four races of European larch.[a]

Race	Natural Range
Alpine	Higher elevations throughout the central Alps of southeastern France eastward through southwestern Austria. This range does not encompass a single uniform climate consequently the genetic uniformity of a single race is lacking. This lack of genetic uniformity has been demonstrated in numerous provenance tests. This race can be more adequately described as representing a group of races and/or clines.
Polish	Considered a race of the "plains" with an original natural range throughout southeast Poland at elevations of 150 to 600 meters. Its "natural" range is now limited to scattered stands throughout central and southern Poland.
Sudeten	Isolated range on the east slope of the Altvater Mountains in southeastern Sudetenland, Czechoslovakia and Poland at elevations between 316 and 850 meters.
Tatra	Limited natural range in the high and low Tatra Mountains of Czechoslovakia and Poland at elevations ranging from 700 to 1,500 meters.

[a] Adapted from McComb (1955), Genys (1960), Dallimore *et al.* (1967), Giertych (1979) and Boyle *et al.* (1989).

Provenance tests have revealed other undesirable traits in the Alpine race which make it an unattractive candidate for planting programs in northeastern North America. The slow growth of the Alpine race in comparison to other races of European larch has been documented by numerous authors (McComb 1955; Genys 1960; Giertych 1979; Boyle *et al.* 1989). The high susceptibility of the Alpine race to larch canker (*Lachnellula willkomii* (Hartig) Dennis) has been reported by both Genys (1960) and Boyle *et al.* (1989). The high mortality associated with larch canker coupled with the presence of this canker in the Northeast (Ostaff 1987; Boyle *et al.* 1989) has resulted in recommendations which encourage the incorporation of other races of European larch into planting programs.

Rapid early height growth and resistance to larch canker (McComb 1955; Genys 1960; Giertych 1979) makes the Sudeten race of European larch an attractive candidate for planting programs in the Northeast (Robbins 1985). Both Genys (1960) and Giertych (1979) considered stem crookedness a general characteristic of this race in their respective discussions of the 1944 IUFRO provenance test. Boyle *et al.* (1989) discussed the poor stem form generally found in provenance tests of seeds originating from primary sources of this race. Giertych (1979) reported desired stem form to be inversely correlated with growth. Giertych (1979) and Boyle *et al.* (1989) both indicated that a tree improvement program targeting desired stem characteristics could improve stem form in the Sudeten race relatively rapidly.

Genys (1960) reported the Polish race to be similar to the Sudeten race in all characteristics with the exception of its greater resistance to the woolly larch aphid (*Adelges laricis* Vallot.) Robbins (1985) and Boyle *et al.* (1989) both endorsed this race for planting programs in northeastern North America.

Provenance tests at the Petawawa Experimental Forest in Ontario indicated that the fastest growing Tatra provenances are less productive then the Sudeten and Polish races (Boyle *et al.* 1989). This contrasts with the literature (Tulstrup 1950; Schober 1985) cited by Boyle *et al.* (1989), that described the growth rate of the Tatra race as being comparable to that of the Sudeten and Polish races. Variation in the growth rate and stem form of the Tatra race of European larch has resulted in the mixed endorsement of this race for planting programs in northeastern North America (Robbins 1985; Boyle *et al.* 1989).

European larch has been recognized as an exotic species in Great Britain since 1629 (Michie 1885; Genys 1960; Mitchell 1963). The year 1629 is also the first year of reported cultivation for European larch (USDA Forest Service (1974). It was first introduced to North America in the mid-19th century (Cook 1939; Genys 1960; Nyland 1965). The availability of planting stock from Europe at a time when native nursery stock was unavailable was the principal reason for the establishment of European larch, Scots pine and Norway spruce plantations in the United States during the post Civil War period (Baldwin 1953).

European larch was introduced as an ornamental species in both Great Britain (Michie 1885) and the United States (Nyland 1965). Impressive height and volume growth lead to extensive plantation establishment for timber production in Great Britain beginning in the late-18th century and continuing through the early-19th century (Michie 1885). At the beginning of the 20th century, European larch was used extensively as a reforestation species in the northeastern United States (Nyland 1965).

Intraspecific and interspecific hybridization frequently occurs in the genus *Larix*. The most well known hybrid is *Larix X eurolepis* (Henry) commonly known as the Dunkeld larch. The Dunkeld larch is a hybrid of *L. decidua* and *L. leptolepis* and first occurred "naturally" at the Dunkeld estate in Perthshire, Scotland (Dallimore *et al.* 1967; Cook 1969). The Dunkeld hybrid is valued because of its rapid growth rate, which is superior to that of both parent species (Dallimore *et al.* 1967; Holst 1974; Boyle *et al.* 1989).

Cook (1969) and Einspahr *et al.* (1984) noted several advantages of incorporating European larch into planting programs: high genetic diversity, ready hybridization, desirable wood properties, resistance to scleroderris canker (*Scleroderris lagerbergii* (Lagerb.)) and to spruce budworm (*Choristoneura fumiferana* (Clemens)) and the adaptability of the species to a variety of soils. In addition, Carter *et al.* (1981) and Lee and Schabel (1989) both noted that European larch had a greater tolerance of frost when compared to Japanese larch in provenance tests performed in Maine and Wisconsin.

The primary disadvantages with the incorporation of European larch into large scale planting programs are associated with difficulties in plantation protection. These disadvantages are collectively inherent to the genus *Larix*, and are not unique to European larch. Larch is susceptible to insect and disease infestations from both native and exotic pests. A preference for exotic larch foliage, buds, twigs and bark has also been acquired by several native warm blooded animals.

The susceptibility of the Alpine race of European larch to the larch canker has been noted previously. Michie (1885) and Dallimore *et al.* (1967) reported that European larch is more susceptible to the larch canker than Japanese larch. They both noted that neither species is immune to this fungus, particularly on poorly drained sites. Ostaff (1987) described the spread of this fungus throughout eastern North America since it was first observed in Massachusetts in 1927. In 1980, the larch canker was observed to be widely distributed throughout the southern Maritime Region of Canada when 25-year-old cankers were discovered. Michie (1885) and Ostaff (1987) noted the ability of this fungus to infect healthy vigorous trees and how its presence in Europe has resulted in the exclusion of susceptible species of larch (namely European larch) from plantation programs.

The larch sawfly (*Pristiphora erichsonii* (Hartig)) is a defoliator capable of causing substantial mortality during severe outbreaks. This insect is a native of Europe and its presence in North America was first recorded in 1880 (USDA Forest Service 1985). Coolidge (1963) documented the 1880 to 1890 larch sawfly outbreak in Maine which reportedly killed considerable volumes of tamarack (*Larix laricina* (Du Roi) K. Koch) in the Northeast. Pendrel (1987) described a 1970 outbreak on Prince Edward Island that resulted in 30% mortality to the native tamarack population.

Another defoliator, the larch casebearer (*Coleophora laricella* (Hübner)) was introduced from Europe and first observed in Massachusetts in 1886 (USDA Forest Service 1985). Pendrel (1987) described the life cycle of this defoliator, which is now less of a threat to members of the genus *Larix* then when it was first observed on this continent. He noted that this insect appears to have reached an equilibrium point with its host, predators and parasites in the Northeast.

The eastern larch beetle (*Dendroctonus simplex* LeConte) is native to the North American continent and is reported by Pendrel (1987) as being the greatest killer of Maritime larch in recent history. This insect, a bark beetle, normally creates galleries under the bark of stressed or overmature tamarack trees during its larval stage. Pendrel (1987) described how an exploding population of this insect between 1976 and 1981 resulted in the death of 64% of the healthy, merchantable larch in Nova Scotia, 24% in New

Brunswick and 13% in Prince Edward Island. Similar uncharacteristic behavior of this insect attacking healthy trees was recorded by the USDA Forest Service (1985) in the Adirondack Mountains of New York and the Green Mountains of Vermont where thousands of healthy tamarack were killed during the 1970s.

Hunt (1932) and Cook (1969) agreed on the relatively benign effects caused by the red squirrel (*Tamiasciurus hudsonicus*) feeding on the small twigs of larch. They also reported that the winter feeding of the pine grosbeak (*Pinicola enucleator leucora* (Müller)) caused minimal damage to members of the larch family.

The porcupine (*Erethizon dorsatum dorsatum* Linnaeus) feeds on both the foliage and inner bark of all larches but appears to have a preference for Japanese larch. This mammal has caused severe girdling damage to young larch trees throughout the Northeast (Hunt 1932; Cook 1969; Robbins 1985).

Larch lumber was used to a great extent in 19th century Great Britain. The items constructed from larch lumber included ploughs, harrows, carts, wheelbarrows, rakes, ladders, tables, chairs, household furniture, fencing, posts, gates and bridges (Michie 1885). Other products derived from larch during this time period were tannin, turpentine and charcoal. During the latter half of the 19th century and early 20th century, tamarack harvested in Maine was used for railroad ties, ship timbers and telegraph poles (Coolidge 1963; Judd 1989). Modern day uses of larch lumber include posts, transmission poles, piles and boat planking (Timber Research and Development Association 1980).

The possible incorporation of larch into the fiber supply of pulp mills in the Northeast has been recently studied (Einspahr *et al.* 1984; Hatton 1987; Lawford 1987; Keith and Chauret 1988). The primary problem associated with the use of pulp obtained from the genus *Larix* is the amount of extractives contained in the wood cells of older trees (Keith and Chauret 1988). Einspahr *et al.* (1984) reported that older (50-year-plus) and slower grown larch has a high proportion of heartwood and the associated hot-water extractive arabinogalactan. In comparison, Keith & Chauret (1988) reported that pulp produced from short-rotation (18- to 24-year-old) plantation larch had about 50 percent less extractives then the amounts reported by Einsphar *et al.* (1984) in older trees. Lawford (1987) suggested that, depending upon the pulping process, it would be possible to include up to a 30% larch mixture in the wood supply of a pulp mill. While young larch presently show good potential as a future resource for chemical pulping processes, particularly kraft, additional research is needed to determine its potential for inclusion in the wood supply of mechanically produced pulp (Hatton 1987).

Forest Site Evaluation

Carmean (1975) reviewed the methods of forest site evaluation that were considered during the first quarter of the 20th century by early U.S. foresters. They were: 1) the use of volume as a bioassay of site, which was the standard used in Germany at the time, 2) the system of "forest site-types", then being pioneered in Finland, and 3) the use of height growth as an index of site.

In his review, Carmean (1975) described direct and indirect methods of evaluating forest site quality. He defined site index curves, site index comparisons between species and the growth intercept method of site determination as being direct measures of site quality. Carmean (1975) described the indirect methods of evaluating forest sites as being mensurational methods, plant indicator species, physiographic (total site) site classification, synecological coordinates (ranking of important environmental factors), soil-site evaluations, and soil surveys. These indirect methods of forest site evaluation are described later in this review. Carmean (1975) recommended the use of indirect measures of site evaluation in stands that were uneven-aged, or stands that had been harvested, and lacked suitable site trees, or in areas under consideration for plantation establishment.

In contrast to Carmean's classification of site evaluation methods, Pritchett and Fisher (1987) defined three categories of site classification systems. The first category was based on forest productivity and included site index and vegetation types. The second category was based on soil properties, while the third category was based on multifactor systems of site analysis.

Jones (1989) differed from both Carmean (1975) and Pritchett and Fisher (1987), by proposing a new conceptual framework for the evaluation of site quality. Using an earlier work of Pritchett (1979) as a paradigm, Jones (1989) postulated that direct measures of forest site are not all known or able to be quantified and thus are not measurable. He divided the conventional methods of site evaluation into three indirect orders of expression. First order expressions were defined as actual measures of site production (e.g., total carbon production, total caloric storage, total organic matter production). Second order expressions were defined as being one step removed from first order expressions (e.g., estimates of first order expressions such as tree volume, mean annual increment, periodic annual increment). Finally, third order expressions were defined as being a gauge for second order expressions (e.g., site index, basal area, indicator species).

Jones (1989) noted that soil-site analyses and site classification schemes are useful if a relationship can be established with a reliable dependent variable. By definition, such a variable would be an indirect expression of site quality.

Site Index

Monserud (1984a) noted that in 1923, the use of site index curves in conjunction with yield tables was the method of site evaluation recommended by the Society of American

Foresters. Site index, determined by the height of a free growing dominant or codominant tree at a base age, is now the most widely accepted method for estimating site quality in the United States. Site productivity can be appraised by relating site index to yield tables for a given species (Carmean 1975, 1986). Two assumptions made in the construction of site index curves are 1) height is an indicator of site potential and is not influenced by nonsite factors such as density and site preparation; and 2) site index is constant over time (Monserud 1984a).

These assumptions, however, do not always hold true. Vincent (1961) critically reviewed the use of site index curves by practicing foresters. A variety of factors influence the observed height/age relationship: tree injury (caused by mammals, insects or frost), early suppression, and growth rate variation on different sites and between neighboring trees. Consequently, it is often difficult to locate site trees suitable for the estimation of site index.

The assumption that site index remains constant over time is not always true. Foresters must be cognizant of potential positive changes in site index through site improvements which include fertilization, irrigation or drainage (Carmean 1975; Trettin and Jones 1989) as well as potential negative site changes caused by erosion and soil compaction (Carmean 1975).

Carmean (1975) and Monserud (1984a) described how the technique used to construct site index curves has evolved since the 1920s. Bruce (1926) established the framework for site index curve and yield table construction that was to last into the 1960s (Monserud 1984a). These early site index curves were known as harmonic, anamorphic or proportional site index curves. They were constructed by obtaining paired total height and total age measurements from dominant and codominant trees on many growth and yield plots believed to cover the range of sites and ages within the natural range of a given species. An average growth curve was constructed and this curve was fitted proportionally over the range of good to poor sites (Curtis 1964; Carmean 1975). Hegar (1968) presented a method of anamorphic curve construction using stem analysis data.

Monserud (1984a) criticized the harmonic guide curve method as being universally applied, inflexible and generally incorrect. He identified three erroneous assumptions used as a basis for their construction:
1) the sample plot data adequately represented the range of sites in each age class, 2) the growth curves are proportional to site, and 3) differences in site affect height growth the same at all ages.

Curtis (1964) cited several researchers who constructed polymorphic, or non-proportional, growth curves for several species. When comparing anamorphic curves to polymorphic curves, the anamorphic curves generally increase too rapidly and flatten out too quickly. This creates a pattern of overestimating site index when using anamorphic curves at an age less than the index age and underestimating site index at an age older then the index age (Monserud 1984a).

Stem analysis is the favored field procedure for collecting data to generate site index curves (Carmean 1975). Stem analysis techniques and the construction of site index curves are discussed in detail by Curtis (1964), Carmean (1972), Hermon *et al.* (1975), Vicary *et al.* (1982) and Furnival *et al.* (1990). It is important to note that despite their widespread usage, site index curves alone are not a measure of productivity (Curtis 1964; Jones 1989).

Three separate studies have generated site index curves for exotic larches in North America. Aird and Stone (1955) constructed site index curves for both European and Japanese larch from data collected from southern New York and New England. Because of their limited data base, Bolghari and Bertrand (1984) were forced to construct a combined set of site index curves for European larch and Japanese larch in southern Quebec. More recently, Shipman and Fairweather (1989) constructed site index curves for Japanese larch in Pennsylvania.

Growth Intercept

The growth intercept method of estimating site quality utilizes a designated period of early height growth as an indicator of site quality as opposed to the extended height growth pattern exhibited in site index curves (Carmean 1975, Thrower 1987). Carmean (1975) noted that this method would be most useful when applied to short rotations when height growth would be predicted for only a few years beyond the growth intercept measurements.

The advantages of the growth intercept method listed by Alban (1972) and Thrower (1987) are: 1) the method can be used in stands too young for estimating site index with standard site index curves, 2) the method eliminates the need to measure tree age and height, either of which may be a major source of error, 3) trees can be measured easily and rapidly, and 4) much of the slow and erratic height growth associated with early establishment can be reduced or eliminated by measuring internode length above breast height, thus resulting in more accurate estimates of site quality.

The disadvantages of the growth intercept method are that early height growth patterns may not be a reflection of later height growth patterns (Vincent 1961; Carmean 1975; Thrower 1987) and that atypical weather conditions which have an effect upon annual height growth can influence estimates of site quality (Alban 1979; Thrower 1987).

Methods of preparing growth intercept tables are presented by Wakely and Marrero (1958), Wilde (1964), Alban (1979) and Thrower (1987).

Indirect Methods

Carmean (1975) reviewed what he considered the common indirect methods of estimating forest site quality. He described mensurational methods as being useful in uneven-aged stands or stands which experienced early suppression but recommended more fruitful methods of indirectly estimating site quality such as the soil-site method. Mensurational methods that deserve mention are the height-over-diameter curves for uneven-age red spruce proposed by McLintock and Bickford (1957) and the use of diameter or volume growth as a measure of site quality (Carmean 1975).

The plant indicator approach to site estimation has been found to be more applicable to the relatively simple northern ecosystems found in northern Europe and Canada (Rowe 1962; Carmean 1975). Carmean (1986) referred to work performed by one of his students (Wiltshire 1982) that proved successful in the classification of jack pine (*Pinus banksiana* Lamb.) at the extremes of site quality using an indicator species approach. Carmean (1975) cited Cajander (1926) as using understory vegetation in Finland as a basis for determining different site classes. In contrast, the ecosystems found within forests in the United States that have been disturbed by logging, farming or forest fires and fall within the natural range of many hardwood species are more complex. In these types of ecosystems, which encompass many stages of plant succession, the use of individual indicator species would be unrealistic. Rather, Carmean (1975) suggested the use of an indicator plant spectrum.

Coile (1938) criticized the use of indicator plants as a site predictor. Rather, he suggested the use of ground cover vegetation as indicators of fertility. Coile (1938) maintained that a forest site classification system should be based upon physiographic features which are fixed in the landscape (e.g., soil properties, topographic features, elevation).

Meades and Morres (1989) used indicator species in conjunction with topography and soils to develop a forest site classification manual for Newfoundland. Zelazny *et al.* (1989) incorporated a similar approach in their development of a field guide to classify forest sites in New Brunswick.

Carmean (1986) grouped holistic site classification schemes, including physiographic site classification and synecological coordinates, into an ecosystem type approach. Noting that there was a poor relationship between site index and ecosystem classification units in the Ontario Clay Belt, Carmean (1986) discounted the applicability of this approach.

Soil-Site Relationships

Carmean (1975, 1986) noted that soil-site studies are particularly useful in areas where site quality, soil, and stand conditions are extremely variable and in forest stands not suited for the direct measurement of site index. Results from soil-site studies are only applicable to the particular area studied and then only to the particular soil and topographic conditions sampled (Carmean 1975; Parsonage 1989).

In order to perform a soil-site study, many plots must be located in older forest stands that represent the range of site, soil, topography and climatic conditions encountered within the study region (Carmean 1975, 1986).

Multiple regression methods are then employed to relate site index to soil and topographic variables. The resulting equations are applied in areas not suitable for the direct estimation of site index (Carmean 1986).

There is only one soil-site study reported for an exotic larch in North America that incorporated a multiple regression technique in predicting site index. Parsonage (1989) was able to explain 53% of the variability encountered in site index for Japanese larch using three soil variables in a study conducted in Pennsylvania.

In an earlier study, Aird and Stone (1955) reported a simple linear relationship between free rooting depth and site index, and soil drainage class and site index for European and Japanese larch in southern New York.

Monserud *et al.* (1990) were disappointed with the results obtained from their soil-site study for inland Douglas-fir (*Pseudostsuga menziesii* var. *glauca* (Beissn.) Franco). The large number of measured soil-site variables explained only a small portion of the variability in site index for Douglas-fir. The low soil-site correlations were attributed to two factors: 1) the number of important site factor interactions occurring in this large and complex study far exceeded the sample size, and 2) there was a failure to measure the true causes of site productivity.

Volume Equations

Volume equations for Japanese larch in Vermont (Adams and Hutchison 1961; Turner and Myers 1972) and Pennsylvania

(Shipman and Fairweather 1986) are the only published equations for exotic larches in the Northeast. There are no published volume equations for European larch in North America.

The selection of an appropriate model to predict volume can be a source of much consternation. The root mean square residual and the coefficient of multiple determination are appropriate statistics for comparing models that have the same dependent variables. Neither of these statistics, however, are suitable for the comparison of models having different dependent variables. Based upon the least squares assumptions of independent, normally distributed residuals with a constant standard error, Furnival (1961) developed an index to compare alternative models used to predict volume. He demonstrated that, for a given set of data, these assumptions cannot be simultaneously fulfilled by different models. Using the concept of maximum likelihood, he then developed an index to identify the model which best fits the data and satisfies the assumptions of least squares.

Volume equations have been recently compared for spruce and fir in Maine and Canada. Reams and Brann (1981) compared different models (Schumacher 1933; Spurr 1952; Honer 1964) used for the prediction of volume in spruce and fir trees in Maine. They noted that the relationship between diameter and volume was linear when the merchantable diameter remained above 20 centimeters. When the merchantable diameter decreased below 20 centimeters, the accuracy of their models declined. They suggested the use of piecewise regression or the use of a nonlinear model to overcome this problem.

Morton *et al.* (1990) assessed the various models in use across Canada for estimating the standing tree volume in white spruce (*Picea glauca* (Monench) Voss). In addition to the models examined by Reams and Brann (1981), they also evaluated regional models used in various provinces. Although they determined that two Quebec models and the model credited to Schumacher (1933) performed better than the respective models of Spurr (1955) or Honer (1965), Morton *et al.* (1990) concluded that any of the volume equations they evaluated could be applied to broad regions across Canada without suffering significant losses in accuracy.

Summary

The first part of this literature review focused on the genetic variability encountered in the genus *Larix*. This genetic variability is particularly evident in the species *L. decidua* Miller. The advantages and disadvantages of establishing larch plantations were reviewed and the potential uses for larch wood were discussed.

Site index curves (Aird and Stone 1955; Bolghari and Bertrand 1984; Shipman and Fairweather 1989) and soil-site studies (Aird and Stone 1955; Parsonage 1989) pertaining to exotic larches were also reviewed.

The primary problem associated with the application of these results to plantations in Maine is that they were developed in a different geographic area with different site conditions. For example, Aird and Stone's (1955) work in southern New York and southern New England and, Shipman and Fairweather's (1986, 1989) and Parsonage's (1989) work in Pennsylvania are located in a mesic soil temperature regime (Soil Survey Staff 1990).

Bolghari and Bertrand's (1984) area of study in Quebec, like Maine, is located in a frigid soil temperature regime (Soil Survey Staff 1990). However, because of the limited number of European larch plantations located in their study area, they were forced to combine the data collected from European and Japanese larch plantations to generate a single set of site index curves and yield tables. The genetic differences between European and Japanese larch, previously described in this review, suggest the risk associated with this technique.

Methods of selecting an appropriate model in order to predict tree volume were examined. Furnival's (1961) index of comparison provides an objective approach to model selection based upon the fit of the model and the fulfillment of the assumptions of least squares.

The recommendation of the Society of American Foresters (1923) to use site index curves in conjunction with yield tables was prudent during the early epoch of forestry in the United States. At that time, few forest plantations existed in North America and it was necessary to evaluate the productivity of the natural forests throughout the continent. This method contrasted with the use of volume as a measure of site productivity which was the standard used in Germany during the early part of the 20th century (Carmean 1975).

Since then, foresters in the United States have attempted to use the tools designed for the site evaluation of natural stands (e.g., site index curves and yield tables) in forest plantations. Europeans on the other hand have developed the yield class concept whereby plantation productivity estimates are based on the stand age when the peak mean annual increment is reached (Hamilton and Christie 1971; Holten-Anderson 1989). The yield class method eliminates the problem of having two stands that differ in productivity but express the same site index. Although creation of a yield class system for evaluating European larch in Maine is beyond the scope of this study, plantation sites in North America may be better evaluated using a yield class approach modeled after the systems currently used in Europe.

CHAPTER 1

VOLUME EQUATIONS AND SITE INDEX PREDICTION FOR PLANTATION-GROWN EUROPEAN LARCH (*LARIX DECIDUA* MILLER) IN MAINE

INTRODUCTION

Wood supply shortages are projected in New Brunswick (Baskerville 1983), Maine (Greenwood *et al.* 1988; Seymour and Lemin 1989), and in the Lake States (Einspahr *et al.* 1984) if the passive forest management practices presently being implemented in northeastern North America continue. These projected wood supply shortages have stimulated research examining the incorporation of fast growing exotic larch species into the wood supply of pulp mills located in the Northeast (Hatton 1987; Lawford 1987).

For over two and a half centuries, European larch (*Larix decidua* Miller) has been recognized as a fast growing exotic species exhibiting impressive volume growth (Michie 1885; Cook 1969). Impressive early height and volume performance has been observed in numerous provenance tests and plantation trials throughout the Northeast (Carter *et al.* 1981; Park and Fowler 1983; Einsphar *et al.* 1984; Mroz 1988; Boyle *et al.* 1989).

A proper evaluation should be made of the biological performance of an exotic species prior to its acceptance into large-scale reforestation programs. Only a few evaluations of this nature have been completed for European larch in North America. While no volume equations have been reported for European larch, Shipman and Fairweather (1986) constructed equations to predict inside bark merchantable volume for Japanese larch (*L. leptolepis* Sieb. and Zucc.) in Pennsylvania. Aird and Stone (1955) constructed site index curves for European larch using data collected from plantations in southern New York and southern New England. Bolghari and Bertrand (1984) combined data collected from European and Japanese larch plantations and constructed site index curves for exotic larches in southern Quebec. Prior to the current study, the applicability of these results to European larch plantations in Maine was unknown.

Objectives

The data for this study were collected as part of a comprehensive soil-site study for European larch in Maine; those results are reported in Chapter 2. The objectives for this study were: 1) to develop a volume equation, 2) to develop site index curves, and 3) to develop a model for the prediction of site index from early height growth data for European larch in Maine.

METHODS

Study Area

The study area is located in the central portion of Maine following a northeasterly band from Rumford to Milo. The area spans three climatic regions: the northern, central, and southern; where annual precipitation ranges from 95 to 112 cm and is evenly distributed throughout the year (Briggs and Lemin *In press*). Elevations of the individual study sites, determined from USGS topographic maps, ranged from 35 to 300 meters. Soils are of glacial or glacial-fluvial origin, acidic, sandy to silt loam in texture, and are characterized by a frigid soil temperature regime (Rourke *et al.* 1978). Spodosols, Inceptisols and Entisols are represented in this study.

Site Selection

A list of the European larch plantations established in Maine prior to 1981 was compiled with the assistance of Reed Johnson, S.D. Warren Company Project Forester, during the spring of 1990. A plantation was considered suitable for plot establishment if it was adequately stocked, unfertilized, composed predominantly of European larch, and apparently free from intense competition with other species. These criteria were evaluated in the field prior to plot establishment. The study locations are illustrated in Figure 1.1. and described in Table 1.1.

Field Procedure

Thirty-one temporary measurement plots were established in twelve European larch plantations during the summers of 1990 and 1991. Because of the limited number and size of the European larch plantations in Maine, one or more plots of varying dimensions (0.08 to 0.04 ha) were located within each plantation. Plots were established to insure the uniformity of soil-site properties within the plot boundaries. If more than one plot was established within a plantation, their locations were selected to incorporate differences in one or more edaphic and/or physiographic features.

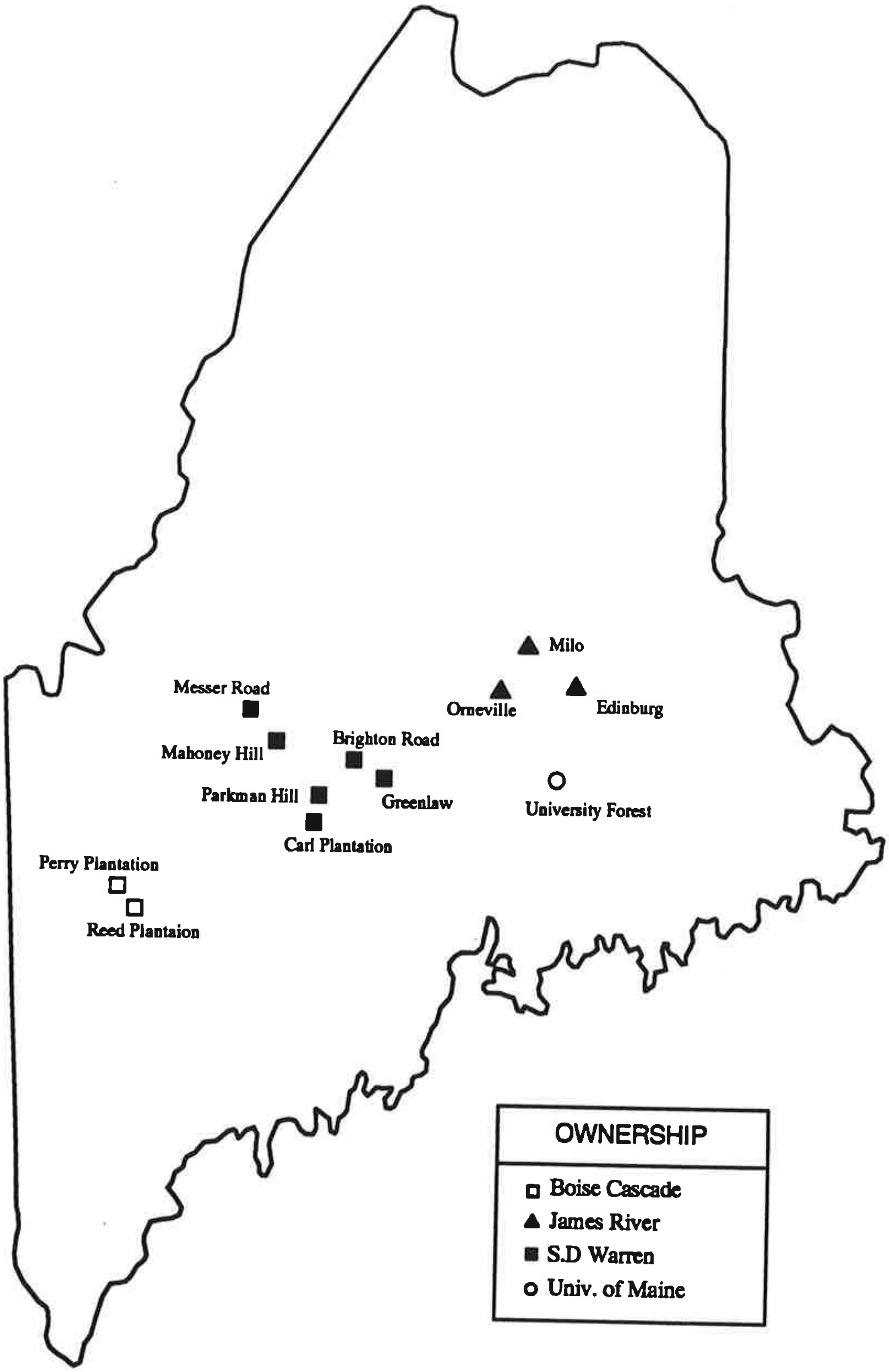

Figure 1.1. Geographic distribution, and ownership, of the European larch plantations from which stem analysis data were collected.

Table 1.1. Approximate longitude and latitude[1] of plantations from which stem analysis data were collected.

Plantation	Latitude	Longitude	Plots
Messer Road	N 45° 05′	W 69° 52′	S01, S02
Mahoney Hill	N 45° 02′	W 69° 50′	S03, S04, S05 S06, S07
Parkman Hill	N 44° 57′	W 69° 47′	S08, S09, S10 S11, S12
Carl Plantation	N 44° 55′	W 69° 49′	S13
Greenlaw Plantation	N 44° 57′	W 69° 40′	S14, S15
Brighton Road Plantation	N 44° 58′	W 69° 44′	S16, S17
Milo	N 45° 16′	W 68° 58	D01, D05, D06
Edinburg	N 45° 09′	W 68° 39′	D02, D03, D04
Orneville	N 45° 10′	W 68° 59′	D07, D08, D09
Perry Plantation	N 44° 42′	W 70° 37′	B01
Reed Plantation	N 44° 40′	W 70° 35′	B02, B03, B04
University Forest	N 44° 56′	W 68° 41′	U01

[1] Determined from USGS topographic maps.

Three vigorous dominant or codominant site trees (4 site trees from 2 plots) were selected for stem analysis from each plot. Site trees had no observable top damage and had well developed, apparently healthy crowns with no indication of suppression or damage. Data collected from nonsite trees (those damaged during the felling of site trees) were included in the volume equations. A total of 101 trees (95 site trees and 6 nonsite trees) were destructively sampled. After felling, outside bark diameters (dob) were marked, measured and recorded to the nearest 0.1 cm at the stump (0.15 m), breast height (bh = 1.37 m) and at successive one-meter intervals above bh. A disk approximately 5 cm thick was removed from each site tree at the marked sections. Each disk was labelled and returned to the laboratory at Orono where it was sanded and aged. For each tree, the time to attain bh was determined by subtracting the bh age (i.e., number of rings in bh disk) from the plantation age as determined by landowner records.

All field data were collected in metric units. In order to produce an end product having the greatest utility for practicing foresters, the final results for volume equations, site index prediction models, and site index curves are presented in both metric and English units.

Data Analyses

Volume Equations

Data collected from stem analyses were used to generate volume equations. Diameter inside bark (dib) and bark thickness were measured in the laboratory 6 to 8 months after field collection. Disk shrinkage (from air drying) and physical loss (through handling) were evident. Consequently, dib calculations were made based upon the assumption that a proportional reduction in the radial measurement occurred through shrinkage. Disks that were broken in handling or had lost excessive amounts of bark were not remeasured. A subsample of 1450 discs from 79 trees were remeasured.

The dib/dob ratio (R), its bias and standard error were calculated (Cunia 1984). Ocular analysis of the plotted height verses bark ratio values suggested no relationship. Formulae for the calculation of bark ratio statistics were:

[1] $R = \Sigma \text{ dib} / \Sigma \text{ dob}$, where

R = the average bark ratio

Σ dib = the sum of the dib measurements and,
Σ dob = the sum of the dob measurements.

The bias and variance of this ratio were determined as follows:

[2] $B_R = ((R * S_{xx}) - S_{xy}) / (n * xb^2)$, and

[3] $S_{RR} = (S_{yy}-(2*R*S_{xy})+(R^2 * S_{xx}))/((n* (n-1))*xb^2)$, where

B_R = the bias of R,
S_{RR} = the variance of R,
S_{xx} = the dob variance,
S_{yy} = the dib variance,
S_{xy} = the dob and dib covariance,
xb = the average dob, and
n = the total number of samples.

Individual tree volumes were calculated based upon the assumption of a conic shape using the equation:

[4] $V = (L / 3) * (A_b + A_t + (A_b * A_t)^{1/2})$

for the frustum sections, and

[5] $V = (A_b * L) / 3$ for the last conic section,

where V = volume of section,
L = length of section,
A_b = area of the section base, and
A_t = area of the section top,

and then adding all of the individual section volumes. Merchantable tree volumes were calculated using merchantability limits of a 10 cm (4 in) top diameter and a minimum merchantable height of 4 m (12 ft). For outside bark volumes, the top diameter limit applied to the outside bark measurement and, for inside bark volumes, the top diameter limit applied to the inside bark measurement. The bark ratio method (Wenger 1984) was used to generate inside bark volume equations.

Four models commonly used to generate tree volume equations were fit to the data (in metric units) to predict total outside bark volume. They were:

Honer's (1965) model

[6] $D^2 / V = a + b / H + e$,

Schumacher's (1933) logarithmic model

[7] $\ln(V) = \ln(a) + b\ln(D) + c\ln(H) + \ln(e)$,

Spurr's (1952) combined variable, unweighted

[8] $V = a + bD^2H + e$, and

Spurr's (1952) combined variable,

[9] $V = a + bD^2H + e$, weighted by $(1 / D^2H)^2$, where

D = diameter at breast height,
H = total height,
V = cubic volume, either total or merchantable,
a, b, c are estimated coefficients, and
e = error NID~$(0, \sigma^2)$

The fit of each of these four models were evaluated using Furnival's (1961) index. This index was computed in three stages: 1) mean square residuals (S) were obtained by fitting each model to the data; 2) the geometric mean of the derivative of each dependent variable with respect to volume was computed with the aid of logarithms; and, 3) each root mean square residual was multiplied by the inverse of the appropriate geometric mean in order to determine an index value. The model with the lowest index value best fulfilled the assumptions of least squares and had the best overall fit.

Height Correction

The height of a tree at a given point of sectioning is usually less than the actual tree height at the age determined for a cross sectional point because the point of sectioning will usually occur at some point below the terminal point of a given annual leader. Thus, the direct use of height age data obtained from stem analyses in a model to predict height growth will result in a bias that underestimates total height (Dyer and Bailey 1987).

To correct for this bias, the technique described by Carmean (1972) and modified by Newberry (1991) was used. The two assumptions upon which this technique is based are 1) the stem will be sectioned, on the average, in the middle of a given year's height growth, and 2) the height growth per year in between section points is constant.

The following equation was used to calculate a corrected height for each section except the terminal:

$$[10]\quad CHT_{ij} = HT_i + [(HT_{i+1} - HT_i)/(R_i - R_{i+1})]/2 + (j-1)[(HT_{i+1} - HT_i)/(R_i - R_{i+1})],$$ where

CHT_{ij} = corrected total height for growth ring j based on section point i,

HT_i = height at the ith section point,

R_i = number of growth rings at the ith section point and,

j = growth ring number (assuming the pith as the starting point).

For each terminal section, the following equation was used:

$$[11]\quad CHT_{ij} = HT_i + [(HT_{i+1} - HT_i)/(R_i - R_{i+1} - 0.5)]/2 + (j-1)[(HT_{i+1} - HT_i)/(R_i - R_{i+1} - 0.5)]$$

The application of this height correction method is illustrated in Figure 1.2. Substituting the HT data from Figure 1.2 into equations [10] and [11]:

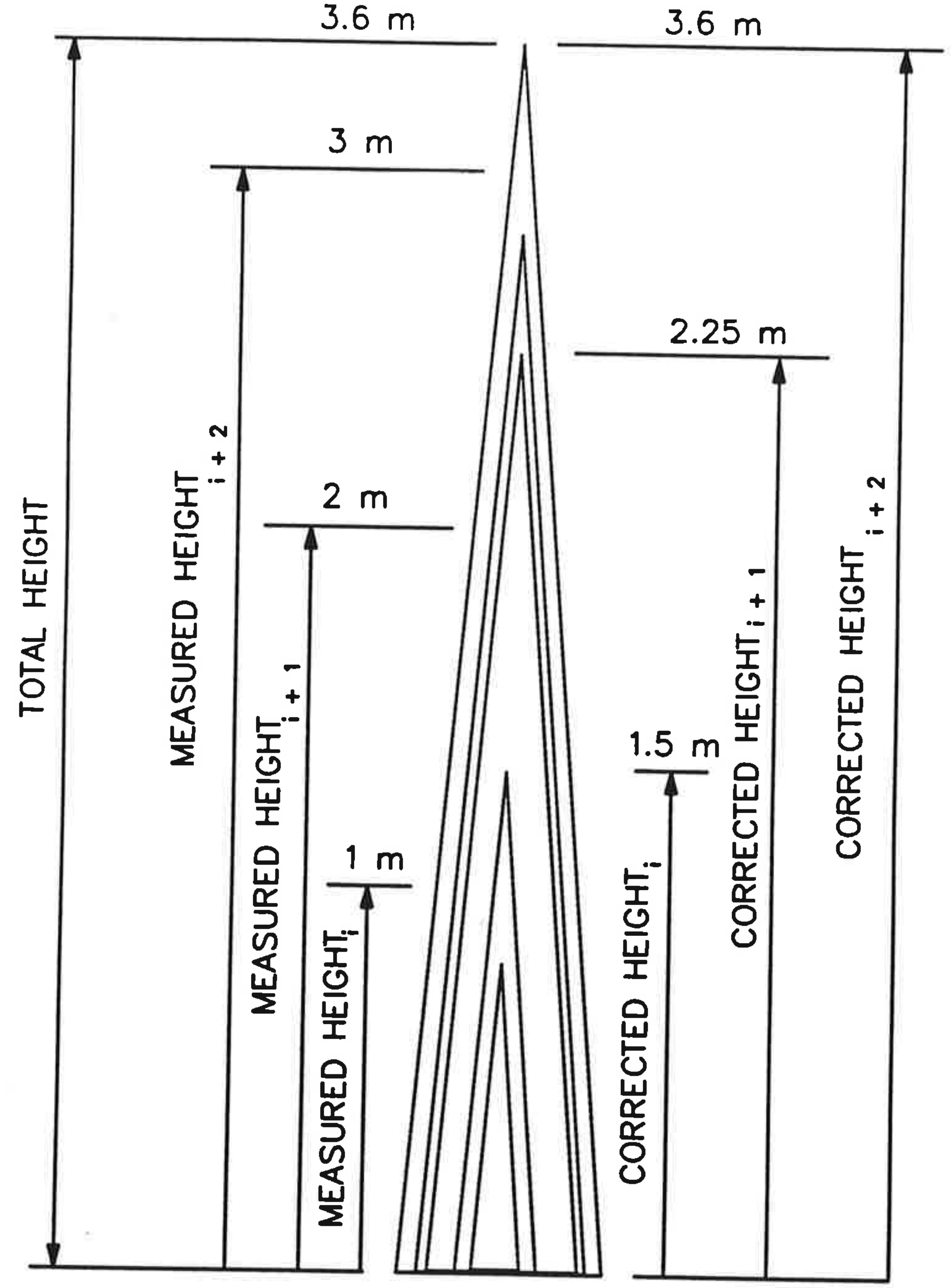

Figure 1.2. Schematic diagram illustrating the corrected height calculations of Carmean (1972) and Newberry (1991). The growth rings are represented by cones.

$CHT_{1,1}$ = 1 + [(2-1)/(4-3)]/2 = 1.5, since the estimation of the first growth ring *j* from the pith is the only growth ring of interest, the second part of this formula = 0 and is thus omitted,

$CHT_{2,1}$ = 2 + [(3-2)/(3-1)]/2 = 2.25,

and for the last section

$CHT_{3,1}$ = 3 + [(3.6-3)/(1- 0 - 0.5)]/2 = 3.6.

Site Index Curves

Site index is defined as the average total height of representative site trees, within a stand, at an index, or base age. For this study, an index age of 20 years at bh (SI_{20}) was chosen. Choosing an index age at bh age rather than total tree age eliminates a source of variation caused by slow and/or erratic early height growth which is strongly influenced by nonsite factors (Monserud 1984a, Thrower 1987). The index age of 20 years at bh was chosen because of the lack of older plantations in Maine and the short rotation potential for European larch.

Fifty-three trees from 17 plots in 6 of the 12 plantations included in this study had attained the base age of 20 years at bh. The data from these trees were used to generate site index curves and to predict site index from early height growth data.

Recall, however, that site expression, not individual tree height, is the item of interest in this study. The height development of the tree is merely a phytometer of site. The average growth curve for each plot was obtained using a simple yet flexible nonlinear model [12] introduced by Richards (1959):

$$[12]\quad HTBH_i = b_1[1 - \exp(-b_2 BHAGE)]^{b_3} + e$$

where,

b_k = parameter estimates,
$HTBH_i$ = height above bh,
BHAGE = bh age,
exp = base of natural logarithms, and
e = error which is assumed NID~$(0,\sigma^2)$.

Visual inspection of the height-age data suggested a sigmoidal pattern that could be adequately described using a nonlinear model. Several authors have used nonlinear models in their development of site index curves (Lundgren and Dolid 1970; Payandeh 1974; Monserud 1984b; Newnham 1987).

Average height-age pairs were generated for each plot and then fit to two nonlinear models for comparison. Each nonlinear model incorporated site index as an independent variable, the first being an exponential-monomolecular function [13], and the second, a simple monomolecular function [14] (Lundgren and Dolid 1970).

$$[13]\quad HTBH_i = b_1 H[1 - \exp(b_2 BHAGE)]^{b_3} + e,$$

$$[14]\quad HTBH_i = H[b_1 + b_2 \exp(b_3 BHAGE)] + e,$$ where

b_k = parameter estimates,
$HTBH_i$ = predicted height above bh (from model [14]),
BHAGE = breast height age,
H = height above bh at BHAGE = 20,
exp = base of a natural logarithm, and
e = error which is assumed NID~$(0,\sigma^2)$.

Site Index Prediction from Early Height Growth

Height above bh values for bh ages 1 through 10 were either obtained directly or interpolated. The height values were then averaged per plot. Statistically, this eliminated the within-plot variation and provided a better estimation of site expression.

Visual analysis of the graphed relationship of SI_{20} expressed as a function of total height at different early growth periods failed to suggest a clear pattern. Therefore, the data were fit to the second order polynomial:

[15] $SI_{20} = b_0 + b_1 EG(X) + b_2 EG(X)^2 + e$, where

SI_{20} = plot site index at bh age = 20,
b_i = parameter estimates,
$EG(X)$ = plot average of the early height growth for bh ages $X = 1 - 10$, and
e = the error term which is assumed $NID \sim (0, \sigma^2)$.

The coefficient for the quadratic term in the model was found to be insignificant in all cases except with EG(1) ($p = 0.0001$). Therefore, the quadratic term (b_2) was eliminated and the final model:

[16] $SI_{20} = b_0 + b_1 EG(X) + e$

was used.

RESULTS AND DISCUSSION

Volume Equations

Diameter at bh ranged from 7.3 to 52.2 cm and total height range from 5.5 to 33.5 m (Table 1.2) for the 101 trees sampled to generate the total volume equations. A subset of 82 of the 101 trees sample satisfied the merchantability criteria (≥10 cm top diameter at ≥4 m); their diameters ranged from 12.9 to 52.2 m with merchantable heights ranging from 4.4 to 29.5 m (Table 1.3).

The dib/dob bark ratio calculated from these data was 0.943 with a bias of 1.467E-6 and a standard error of 3.047E-5. The 79 trees from which the bark ratio data were obtained had an average dbh of 25.3 cm with a range of 7.3 to 52.2 cm.

Table 1.2. Descriptive statistics for trees measured to generate the total volume equations (n=101).

Variable	Mean	Range
dbh (cm)	26.8	7.3 - 52.2
(in)	10.6	2.9 - 20.6
total ht (m)	19.2	5.5 - 33.5
(ft)	63.0	18.0 - 109.9

Table 1.3. Descriptive statistics for trees measured to generate the merchantable volume equations (n=82).

Variable	Mean	Range
dbh (cm)	30.3	12.9 - 52.2
(in)	11.9	5.0 - 20.6
merch. ht (m)	17.0	4.4 - 29.5
(ft)	55.8	14.4 - 96.8

Several alternative regression models were compared in developing the volume prediction equation. They were: [6] Honer's (1965), [7] Schumacher's (1933), [8] Spurr's (1952) unweighted and [9] Spurr's (1952) model weighted by $(1 / D^2H)^2$. The parameter estimates, their standard errors, the coefficient of determination and the mean square error (MSE) for each model evaluated in the prediction of outside bark total volume (OBTVOL) in cubic meters are provided in Table 1.4.

The usual indices of fit, the MSE and coefficient of determination, cannot be used to compare equations that have different dependent variables. In addition, the assumptions of least squares cannot be simultaneously satisfied by a number of models because their respective residual values will not share an equal normal, independent distribution

Table 1.4. Summary of regression analyses to predict total outside bark volume (m^3).

Equation[a]	Parameter Estimate	Standard Error	Model	
			MSE[b]	r^2
Honer [6] $D^2/V = a + b/H$	a 268.718 b 22991	35.15 436.67	32273	0.97
Schumacher [7] $\ln(V)=\ln(a)+b\ln(D)+c\ln(H)$	a -9.852 b 1.911 c 0.966	5.707E-2 4.573E-2 4.319E-2	0.008	0.99
Spurr, unwt. [8] $V = a + bD^2H$	a 0.032 b 3.29E-5	1.507E-2 4.7E-7	0.012	0.98
Spurr, wt. [9] by $(1 / D^2H)^2$	a 4.17E-3 b 3.49E-5	5.8E-3 3.8E-7	1.2E-19	0.99

[a] D = dbh (cm), H = total height (m), V = volume (m^3)
[b] MSE = mean square error

with a constant standard error. If, for example, the residuals from model [9] have a constant standard error, than the residuals for model [8] cannot have a standard error proportional to D^2H.

Furnival (1961) developed an index to select a model that provides the best fit to the data and best satisfies the assumptions of least squares. A summary of the computations for Furnival's (1961) index is provided in Table 1.5. It should be noted that the absolute value of the derivative of the dependent variable with respect to volume was used when applying Furnival's (1961) index to model [6] because the natural log of a negative number is undefined.

Spurr's (1952) [9] model weighted by $(1 / D^2H)^2$ was determined to be the most appropriate for these data. The effect of weighting has a relatively small impact upon the parameter estimates for a given model. However, when data exhibit heteroscedasticity, the application of a weighting factor provides a more accurate assessment of the confidence limits (Figure 1.3).

Parameter estimates for the prediction of OBTVOL, inside bark total volume (IBTVOL), outside bark merchantable volume (OBMVOL), and inside bark merchantable volume (IBMVOL) were calculated in both metric and English units using Spurr's weighted model [9] and are provided along with their respective standard errors, model MSE, and coefficients of determination in Table 1.6.

Table 1.5. Computation of Furnival's (1961) index of fit for models 6, 7, 8 and 9 to predict outside bark total volume in metric units (n=101).

Computations[a]	Model[b] 6	7	8	9
(1) S	179.64	0.0089	0.109	3.28E-6
(2) $(\Sigma \ln[f'(V)])/n$	-8.48	1.70	0	-9.156
(3) antilog (2)	2.08E-4	2.915	1	1.06E-4
(4) index=(1)*(3)	0.037	0.259	0.109	3.46E-10

[a] Brackets [ ] signify a geometric mean

[b] models: 6. $D^2/V = a + b/H$; 7. $\ln(V) = \ln(a)+b\ln(D)+c\ln(H)$; 8. $V = a + bD^2H$, unwt.; 9. $V = a + bD^2H$, wt. by $(1 / D^2H)^2$

The weighted Spurr model has been shown to be a good model for many species, including Norway spruce (Jokela *et al.* 1986) and white spruce (Morton *et al.* 1990).

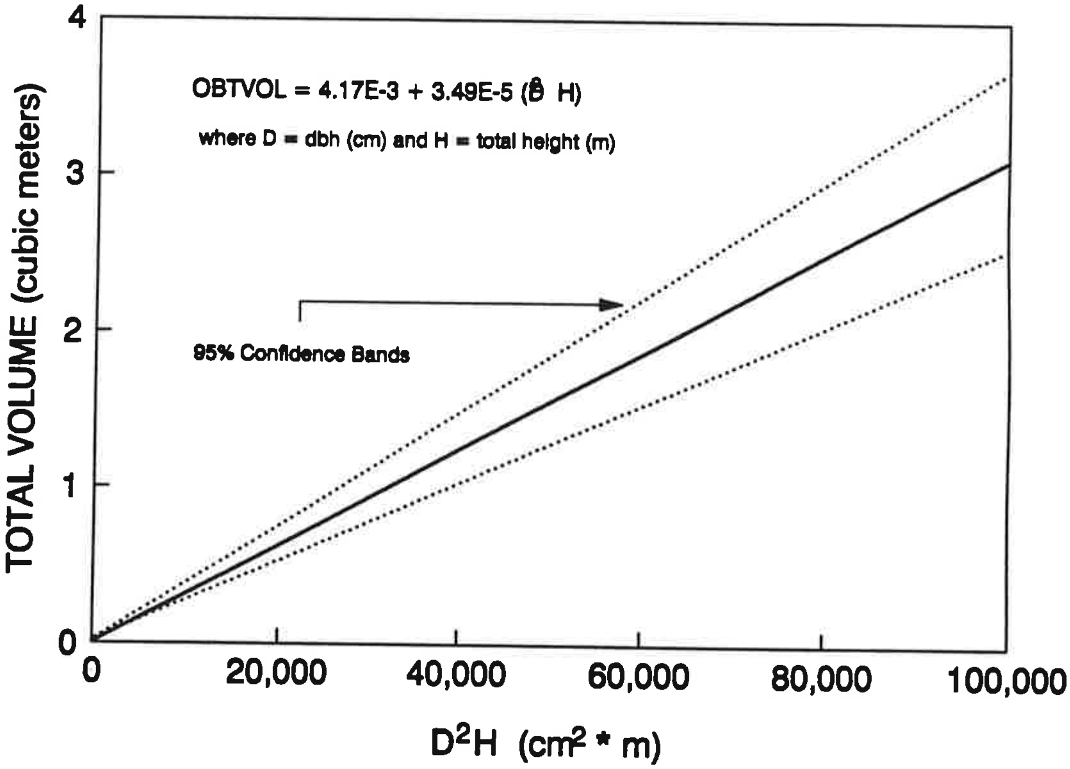

Figure 1.3. Relationship between total volume and D^2H with the 95% confidence band for Spurr's (1953) weighted model [9].

Table 1.6. Parameter estimates, their standard error and coefficients of determination for Spurr's weighted model [9] to predict OBTVOL, IBTVOL, OBMVOL and IBMVOL in metric (m^3) and English (ft^3) units.

Volume Predicted[a]	Parameter Estimate[b]	Standard Error	Model	
			MSE[c]	r^2
		Metric		
IBTVOL	*a* 3.70E-3	5.16E-4	0.01E-8	0.99
	b 3.11E-5	3.4E-7		
OBMVOL	*a* -9.39E-3	3.52E-3	0.01E-8	0.98
	b 3.46E-5	5.7E-7		
IBMVOL	*a* -1.03E-2	3.40E-3	0.01E-8	0.98
	b 3.07E-5	5.3E-7		
		English		
OBTVOL	*a* 0.146	2.05E-2	5.0E-8	0.99
	b 2.43E-3	2.63E-5		
IBTVOL	*a* 0.130	1.82E-2	2.03E-4	0.99
	b 2.16E-3	2.34E-5		
OBMVOL	*a* -0.332	0.124	1.0E-7	0.98
	b 2.40E-3	3.96E-5		
IBMVOL	*a* 0.364	0.120	8.0E-8	0.98
	b 2.13E-3	3.65E-5		

[a] OBTVOL = outside bark total volume,
IBTVOL = inside bark total volume,
OBMVOL = outside bark merchantable volume,
IBMVOL = inside bark merchantable volume.

[b] Volume = $a + bD^2H$ where D = dbh (cm or in) and H = total height (m or ft)

[c] mean square error

A graphical comparison was made (Figure 1.4) between the IBMVOL prediction equation for Japanese larch in Pennsylvania and European larch in Maine. There is a negligible difference between these equations and, given the error of prediction (Figure 1.3), either equation would provide forest mangers with equally reliable estimates of inside bark merchantable volume (4 in top diameter and 12 ft merchantable bole).

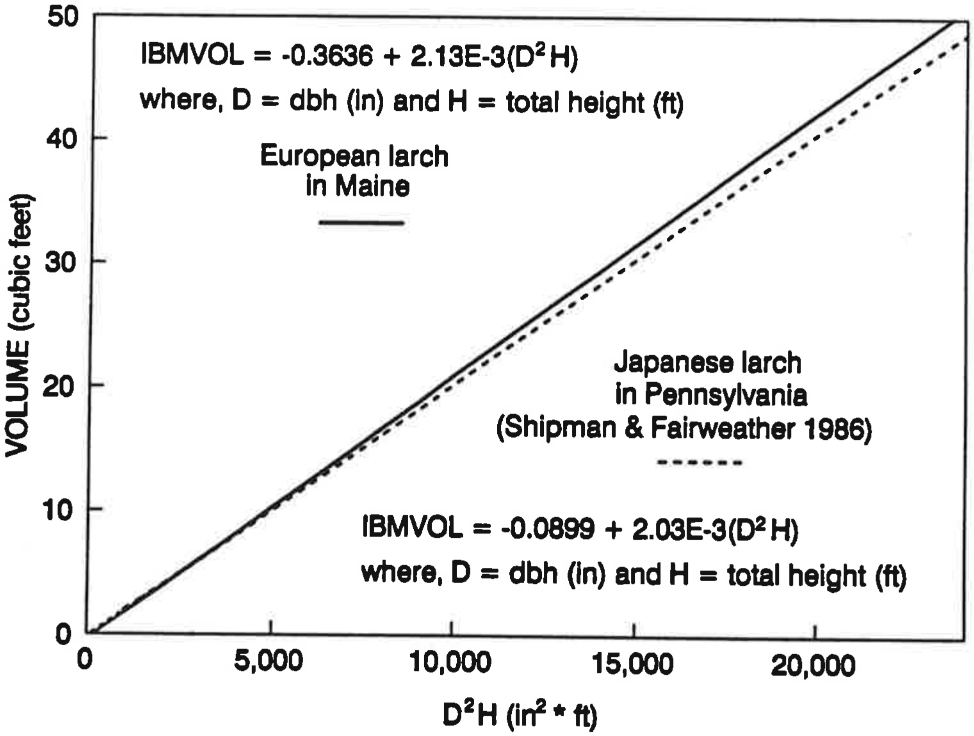

Figure 1.4. Graphical comparison of the inside bark merchantable volume equation for Japanese larch in Pennsylvania and the inside bark merchantable volume equation for European larch in Maine.

Site Index Curves

Measurements from fifty-three trees, from 17 plots, having an average total age of 53 years with a range of 33 to 60 years, an average number of years to attain bh of 6 years with a range of 3 to 12 years, and an average SI_{20} of 15 m with a range of 11.2 to 19.4 m were used to generate site index curves. The parameter estimates, model MSE and model pseudo r^2 values (Newnham 1988) for the average growth curves from each plot obtained using the Richards (1959) function are provided in Table 1.7.

The 17 within-plot MSE values for the Richards function [12] averaged 0.85 m with a standard error of 0.55 m. While this error may at first appear excessive, recall the variability inherent to this species. Examination of the plotted predicted versus residual values for each plot revealed a harmonic pattern in almost all cases, suggesting a multicollinearity problem (Figure 1.5). This is not surprising given the fact that multiple observations were taken from each tree. Given the limited data base for this study, there is little that can be done to correct this problem.

The parameter estimates, MSE and pseudo-r^2 values (Newnham 1988) for the 2 models compared to generate site index curves are provided in Table 1.8. The two models were evaluated based upon the usual indices of fit (Table 1.8) and an examination of their residual plots.

Table 1.7. Parameter estimates, model mean square error (MSE) and model pseudo-r^2 values for the Richards function[a] [12] for the 17 plots used in the construction of the site index curves.

	Parameter Estimates				
Plot	b_1	b_2	b_3	MSE	pseudo-r^2
				m	
D01	46.82	0.017	0.889	0.459	0.99
D05	35.24	0.023	0.883	0.604	0.98
D06	28.68	0.045	1.057	0.170	0.99
S03	34.92	0.016	0.810	0.138	0.99
S04	31.43	0.029	0.946	1.641	0.96
S05	35.47	0.027	0.896	0.991	0.98
S06	37.54	0.027	0.883	1.054	0.98
S07	35.33	0.031	0.951	1.642	0.97
S08	41.74	0.023	0.950	1.610	0.97
S09	49.41	0.015	0.829	0.291	0.99
S10	50.62	0.017	0.893	0.613	0.99
S11	38.70	0.029	1.075	0.266	0.99
S12	43.71	0.020	0.918	1.627	0.97
S13	23.60	0.043	0.955	1.175	0.96
S14	39.30	0.023	0.929	0.837	0.98
S15	32.01	0.029	1.070	0.359	0.99
U01	23.70	0.049	1.336	0.999	0.96

[a] $HTBH_i = b_1[1 - \exp(-b_2 BHAGE)]^{b_3}$, where
$HTBH_i$ = height above bh (m),
BHAGE = bh age,
exp = base of natural logarithms

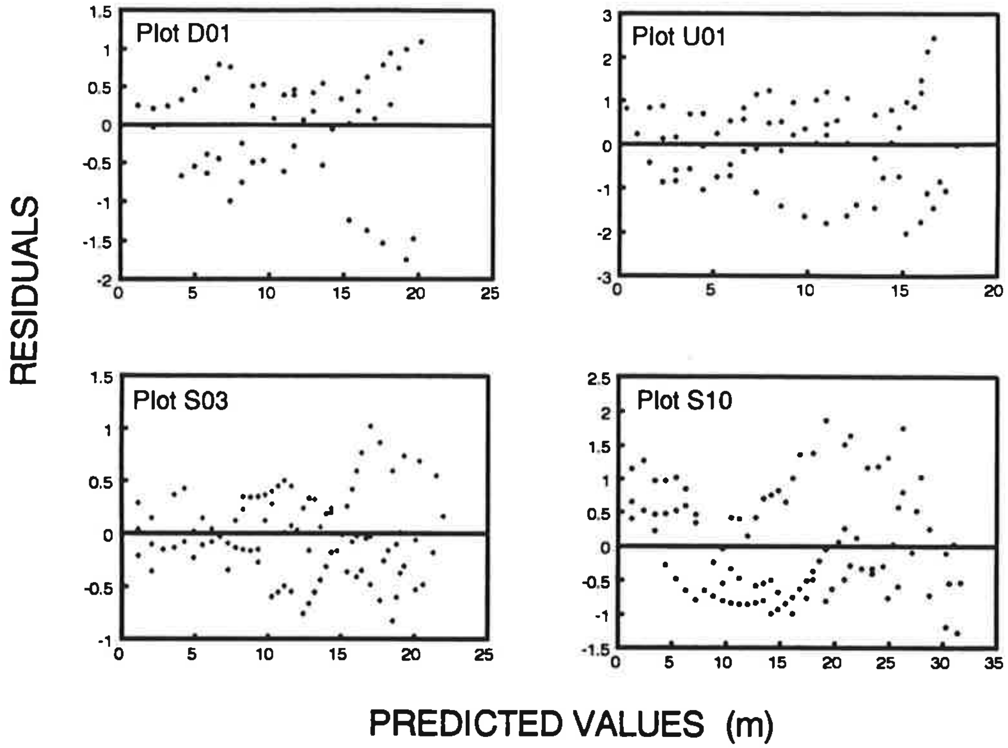

Figure 1.5. Typical patterns encountered in the residual plots for the Richards [12] growth function.

The MSEs and pseudo-r^2 values for [13] and [14] were similar. The residual plots for each model were also similar and did not suggest any serious departures from normality. Thus, the choice of one model over the other was subjective. Model [14] was chosen because of its simpler form.

The parameter estimates, their standard errors and the coefficients of determination are nearly equal for both the metric and English versions of model [14]. The parameter estimates differ at the one ten thousandth of a decimal place. At first this may appear surprising, but recall that

Table 1.8. Parameter estimates, mean square error (MSE) and pseudo-r^2 values the two nonlinear models[a] compared to predict the height growth of European larch at an index age of BHAGE=20.

Model	Parameter Estimates b_1	b_2	b_3	MSE	Pseudo-r^2
[13]	2.437	-0.025	0.927	0.250	0.9784
[14]	2.325	-2.300	-0.028	0.253	0.9787

[a] [13] $HTBH_i = b_1 H[1 - \exp(b_2 BHAGE)]^{b_3}$,
[14] $HTBH_i = H[b_1 + b_2 \exp(b_3 BHAGE)]$, where
$HTBH_i$ = predicted height (m or ft) above bh values from model [12],
BHAGE = breast height age,
H = height (in m or ft at bh age=20) - bh,
exp = exponent of the natural logarithm

this nonlinear model merely describes a curve shape using two reference points, age and height.

Site index curves generated from model [14] in metric and English units of measure are provided in Figures 1.6 and 1.7. The average site index per plot was 15.4 m with a range of 12.0 to 18.2 m and a standard error of 1.5 m.

A common problem associated with site index curves constructed using nonlinear models is they fail to pass directly through the site index point at a given base age (Newnham 1988; Carmean *et al.* 1989). Because of the limited data base, no attempt was made to correct for this. This is reasonable from a pragmatic standpoint because the size of this error relative to the MSE of the model is quite small.

The site index curves provided in this report may be directly applied by forest managers. It is recommended that SI_{20} be determined for at least three trees per site, and averaged. The application of the model, however, requires

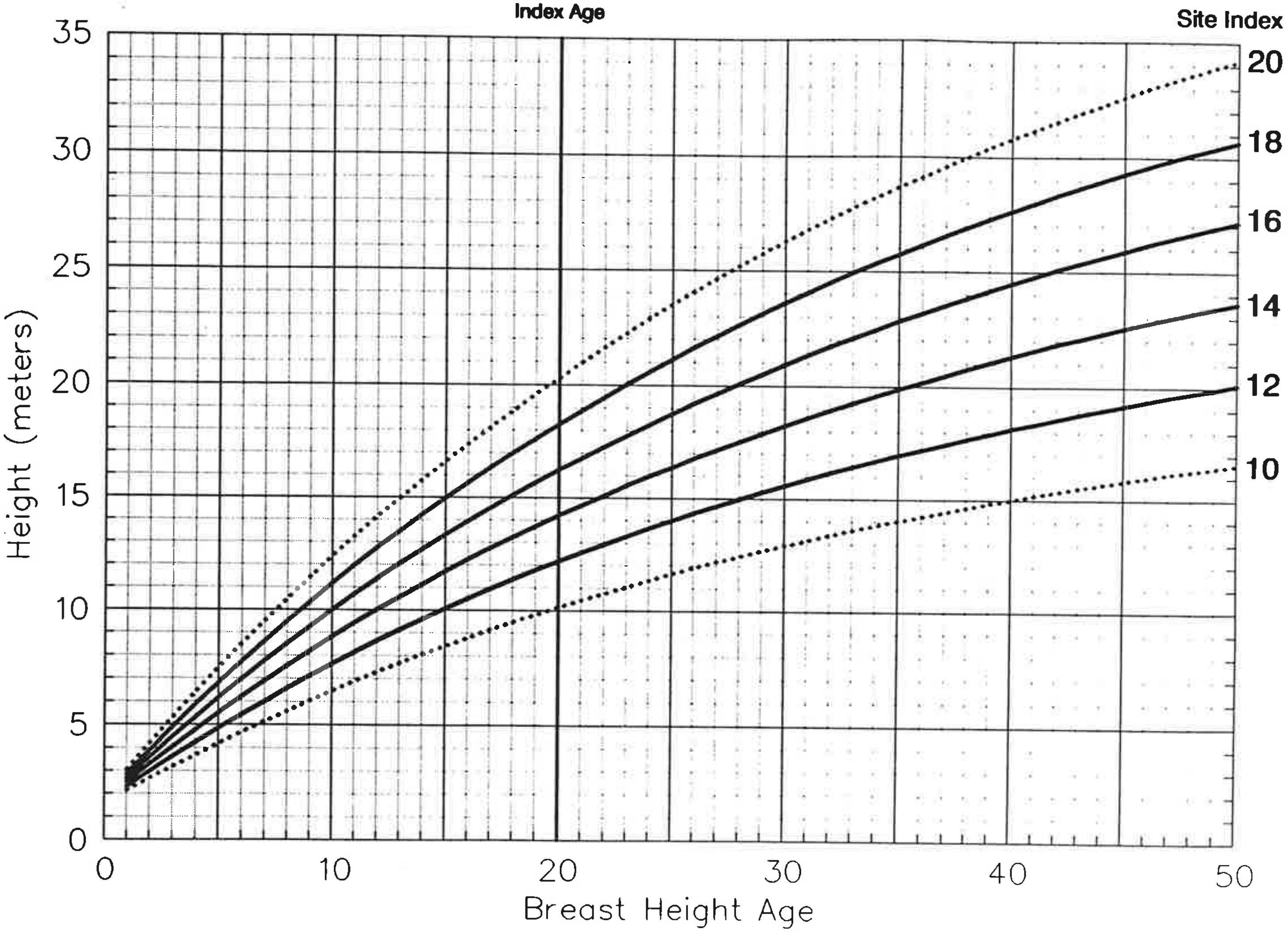

Figure 1.6. Site index curves for European larch in metric units. Curves constructed within the range of stem analysis data are indicated with solid lines. Extrapolated curves are indicated with dotted lines.

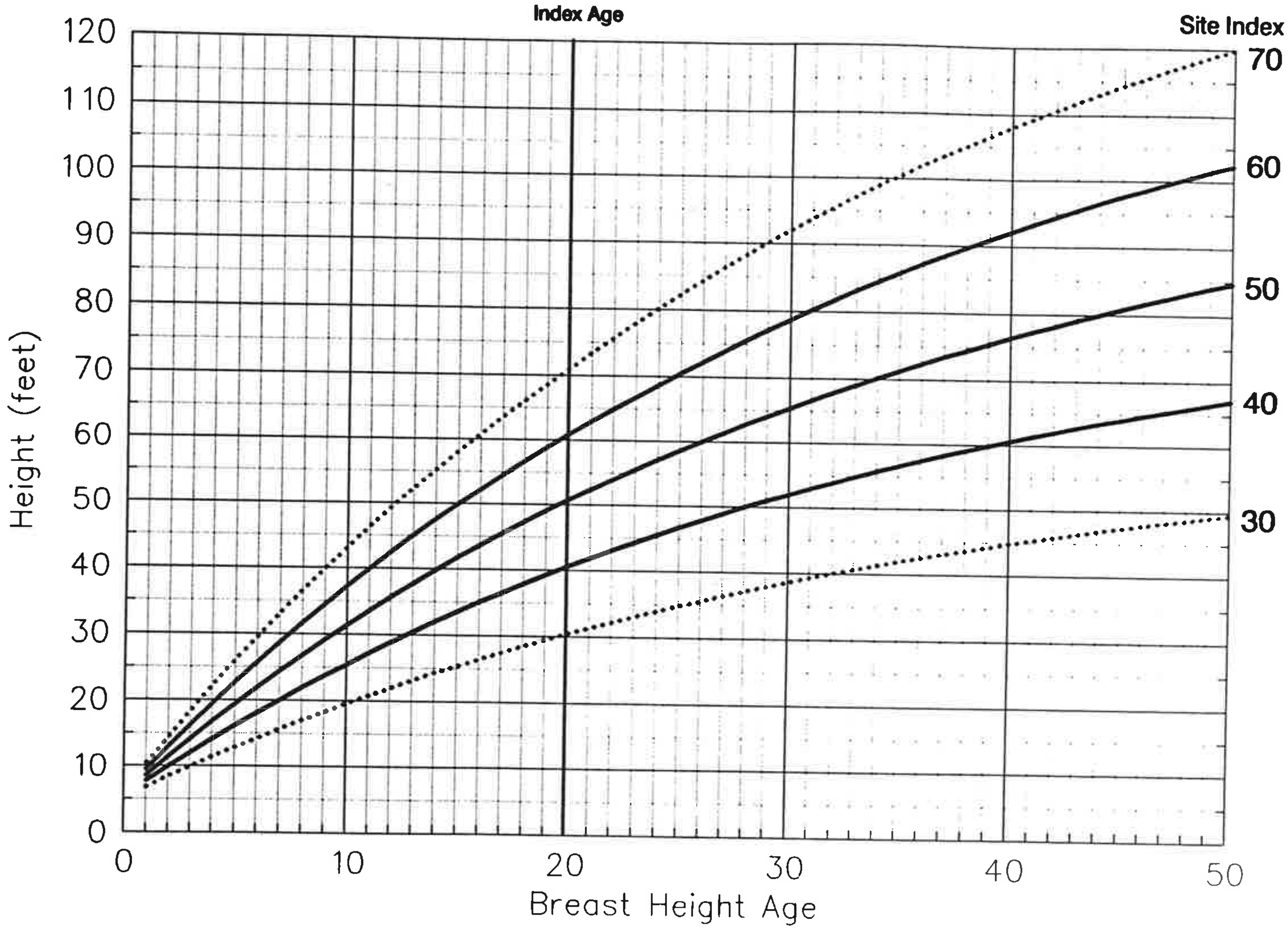

Figure 1.7. Site index curves for European larch in English units. Curves constructed within the range of stem analysis data are indicated with solid lines. Extrapolated curves are indicated with dotted lines.

slight modification. Recall that [14] is based upon height growth above bh. Therefore in order to predict total height, simply add bh (1.37 m or 4.5 ft) to the results obtained from [14]. If, for example, a curve for a $SI_{20}=50$ ft is desired, 4.5 ft (bh) must first be subtracted from 50 ft in order to generate a site index curve with 50 ft as the total height at a bh age of 20 years. Breast height (4.5 ft) is then simply added to the results.

A comparison was made between the site index curves developed from this study (SI_{20} = 40, 50, 60) and those developed by Aird and Stone (1955) as formulated by Carmean *et al.* (1989) (Figure 1.8). The time period to attain bh was assumed to be 3 years (Carmean *et al.* 1989) and the index age of 47 years at bh (SI_{47}) was used for comparison.

The two sets of site index curves compare favorably up to the bh age of 20 years (Figure 1.8), beyond which they diverge. The curves depicting the lower site indices [SI_{20} = 40 for this study, SI_{47} = 59 (Aird and Stone 1955)] differ less (6 ft at index age 47 at bh) then those depicting the higher site indices (SI_{20} = 50 and 60 this study, SI_{47} = 74 and 88 (Aird and Stone 1955)) which have differences at SI_{47} of 8 and 12 feet respectively. It should be noted that the site index curves constructed from this study are supported by data within the range depicted, while the SI_{47} = 88 curve of Aird and Stone (1955) is extrapolated beyond the range of curves originally published. It is also important to note that Figure 1.8 is merely a comparison between different

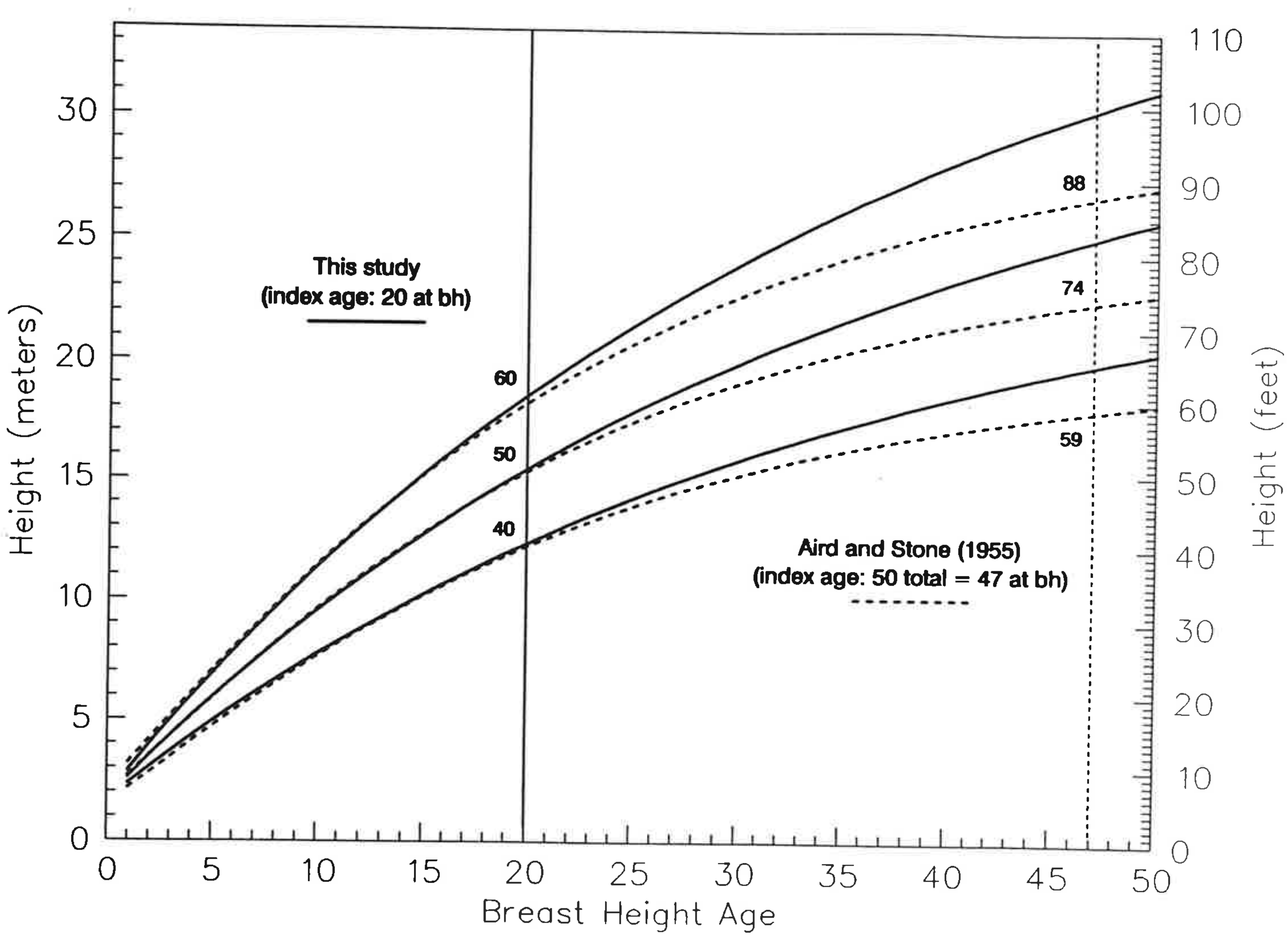

Figure 1.8. Graphical comparison of site index curves developed for European larch in Maine (This study), and in southern New York (Aird and Stone 1955). Time to bh for the curves of Aird and Stone (1955) assumed to be 3 years (Carmean *et al.* 1989).

site index curves for European larch. No relationship between soils or other site factors is implied.

Site Index Prediction from Early Height Growth

The conventional growth intercept method of site estimation involves measurement of the distance between growth whorls above bh and relating that measurement to site index at a given base age. Because of the indeterminate height growth pattern characteristic of the genus *Larix*, it is not possible to distinguish annual whorls. Consequently, it was necessary to modify this technique and relate total height at a given bh age directly to SI_{20}.

Site indices (Table 1.9) from the fifty-three trees destructively sampled from 17 plots in 6 plantations were used as the dependent variable and the average height at 10 different growth periods (bh ages 1 through 10) from each plot (Table 1.10) were incorporated as independent variables in 10 equations, using [16] to predict SI_{20}.

Parameter estimates, their standard error, the model mean square error and coefficients of determination for [16] are provided in Table 1.11. As bh age increases, note the improvement in the fit of the model (increasing r^2 and reduced MSE). Not surprisingly, the parameter estimates for slope are identical in both metric and English units.

Previous studies have shown that there is a significant correlation between growth internode distances and site

Table 1.9. Site indices (SI_{20}) for individual trees with bh ages > 20 years used to construct the site index equations.

Plot	Tree	SI_{20}
		m
D01	1	17.25[a]
D01	2	16.87
D01	3	15.62
D05	1	14.62
D05	2	15.43[a]
D05	3	16.87
D06	1	18.12[a]
D06	2	17.50
D06	3	17.54
S03	1	13.50
S03	2	13.81[a]
S03	3	12.81[a]
S04	1	16.87
S04	2	13.62
S04	3	16.12
S05	1	16.62
S05	2	18.43[a]
S05	3	16.93[a]
S06	1	18.87
S06	2	17.12
S06	3	18.12
S07	1	18.12
S07	2	16.62
S07	3	20.50[a]
S08	1	18.25
S08	2	15.62
S08	3	17.87
S09	1	17.37
S09	2	17.62
S09	3	18.12
S10	1	19.62
S10	2	17.37[a]
S10	3	17.62
S11	1	17.12
S11	2	16.87
S11	3	17.37
S12	1	18.62
S12	2	16.87
S12	3	15.62
S13	1	16.12
S13	2	13.62
S13	3	16.56[a]
S13	4	15.00
S14	1	16.87
S14	2	16.87
S14	3	15.62
S15	1	15.54
S15	2	14.25[a]
S15	3	14.12[a]
U01	1	14.06[a]
U01	2	13.78[a]
U01	3	14.90[a]
U01	4	12.62

[a] Indicates interpolated values.

Table 1.10. Summary statistics for the average plot heights for early growth periods in meters (n=17).

Growth Period	Average Height	Range	
		Minimum	Maximum
bh age	m	m	m
1	2.96	2.12	3.89
2	3.87	2.58	4.95
3	4.72	3.07	5.83
4	5.59	3.65	6.87
5	6.46	4.34	7.95
6	7.22	5.00	8.62
7	8.00	5.65	9.24
8	8.72	6.46	9.95
9	9.40	7.28	10.79
10	10.06	8.12	11.53

Table 1.11. Parameter estimates, their standard error, model mean square error (MSE) and coefficients of determination for the prediction of SI_{20} from average periods of early height growth using model [16][a] (n=17).

Growth Period	Parameter Estimates b_0	SE	b_1	SE	Model MSE	r^2
			Metric			
1	9.33	1.66	2.413	0.553	1.10	0.56
2	9.89	1.46	1.701	0.371	1.04	0.58
3	9.56	1.52	1.467	0.319	1.02	0.58
4	8.53	1.61	1.424	0.285	0.94	0.62
5	7.37	1.61	1.411	0.247	0.79	0.68
6	6.33	1.72	1.405	0.236	0.74	0.70
7	4.76	1.83	1.467	0.228	0.66	0.73
8	3.08	1.93	1.537	0.220	0.59	0.76
9	2.23	1.95	1.516	0.206	0.54	0.78
10	1.56	1.79	1.470	0.175	0.44	0.82
			English			
1	30.62	5.44	2.413	0.553	11.9	0.56
2	32.47	4.78	1.701	0.371	11.2	0.58
3	31.37	6.25	1.467	0.319	11.2	0.58
4	27.99	5.28	1.424	0.285	10.1	0.62
5	24.19	5.28	1.411	0.247	8.5	0.68
6	20.79	5.64	1.405	0.236	8.0	0.70
7	15.63	6.01	1.467	0.228	7.2	0.73
8	10.11	6.33	1.537	0.220	6.3	0.76
9	7.32	6.38	1.516	0.206	5.8	0.78
10	5.10	5.87	1.470	0.175	4.7	0.82

[a] [16] $SI_{20} = b_0 + b_1 EG(X)$ where,
SI_{20} = plot site index
$EG(X)$= plot average of the early height growth for bh ages X = 1 - 10

index (Wakely and Marrero 1958; Alban 1972; Alban 1979; Thrower 1987). While the conventional method of growth intercept does not require that the tree age, or plantation age, be known, the accurate measurement of widely spaced internodes can be cumbersome.

The information required to utilize this method of predicting site index is bh age and the corresponding total tree height. The reliability of SI_{20} estimates using [16] and early height growth information improves with increasing bh. It is recommended that SI_{20} be determined for at least three trees per site and averaged.

SUMMARY

The volume equation constructed from stem analysis data collected from 12 European larch plantations in Maine to predict IBMVOL compares favorably with a similar volume equation constructed to predict IBMVOL for Japanese larch in Pennsylvania. In addition, volume equations were constructed to predict OBTVOL, OBMVOL, IBTVOL. Site index curves constructed from stem analysis data collected from 53 trees from 6 plantations compare favorably with site index curves constructed for European larch in New York to a bh age of 20 years. Beyond a bh age of 20, the curves diverge, with those developed in New York consistently underestimating height as predicted by the curves from Maine. Using a simple linear model, 10 separate equations were constructed to predict SI_{20} from different periods of

early height growth (bh ages 1-10). The predictability of this model improves substantially as bh age increases.

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CHAPTER 2

SOIL-SITE RELATIONSHIPS FOR EUROPEAN LARCH (*LARIX DECIDUA* MILLER) PLANTATIONS IN MAINE

INTRODUCTION

Projected wood supply shortages in the Northeast Baskerville 1983; Einspahr *et al.* 1984; Greenwood *et al.* 1988; Seymour and Lemin 1989) resulting from passive forest management practices coupled with a multitude of conflicting demands being placed upon our forest resources (e.g., wildlife habitat preservation, forest preserves, recreation, second home development) have stimulated interest in the establishment of "high yield" forest plantations in Maine. If practiced on a large enough scale, it would be possible to reduce the land base used for timber production (Seymour and McCormack 1989).

European larch (*Larix decidua* Miller) is an exotic species whose rapid early growth has exceeded that of native conifers planted on comparable sites (Robbins 1985; Carter and Selin 1987). The rapid growth rate and desirable wood properties of this species (Einspahr *et al.* 1984) make it a prime candidate for inclusion in "high yield" plantation programs.

Two key factors in the establishment of "high yield" plantations are proper species selection and proper site evaluation (McCormack *et al.* 1989). Site index, determined by the height of a free growing dominant or codominant tree at an index age, is the most widely accepted method for the direct estimation of site quality in the United States (Carmean 1975). With an exotic species, however, the direct estimation of site index for potential plantation sites is often not possible. Soil-site studies, which employ multiple regression methods to indirectly estimate site index from edaphic and physiographic features, are useful for indirectly predicting site index (Carmean 1975, 1986).

A thorough review of the literature has revealed only two soil-site studies for exotic larches in North America. Aird and Stone (1955) examined the effects of soil-site variables on the productivity of European and Japanese larch (*L. leptolepis* Sieb. and Zucc.) in the uplands of southern New York and southern New England. They reported a linear relationship between free rooting depth and site index (base age 25) for both European and Japanese larch. Parsonage (1989) examined soil-site relationships for Japanese larch in 52 thinned and unthinned plantations in Pennsylvania. Using stepwise regression, 50% of the variation in site index was accounted for by three variables: surface soil percent silt, drainage class, and the free rooting depth X subsoil percent sand interaction term.

The applicability of these results beyond their respective areas of study is unknown. The results from Aird and Stone's (1955) and Parsonage's (1989) studies were derived from plantations located in a mesic soil temperature regime (Soil Survey Staff 1990). All soils in Maine are in a frigid soil temperature regime (Soil Survey Staff 1990). Carmean (1975) suggested limiting the application of results obtained from any given soil-site study to areas having similar soil-site characteristics within the same geographic region.

As interest in the inclusion of European larch into "high yield" plantation programs increases, an understanding of the relationship between soil-site characteristics and site quality for this species in Maine will become essential.

Objectives

The primary objective of this study was to examine the relationship between site quality (as expressed by site index) and soil-site characteristics. The effect of soil drainage class upon early height development, and site index was first examined. Next, two types of exploratory analyses were used: 1) stepwise regression was used to construct site index prediction models using soil-site variables, and 2) discriminant analysis was used to classify sites into different categories of site index using soil-site variables.

METHODS

A physiographic description of the study area, the plantation selection criteria, and a map illustrating the geographic distribution and ownership of the plantations included in the European larch soil-site study are provided in Chapter 1.

Field Procedure

A soil pit was excavated near the center of each plot to a depth of 1 m or an impermeable layer. The thickness of each horizon, rooting depth, depth to drainage mottles and the depth to a root restricting layer were measured along each pit face and averaged. Soil drainage class was determined based upon the depth of drainage mottles having a chroma of 2 or less and a value of 4 or more (Maine Association of Professional Soil Scientists 1990). The range of depths for drainage models within each drainage class were: poorly drained ≤ 7 in, somewhat poorly drained 7 to 16 in, moderately well drained 16 to 40 in, and well drained ≥ 40 in (Maine Association of Professional Soil Scientists 1990). Soil samples were collected from each horizon, labelled and returned to Orono for chemical and textural analyses.

Three dominant or codominant trees were selected for detailed stem analysis from each plot. These results are reported in Chapter 1. Site indices at a base age of 20 years breast height (SI_{20}) were directly determined, or predicted, for each of the sample trees (Chapter 1).

Soil drainage class ranged from poorly (PD) to well drained (WD), aspect was considered either northeasterly or southwesterly (Jones and Saviello 1991), percent slope ranged from 2 to 19%, topographic position ranged from a toe slope to a summit, and elevation above sea level ranged from 35 to 299 meters (Table 2.1).

Table 2.1. Topographic characteristics and soil drainage classes for the study plots in the European larch soil-site study.

Plot	Drainage Class[a]	Aspect[b]	Percent Slope	Slope Position[c]	Elevation[d]
					m
B01	WD	A	3	TS	238
B02	WD	B	4	TS	216
B03	WD	B	2	TS	216
B04	WD	B	2	TS	216
D01	MWD	A	4	SM	107
D02	SPD	A	4	TS	43
D03	WD	A	19	BS	46
D04	PD	B	6	SM	43
D05	WD	B	3	FS	107
D06	WD	B	3	FS	91
D07	WD	B	3	PT	151
D08	WD	B	4	PT	157
D09	WD	A	4	PT	157
S01	SPD	B	15	BS	250
S02	PD	B	9	TS	238
S03	WD	A	9	SM	299
S04	WD	A	7	SM	293
S05	MWD	A	11	FS	286
S06	SPD	A	15	FS	268
S07	MWD	A	11	FS	268
S08	MWD	A	21	SH	244
S09	MWD	A	11	BS	213
S10	MWD	A	12	BS	183
S11	MWD	A	11	TS	171
S12	MWD	B	10	TS	152
S13	WD	B	7	SH	152
S14	SPD	B	9	TS	244
S15	MWD	B	7	FS	244
S16	WD	A	17	SH	222
S17	WD	A	11	SH	229
U01	PD	A	7	FS	35

[a] PD = poorly drained, SPD = somewhat poorly drained, MWD = moderately well drained, WD = well drained

[b] A = 315^{0} to 134^{0}, B = 135^{0} to 314^{0} (Jones and Saviello 1991)

[c] TS = toeslope, SM = summit, BS = backslope, FS = footslope, PT = plateau

[d] Determined from USGS topographic maps and converted to meters

Laboratory Procedures

Soils were sieved to pass through a 2 mm screen to obtain the fine earth fraction from which subsamples were taken for all chemical and textural analyses. Soil pH and soil texture were determined on all horizons from each plot. The percent organic carbon, effective cation exchange capacity (ECEC), extractable P, and exchangeable acidity analyses were determined only for the solum horizons. Duplicate analyses were run on all samples and averaged, except the base cation extractions, for the soils sampled in 1990. Duplicate analyses were run only with the organic carbon analysis for the soils sampled in 1991.

Chemical Soil Analyses

Soil pH was measured with a 1:1 paste of soil:solution using distilled water, and using 1 *N* KCl. Twenty grams of soil were added to 20 ml of solution, the samples were mixed and allowed to stand overnight after which the pH was measured (Peech 1965) using a glass electrode Fisher Accumet^R pH Meter Model 620.

Organic matter was determined using the Walkley-Black method (Allison 1965). Subsamples from each horizon were ground to pass a 0.5 mm sieve. Subsample weights varied according to organic matter levels by horizon as follows: Ap, 0.10 to 0.15 g; Bs, 0.50 g; Bw, 0.30 to 0.35 g; and, BC, 1.00 g. Exactly 10 ml of 1 *N* K_2CrO_7 was added to a flask with the soil sample. The C was then oxidized with 20 ml of concentrated H_2SO_4 for 30 minutes after which the solution was diluted with 200 ml of distilled water. A ferroin indicator was added and the solution titrated with 0.5 *N* $FeSO_4$ (Allison 1965).

Exchangeable cations and extractable P were determined by leaching a 10 g soil sample with 300 ml 1 *N* NH_4OAc (pH 3.0) and analysis of the filtrate using atomic absorption methods. The filtrates were analyzed for concentrations of Na and K using a Thermo Jarrell Ash Model 975 inductively coupled argon plasma emission spectrophotometer, and for concentrations of Ca, Mg, and P using a Instrumentation Laboratories Model Video 12 atomic absorption spectrophotometer. Solution concentrations in ppm were converted to meq/100 g using the following conversion factors: ppm Na X 0.1305, ppm K X 0.0768, ppm Ca X 0.150, and ppm Mg X 0.247.

Exchangeable acidity was determined by the extraction of the Al and H ions from soil samples of 10 g using 75 ml of a 1 *N* KCl leachate. The filtrate was titrated with 0.1 *N* NaOH using a phenolphthalein indicator (Mclean 1965).

The effective cation exchange capacity (ECEC) was calculated as the sum of cations.

Soil Textural Analyses

Soil samples (30 g) were agitated overnight in a 5% solution (30 ml) of sodium hexametaphosphate. The soil solutions were placed into 1 liter cylinders, brought to volume, and placed in a constant temperature (20^0C) room for temperature adjustment overnight. The following day, the cylinders were agitated (Bouyoucos 1962) and hydrometer readings were taken at 2 hour and 8 hour intervals. Following the 8 hour readings, the solutions were sieved through a 0.053 mm screen, washed, weighed, and the percent sand determined. Clay (%) was determined from the 8 hour hydrometer readings (Bouyoucos 1962, Day 1965). Silt (%) was determined by subtracting the sand and clay fractions from 100%.

Errors in this method of textural analysis became apparent when negative and excessive amounts of clay (%) were calculated. Since the sand (%) was determined by weighing, corrections in the clay (%) readings were made using the following procedure: 1) the negative values for clay were set to zero percent, and 2) excessive values for clay were corrected by subtracting the sand (%) from 100%. These aberrant clay readings were infrequent and probably resulted from biological activity taking place in the soil solutions due to the presence of organic matter. Because of this, pipette analysis (Day 1965) was performed on all soil samples collected during the 1991 field season.

Prior to pipette analysis, the organic matter in 10 g samples of soil was oxidized using hydrogen peroxide. Ten ml of 5% sodium hexametaphosphate was added to each sample and they were agitated overnight. The sand fraction was removed by sieving, dried, and the percent sand calculated. The solutions of suspended silt and clay were placed into 1 liter cylinders, brought to volume, and immersed in a 30^{0}C water bath overnight. Solutions were then agitated for 1 minute followed by pipette extractions at a 10 cm depth, after 6 hours and 22 minutes. Pipetted samples were drained into preweighed beakers and oven dried; clay (%) was determined by weighing (Day 1965). Percent silt was calculated by subtracting the sand and clay fractions from 100%.

Data Analyses

Master horizons (A, B, BC) were designated (e.g., Bs, Bw were included in the B master horizon) and, excepting pH, the mean values for soil variables (Table 2.2) were computed for each master horizon within each soil profile. Soil variables were then weighted by horizon thickness and averaged for the solum in order to assign a single textural and chemical variable to each plot.

Separate analyses of variance (ANOVA) were used to test the null hypothesis of equal means for soil variables (Table 2.2) among drainage classes for the solum and each master horizon. If the hypothesis of equal means was rejected ($\alpha=0.1$), the following linear contrasts (Steel and Torrie 1980) were tested: 1) PD versus moderately well drained (MWD) and WD soils, 2) somewhat poorly drained (SPD) versus MWD and WD soils, and 3) PD versus SPD soils.

Two separate analyses were performed to assess the impact of soil drainage class upon the first 10 years of growth after attaining bh. Average height growth for each year (1 - 10) was determined from the site trees

Table 2.2. Edaphic and physiographic variables examined in the European larch soil-site study.

Edaphic Variables	Physiographic Variables
solum P (ppm)	% slope
solum K (meq/100 g)	elevation (m)
solum Ca (meq/100 g)	aspect
solum Na (meq/100 g)	slope position
solum Mg (meq/100 g)	
exchangeable acidity (meq/100)	
effective CEC (meq/100)	
% organic matter	
A horizon H_2O pH	
B horizon KCl pH	
A horizon H_2O pH	
B horizon KCl pH	
% sand	
% silt	
% clay	
effective rooting depth (cm)	
solum thickness (cm)	
A horizon thickness (cm)	
B horizon thickness (cm)	
BC horizon thickness (cm)	

destructively sampled on each plot. All available early height growth data (Chapter 1) were included in these analyses up to a bh age of 10 years.

For the first analysis, regression with dummy variables (Cunia 1973; Neter *et al.* 1990) was used to assess the effect of drainage class upon the rate of early height growth. Height was expressed as a function of bh age and drainage class. The data were first fit to a second order polynomial model of the form:

[1] MHTBH $= b_0 + b_1\text{BHAGE} + b_2\text{BHAGE}^2 + e$ where,

MHTBH = the average corrected height growth increment above breast height for each plot,
b_i = parameter estimates,
BHAGE = 0, 1, ..., 10, and
e = error which is assumed NID~$(0,\sigma^2)$.

The quadratic effect in the model (b_2) was not statistically significant (α=0.05), and was therefore eliminated. The complete model used to predict MHTBH for each drainage class was:

$$[2]\ \text{MHTBH} = b_{11}X_{11} + b_{12}X_{12} + b_{21}X_{21} + b_{22}X_{22} + b_{31}X_{31} + b_{32}X_{32} + b_{41}X_{41} + b_{42}X_{42} + e, \quad \text{where}$$

X_{11} = 1 if drainage class = poorly drained (PD);
= 0 otherwise,
X_{12} = BHAGE if drainage class = PD;
= 0 otherwise,

X_{21} = 1 if drainage class = somewhat poorly drained (SPD);
= 0 otherwise,
X_{22} = BHAGE if drainage class = SPD;
= 0 otherwise,

X_{31} = 1 if drainage class = moderately well drained (MWD);
= 0 otherwise,

X_{32} = BHAGE if drainage class = MWD;
= 0 otherwise,

X_{41} = 1 if drainage class = well drained (WD);
= 0 otherwise,

X_{42} = BHAGE if drainage class = WD;
= 0 otherwise,

b_{ij} = estimated coefficients, and

e = error which is assumed NID~$(0,\sigma^2)$.

Since the parameter estimates for slope are equivalent to the rate of early height growth for each drainage class, the null hypothesis of equal slopes across soil drainage classes (H_0: $b_{12} = b_{22} = b_{32} = b_{42}$) was tested. Using the reduced model:

$$[3]\ \text{MHTBH} = b_{11}X_{11} + b_{21}X_{21} + b_{31}X_{31} + b_{41}X_{41} + b_{c2}(X_{12} + X_{22} + X_{32} + X_{42}) + e,$$

where b_{c2} = the combined slope term.

The F statistic was calculated as:

$F^* = [(SSE(R) - SSE(F)) / (df(R) - df(F))] / MSE(F)$, where SSE(F) = sum of squares for the error term in the full model, SSE(R) = sum of squares for the error term in the reduced model, df(F) = degrees of freedom in the error term for the full model, df(R) = degrees of freedom in the error term for the reduced model, and MSE(F) = mean square error term for the full model.

For the second analysis, the average rate of early height growth for individual trees was determined by dividing the height above bh by bh age (10 years). If a tree failed to attain a bh age of 10, the average rate of early height growth was determined from the oldest bh age. The rate of early height growth was averaged for each plot. An analysis of variance (ANOVA) was performed to test the null hypothesis of equal rates of early height growth across soil drainage classes.

Site index, at a base age of 20 years breast height (SI_{20}), was the response variable for stepwise regression and was used to create response categories for discriminant analyses. Thirty-nine of the 91 site trees destructively sampled had not attained a breast height (bh) age of 20. SI_{20} for these trees was predicted from bh age (Chapter 1). Breast height ages of these trees ranged from 4 to 10 years and predicted site indices ranged from 13.65 to 20.48 meters (Table 2.3). An ANOVA was performed to examine the effect of drainage class upon SI_{20}.

Following Jones and Saviello (1991), the aspect of each plot was considered favorable it was northeasterly (between 315^0 and 134^0) and unfavorable if it was southwesterly (between 135^0 and 314^0). A t-test was used to test the null

Table 2.3. Breast height age, height and predicted SI_{20} for trees < 20 years at bh in the European larch soil-site study.

Plot	Tree	BH Age	Height	SI_{20}
		years	m	m
B01	1	10	10.87	17.53
B01	2	10	10.87	17.53
B01	3	10	10.37	16.94
B02	1	9	11.56	19.75
B02	2	10	9.87	16.07
B02	3	10	10.87	17.53
B03	1	10	9.85	16.04
B03	2	10	9.58	15.64
B03	3	9	10.78	18.57
B04	1	9	10.16	17.63
B04	2	10	11.98	19.17
B04	3	10	9.77	15.92
D02	1	7	6.67	14.55
D02	2	7	7.03	15.07
D02	3	7	7.65	15.98
D04	1	9	7.53	13.65
D04	2	8	7.55	14.68
D04	3	8	7.49	14.59
D07	1	4	6.15	17.29
D07	2	3	5.58	17.75
D07	3	2	4.74	17.95
D08	1	5	7.60	18.09
D08	2	4	6.07	17.17
D08	3	5	6.56	16.63
D09	1	4	5.72	16.67
D09	2	4	7.03	18.54
D09	3	4	6.75	18.14
S01	1	10	11.87	19.01
S01	2	10	10.87	17.50
S01	3	10	10.87	17.50
S02	1	10	12.37	19.74
S02	2	10	12.55	20.01
S02	3	10	11.87	19.01
S16	1	10	11.87	19.01
S16	2	10	12.87	20.48
S16	3	10	12.87	20.48
S17	1	8	10.57	19.33
S17	2	9	10.77	18.56
S17	3	9	9.67	16.89

hypothesis of equal plot SI_{20} values for the two aspect categories.

An ANOVA was used to test the hypothesis of equal plot SI_{20} values among slope positions, based upon the hill slope model (Fanning and Fanning 1989).

Due to the absence of a solum, no chemical analyses were performed on Plot D03 (the C horizon of a gravel pit). This reduced the number of plots with soil chemical data to 30.

Soil chemical and physiographic variables provided 61 possible independent variables for analyses. Because of the high number of independent variables in relation to the overall sample size, it was necessary to reduce the number of independent variables included in the stepwise analyses. Three separate data sets were constructed (Table 2.4). They were designed to incorporate data collected at three levels of detail requiring successively more laboratory analyses.

The first data set, which incorporated only the easily observed physiographic and edaphic variables, included all 30 plots. The thickness of the solum and the effective rooting depth were identical in almost all cases and highly correlated ($r=0.92$ $p=0.0001$). Since the solum thickness is easier to determine, it was used instead of the effective rooting depth.

Table 2.4. Independent variables initially included in each of the 3 data sets examined in stepwise analyses.

Data Set 1 No Laboratory Analysis	Data Set 2 B Master Horizon	Data Set 3 Weighted Solum
elevation	elevation	elevation
A horz thickness	A horz thickness	A horz thickness
B horz thickness	B horz thickness	B horz thickness
BC horz thickness	BC horz thickness	BC horz thickness
solum thickness	solum thickness	solum thickness
percent slope	percent slope	percent slope
	extractable P	extractable P
	exchangeable K, Na, Ca, Mg, Al+H	exchangeable K, Na, Ca, Mg, Al+H
	ECEC	ECEC
	% organic matter	% organic matter
	H_2O pH A horz	H_2O pH A horz
	H_2O pH B horz	H_2O pH B horz
	KCl pH A horz	KCl pH A horz
	KCl pH B horz	KCl pH B horz
	% sand	% sand
	% silt	% silt
	% clay	% clay

The second data set incorporated those data in the first data set plus textural and chemical variables from the B master horizon and the pH of both the A and B master horizons. The B master horizon was chosen for analysis because the majority of the A master horizons in this study were altered from prior agricultural activities while the B master horizons were relatively undisturbed. Due to the absence of a B master horizon on two plots, only 28 plots were included in data set two.

The third data set incorporated all of the information from the first data set, plus the mean solum values (weighted by horizon thickness) for soil texture and chemical variables from each plot, and the pH of the A and B master horizons.

Only continuous variables were included in the data sets examined using stepwise techniques. The inclusion of discrete variables (e.g., drainage class, slope position) into these analyses would have required the use of dummy variables. Given the small sample size, too many degrees of freedom would have been sacrificed to employ this technique.

A Pearson correlation analysis was performed to assess the linear relationship among the independent variables, and the relationship between their relationship to SI_{20}. A Spearman rank correlation analysis was performed to examine the relationship between the continuous variables in the three data sets and the discrete variable, soil drainage class.

Cluster analysis was applied to the SI_{20} estimates. Ward's hierarchical clustering method, which incorporates the within group variance as a measure of distance between groups (Anderberg 1973), was used. Two patterns of groupings were identified with the aid of a dendrogram generated from the cluster analysis. One pattern suggested three groups, and the other two groups of plots having similar site indices.

Initially, percent slope and elevation were included as variables in the stepwise regression analyses. They made a contribution to the overall predictability of the model. Further investigation, however, revealed that plots having any appreciable slope were not well distributed throughout the study area; they were concentrated in one plantation (Parkman Hill) and had similar SI_{20} values. Plots also tended to be clustered around common elevations. Because of this, the percent slope and elevation were eliminated from all analyses.

Several subsets of the variables from the three data sets were examined using the stepwise regression and stepwise discriminant analysis procedures. Analyses incorporating the individual cations instead of the ECEC had better predictability. Sodium was eliminated from the analyses because it is not an essential element and is a common contaminant. Because the inclusion of all three descriptor variables for soil texture would have been redundant, sand (%) was eliminated in favor of the silt (%) and clay (%) variables. Predictability was improved by incorporating the solum thickness into the analyses rather than the thickness of individual horizons. Elimination of the pH variables from the analyses greatly improved predictability. The variables included in the final stepwise analyses are provided in Table 2.5.

Several subsets of the physical variables initially included in data set one were evaluated. The single variable with the best predictability and discriminatory power was solum thickness.

The use of stepwise analyses on data set one was not necessary. A simple regression analysis and discriminant

Table 2.5. Independent variables chosen from the three data sets (Table 2.4) for inclusion in the final stepwise analyses.

Data Set 1 No Laboratory Analysis	Data Set 2 B Master Horizon	Data Set 3 Weighted Solum
solum thickness	solum thickness extractable P exchangeable K, Ca, Mg, Al+H % organic matter % silt % clay	solum thickness extractable P exchangeable K, Ca, Mg, Al+H % organic matter % silt % clay

analysis were performed using the solum thickness (cm) as a predictor of SI_{20} and a discriminator for classification into different SI_{20} groupings.

Stepwise regression with SI_{20} as the dependent variable was performed on data sets two and three (Table 2.6). The stepwise method of variable selection utilizing a 0.15 significance level for entry and retention was used (SAS Institute, Inc. 1988).

Stepwise discriminant analysis was used as a screening tool on data sets two and three (Table 2.5) for classification into the different SI_{20} groupings created from the cluster analysis. For the stepwise discriminant analyses, the covariance matrices for each group were assumed equal and a pooled covariance matrix was used with the significance level for entry and retention of a variable being 0.15.

The variables selected by the stepwise analyses were then used in a second discriminant analyses for classification into the different SI_{20} groupings. The equality of the covariance matrices were tested (α=0.1) following Morrison (1976). The covariance matrices for data sets two and three were found to be significantly different. An attempt was made to construct a classification rule using the individual covariance matrices as opposed to the pooled covariance matrix for each data set. The ability of the discriminant functions to correctly classify plots into SI_{20} groupings was evaluated using a jackknife classification procedure. The discriminant functions derived using the individual group covariance matrices for data sets two and three had a higher rate of misclassification than those derived using the pooled covariance matrix. Consequently, the classification rule derived for each data set was based upon the pooled covariance matrices.

RESULTS AND DISCUSSION

Obtaining a sufficient sample size is a common problem encountered in biological studies. This study, (with a sample size of 30 plots for the solum and 28 for the B master horizon) is no exception. These limited sample sizes precluded an assessment of the validity of the assumptions for univariate and multivariate statistical analyses. Consequently, the standard assumptions associated with both the univariate and multivariate statistical procedures used in these analyses were not tested but were assumed valid. Due to the small sample size and the exploratory nature of this study, a probability level of 0.1 was used throughout the univariate portion of these analyses.

SI_{20} ranged from 13.4 to 20.0 m across the range of plots sampled (Table 2.6).

Effect of Drainage Class Upon Edaphic Properties

In the solum (Table 2.7), PD plots had a higher percentage of clay and a lower percentage of sand and silt then SPD and better drained (BD, being the combined MWD and WD classes) plots. The concentration of Mg followed a similar pattern. Higher concentrations of Mg were detected in the PD plots then in the SPD or BD plots. This differs from the results for the other base cations, described below, and suggests that the concentration of Mg in the SPD

Table 2.6. Average plot SI_{20} values (meters) for the European larch soil-site study.

Plot	SI_{20}	Plot	SI_{20}	Plot	SI_{20}
B01	17.3[a]	D08[a]	17.3	S09	17.7
B02	17.8[a]	D09[a]	17.8	S10	18.2
B03	16.8[a]	S01[a]	18.0	S11	17.2
B04	17.6[a]	S02[a]	19.6	S12	17.0
D01	16.6	S03	13.4	S13	15.3
D02	15.2[a]	S04	15.5	S14	16.4
D04	14.3[a]	S05	17.3	S15	14.6
D05	15.6	S06	18.0	S16	20.0[a]
D06	17.7	S07	18.4	S17	18.3[a]
D07	17.6[a]	S08	17.2	U01	13.8

[a] SI_{20} predicted from early height growth information

Table 2.7. Mean values for soil variables in the solum by soil drainage class, p-values[a] generated from ANOVA testing the hypothesis of equal means by drainage class, and p-values[a] for three contrasts (n=30).

					p-values			
	Means[b]					Contrasts[c]		
Variable	WD	MWD	SPD	PD	ANOVA	1	2	3
P (ppm)	18.25	16.35	17.06	15.32	ns			
K[d]	0.12	0.12	0.12	0.15	ns			
Ca[d]	0.91	0.95	2.72	2.45	.010	ns	.004	.027
Na[d]	0.03	0.04	0.05	0.06	.017	ns	.057	.014
Mg[d]	0.12	0.17	0.40	0.88	.003	.042	ns	.001
Al+H[d]	0.64	0.87	0.73	1.14	ns			
ECEC[d]	1.83	2.15	4.03	4.67	.001	ns	.001	.001
OM (%)	1.63	1.55	1.54	1.62	ns			
sand (%)	46.86	35.22	45.25	24.67	.069	.072	ns	.076
silt (%)	35.87	29.38	36.98	9.15	.066	.024	ns	.020
clay (%)	11.76	5.83	8.21	31.05	.018	.011	ns	.003
solum thick.(cm)	80.6	63.1	52.4	52.8	ns			

[a] P-values > 0.1 are reported as nonsignificant (ns)

[b] WD = well drained (n=14), MWD = moderately well drained (n=9), SPD = somewhat poorly drained (n=4), PD = poorly drained (n=3)

[c] Contrast 1 = SPD vs. PD, Contrast 2 = SPD vs. (MWD + WD), Contrast 3 = PD vs. (MWD + WD)

[d] meq/100g

class may be transitional between PD and BD sites. Differences were detected between the PD and BD plots, and between the SPD and BD plots in concentrations of Ca, Na, and the ECEC. No differences were detected between the PD and SPD plots for these variables. The results from this pattern of contrasts suggests differences between imperfectly drained (ID, being the combined PD and SPD classes) and BD plots.

In the A master horizon (Table 2.8), results complemented those from the solum. Results differing from those of the solum, however, were detected in the concentration of Mg between drainage classes. In addition, a fewer differences between drainage classes were detected in the A master horizon. Differences in the concentration of Mg were detected between the SPD and BD plots, no differences were detected between the PD and SPD plots, or between the PD and BD plots. The possible transitional nature of Mg in the SPD plots between the PD and BD plots, while not strongly supported, is implied by these results.

In the B master horizon (Table 2.9), differences were detected in all contrasts examined for the ECEC. These results suggest that the ECEC increases with poorer drainage. Differences in the concentration of Ca were detected between the SPD and combined BD plots, and between the PD and combined BD plots. No differences in Ca were detected between the PD and SPD plots. These results are similar for those of the solum and indicate that

Table 2.8. Mean values for soil variables in the A master horizon by soil drainage class, p-values[a] generated from ANOVA testing the hypothesis of equal means by drainage class, and p-values[a] for three contrasts (n=28).

	Means[b]				p-values			
						Contrasts[c]		
Variable	WD	MWD	SPD	PD	ANOVA	1	2	3
P (ppm)	20.70	12.57	11.23	11.09	ns			
K^d	0.20	0.15	0.26	0.16	ns			
Ca^d	2.18	1.84	4.69	3.69	ns			
Na^d	0.03	0.04	0.06	0.07	.020	ns	.034	.023
Mg^d	0.23	0.33	0.82	0.51	.011	ns	.002	ns
$Al+H^d$	0.98	1.19	1.03	1.46	ns			
$ECEC^d$	3.63	3.56	6.83	5.88	.008	ns	.002	.076
OM (%)	3.26	3.41	4.08	3.60	ns			
H_2O pH	5.45	5.20	5.37	5.16	ns			
KCl pH	4.46	4.23	4.29	4.27	ns			
sand (%)	43.26	34.21	41.67	17.52	.032	.024	ns	.021
silt (%)	43.83	60.90	48.58	62.40	ns			
clay (%)	13.90	4.87	9.74	20.07	ns			
thick. (cm)	21.3	16.7	15.4	20.1	ns			

---

[a] P-values > 0.1 are reported as nonsignificant (ns)

[b] WD = well drained (n=14), MWD = moderately well drained (n=8), SPD = somewhat poorly drained (n=4), PD = poorly drained (n=2)

[c] Contrast 1 = SPD vs. PD, Contrast 2 = SPD vs. (MWD + WD), Contrast 3 = PD vs. (MWD + WD)

[d] meq/100g

concentrations of Ca in ID plots are greater. Differences were detected in the concentration of Mg, KCl pH, silt (%), and the thickness of the B master horizon between the PD and SPD plots, and between the PD and BD plots. No differences were detected for these variables between the SPD and BD plots. Aside from differences in the concentrations of Mg, KCl pH, more pronounced differences in the ECEC, and the depth of the B master horizon, these

Table 2.9. Mean values for soil variables in the B master horizon by soil drainage class, p-values[a] generated from ANOVA testing the hypothesis of equal means by drainage class, and p-values[a] for three contrasts (n=28).

	Means[b]				p-values			
						Contrasts[c]		
Variable	WD	MWD	SPD	PD	ANOVA	1	2	3
P (ppm)	14.74	12.00	12.54	12.06	ns			
K^d	0.09	0.08	0.10	0.19	ns			
Ca^d	0.69	0.60	1.82	2.45	.046	ns	.022	.057
Na^d	0.03	0.03	0.04	0.05	ns			
Mg^d	0.09	0.09	0.20	1.94	.001	.001	ns	.001
Al+H^d	0.58	0.80	0.79	0.74	ns			
ECEC^d	1.47	1.60	2.95	5.37	.001	.015	.004	.001
OM (%)	1.36	1.50	0.96	0.24	ns			
H_2O pH	5.65	5.41	5.85	5.56	ns			
KCl pH	4.62	4.45	4.40	3.97	.049	.001	ns	.001
sand (%)	44.41	39.24	43.76	33.28	ns			
silt (%)	44.72	56.34	47.89	16.17	ns			
clay (%)	10.87	4.41	8.34	50.55	.001	.001	ns	.001
thick. (cm)	29.2	23.2	19.1	83.8	.007	.001	ns	.001

[a] P-values > 0.1 are reported as nonsignificant (ns)
[b] WD = well drained (n=14), MWD = moderately well drained (n=9), SPD = somewhat poorly drained (n=4), PD = poorly drained (n=1)
[c] Contrast 1 = SPD vs. PD, Contrast 2 = SPD vs. (MWD + WD), Contrast 3 = PD vs. (MWD + WD)
[d] meq/100g

results are consistent with those reported for the solum and A master horizons.

In the BC master horizon (Table 2.10), differences in the concentrations of Ca were detected between the PD and SPD plots, and between the SPD and BD plots. No differences were detected between the PD and BD plots. The concentration of Ca in the SPD plots was very high relative to the SPD and BD plots. Differences in the concentration of Al+H were detected between the PD and SPD plots, and between the PD and BD classes. No differences in Al+H were

Table 2.10. Mean values for soil variables in the BC master horizon by soil drainage class, p-values[a] generated from ANOVA testing the hypothesis of equal means by drainage class, and p-values[a] for three contrasts (n=28).

	Means[b]				p-values			
						Contrasts[c]		
Variable	WD	MWD	SPD	PD	ANOVA	1	2	3
P_d (ppm)	18.73	20.93	27.31	23.83	ns			
K^d	0.09	0.13	0.08	0.08	ns			
Ca^d	0.33	0.78	2.13	0.90	.001	.030	.001	ns
Na^d	0.04	0.04	0.05	0.06	ns			
Mg^d	0.07	0.14	0.31	0.14	ns			
$Al+H^d$	0.35	0.65	0.38	1.20	.061	.036	ns	.037
$ECEC^d$	0.88	1.75	2.94	2.38	.001	ns	.001	.044
OM (%)	0.56	0.45	0.36	0.78	ns			
H_2O pH	5.82	5.65	6.08	5.60	ns			
KCl pH	4.70	4.43	4.40	4.35	.027	ns	ns	ns
sand (%)	47.86	38.86	51.51	24.41	ns			
silt (%)	42.40	55.49	43.62	52.00	ns			
clay (%)	9.74	7.66	4.87	22.60	ns			
thick. (cm)	32.43	25.61	17.94	17.14	ns			

[a] P-values > 0.1 are reported as nonsignificant (ns)
[b] WD = well drained (n=14), MWD = moderately well drained (n=9), SPD = somewhat poorly drained (n=4), PD = poorly drained (n=1)
[c] Contrast 1 = SPD vs. PD, Contrast 2 = SPD vs. (MWD + WD), Contrast 3 = PD vs. (MWD + WD)
[d] meq/100g

detected between the SPD and BD plots. The concentration of Al+H in the PD plots was very high relative to the SPD and BD plots. Differences in the ECEC were detected between the SPD and BD plots, and between the PD and BD plots. No difference was detected in the ECEC between the PD and SPD plots. This pattern suggests differences in the ECEC between ID and BD plots. Differences between drainage classes were detected for KCl pH with an ANOVA, but no differences were detected with the three contrasts. This suggests that there is a difference between the MWD and WD classes in KCl pH.

An examination of the four ANOVAs and their appropriate contrasts suggests similar patterns for the solum and master horizons. The concentrations of cations and the ECEC appear to increase with reduced drainage. The observed increase in ECEC with poorer drainage is consistent with results from natural spruce-fir stands in Maine (Pitcheralle *In preparation*). This phenomenon can perhaps be partially explained by landform. Imperfectly drained soils are generally located in downslope positions. The effect of reduced leaching and increased inputs from upper landscape units may contribute to increased cation concentrations. Not surprisingly, the BD plots have more sand.

The majority of the study sites were located on lands formerly under cultivation. The Ap horizon is organically richer than a typical surface mineral horizon and the subsurface horizons. Consequently, the A horizons from this study may have higher levels of exchangeable nutrients than normally found in the surface mineral horizon of forest soils. On the other hand, these soils may have lost nutrients through prior agricultural practices and/or soil erosion. Consequently, the solum may have lower levels of nutrients than typically found in forest soils.

The concentration of extractable P appears to increase with depth. This is consistent with observations of Stone and Kalisz (1991). Not surprisingly, the extractable cations and percent organic matter decreased with depth.

The expected rise in pH with increased depth was also observed. The sand (%), silt (%), and clay (%) were similar between horizons in the BD plots and variable between horizons in the ID plots.

Effect of Drainage Class Upon Early Height Growth and SI_{20}

Plantation ages and the time to attain bh varied considerably among and within soil drainage classes (Table 2.11). Note the paucity of plots in the PD and SPD classes and the lack of very young plantations in the MWD class.

Parameter estimates for the regression model [2] developed to predict early height, by drainage class, from bh age are provided in Table 2.12.

The F statistic calculated to test the null hypothesis of equal slopes was:

$$F^* = [(156.83 - 153.76) / (309 - 306)] / 0.5025,$$
$$F^* = 2.04,$$

We fail to reject the null hypothesis at $\alpha=0.05$ ($F=2.60$), however, the null hypothesis may be rejected at $\alpha=0.11$.

This result suggests that soil drainage class may have an impact upon the rate of early height growth but is not conclusive. Given the variability encountered in

Table 2.11. Summary of plantation age, number of plots, tree age and, number of trees sampled by soil drainage class.

Drainage Class[a]	Plantation Age[b]	Number of Plots[c]	Time to bh[b]	Number of Trees
	years		years	
PD	28.7 (16-41)	3	10.0 (4-19)	10
SPD	41.3 (16-60)	4	6.8 (3-21)	12
MWD	53.3 (33-60)	9	6.2 (3-12)	27
WD	30.1 (8-60)	15	5.6 (2-20)	46

[a] PD = poorly drained, SPD = somewhat poorly drained, MWD = moderately well drained, WD = well drained.

[b] Range of data in parenthesis.

[c] Includes plots D02, D03, D04 located on a reclaimed gravel pit that required 19-21 years to reach bh

Table 2.12. Parameter estimates for the regression model[a] developed to predict heights at bh age 1-10 for European larch by soil drainage class from bh age.

Drainage Class[b]	Intercept b_0	Slope b_1
PD	0.10	0.796
SPD	0.66	0.913
MWD	1.03	0.821
WD	0.62	0.853

[a] Height = $b_0 + b_1(\mathrm{BHAGE})$

[b] PD = poorly drained, SPD = somewhat poorly drained, MWD = moderately well drained, WD = well drained

the early annual height growth and the paucity of plots in the PD and SPD classes, further analyses were warranted.

Two ANOVAs (Table 2.13) failed to detect any differences in the average rate of early height growth or SI_{20} between drainage classes. These results were unexpected, and contrast with those for European larch in New York (Aird and Stone 1955) and Japanese larch in Pennsylvania (Parsonage 1989) who both reported that poor drainage had an adverse impact on site index.

It is important to note, however, that the relationship between soil drainage class and tree height was not examined beyond the base age. A relationship between height and soil drainage class may become apparent beyond a bh age of 20when differences in potential rooting depth and/or moisture availability become more important. It is also important to note that these results were derived from a limited data base. The shape and pattern of the growth curves beyond the 10-year growth period examined is uncertain. Due to the limited number of older plantations in the PD and SPD

Table 2.13. Mean values for the average rate of early height growth and SI_{20}, and p-values generated from ANOVA testing the hypothesis of equal means by drainage class.

	Means[a]				
Variable	WD	MWD	SPD	PD	p-value
Avg. growth rate (m/yr)	1.18	1.05	1.08	0.99	0.29
SI_{20} (m)	15.6	15.8	15.6	14.5	0.70

drainage classes, it was not possible to examine the growth trend past a bh age of 10 years.

This portion of the soil-site study examined only the effect of soil drainage class on early height growth. Other factors such as the availability of soil nutrients, early competition, or genetic variation, may also effect the early height growth of European larch. For example, S.D. Warren Company's plantation records indicate that the Mahoney Hill and Parkman Hill plantations had intense grass competition after planting. The study plots in these plantations were predominantly MWD and WD. The Messer Road plantation was treated with an herbicide to eliminate grass competition prior to plantation establishment and the PD plot (S02) in this plantation had a very high site index (19.6 m). Three of the study plots, on lands owned by James River Timber (D02, D03, D04) representing three drainage classes, were located in a former gravel pit. Not surprisingly, the two plots from this plantation for which chemical data were available were grouped into the low SI_{20} category.

Effect of Aspect and Slope Position

Results of a nonpaired t-test reveal no significant differences (p=0.86) in SI_{20} resulting from aspect. Results of ANOVA testing differences in SI_{20} based upon slope position suggest no significant differences (p=0.06).

Correlation Analyses

In data set two, two pair of variables had correlation coefficients greater then 0.50 ($\alpha \leq 0.1$): the concentrations of Ca and Mg ($r=0.53$, $p=0.001$) and the concentration of Mg and clay (%) ($r=0.71$, $p=0.001$). Four pair of variables in data set three had correlation coefficients greater than 0.50 ($\alpha \leq 0.1$): the concentration of P and K ($r=0.58$, $p=0.001$), the concentrations of Mg and Ca ($r=0.53$, $p=0.002$), the concentration of Ca and Al+H ($r=-0.53$, $p=0.002$), and silt (%) and clay (%) ($r=-0.54$, $p=0.002$).

Surprisingly, there was no correlation between solum thickness and SI_{20}. In data set two, the concentration of Al+H was negatively correlated with SI_{20} ($r=-0.32$, $p=0.10$) as was the percent clay ($r=-0.32$, $p=0.10$). Three variables in data set three were correlated with SI_{20}: the concentrations of Ca ($r=0.38$, $p=0.04$), and Al+H ($r=-0.57$, $p=0.001$), and the percent clay ($r=-0.46$, $p=0.01$).

Weak correlations (Spearman rank $\alpha \leq 0.1$) were observed between variables in the three data sets (Table 2.5) and soil drainage class. Three variables in data set two: the concentrations of K ($r=-0.32$, $p=0.09$), Ca ($r=-0.40$, $p=0.03$), and Mg ($r=-0.45$, $p=0.02$) were negatively correlated with drainage class. Four variables in data set three were correlated with drainage class the concentrations of: K ($r=-0.34$, $p=0.07$), Ca ($r=-0.36$, $p=0.04$), Mg ($r=-0.52$, $p=0.01$), and percent silt ($r=0.30$, $p=0.10$).

Cluster Analysis

The identification of the number of clusters within a data set is subjective. Stopping rules, however, lend a degree of objectivity to the process. The cubic clustering criterion, a statistic available in the SAS software utilized to analyze the data, suggested the presence of two or three (Table 2.14) primary clusters. The three clusters corresponded to low, medium, and high categories of site potential. Combination of the medium and high categories produced a simple dual classification that differentiated poor and good site categories, which would perhaps be a more efficient way to eliminate poor sites from planting programs.

It is interesting to note the range of drainage classes combined into each site index grouping, particularly the high and low groupings, each of which include PD and WD plots. This suggests that factors other than, or in addition to, soil drainage class should be considered when evaluating potential sites for the establishment of European larch.

Regression Analyses

The model constructed to predict SI_{20} using a single independent variable, solum thickness, had low precision. The coefficient of determination was 0.11 (p=0.114). Because of its poor performance, this model was not presented.

Table 2.14. Results of cluster analysis to group plots into low, medium and high SI_{20} categories.

Group	SI_{20} Mean	SI_{20} Range	Plots
	---------- m	----------	
high (n=7)	18.5	18.0 to 19.6	S01, S02, S06, S07, S10, S16, S17
medium (n=15)	17.3	16.4 to 17.8	B01, B02, B03, B04, D01, D06, D07, D08, D09, S05, S08, S09, S11, S12, S14
low (n=8)	14.7	13.4 TO 15.6	D02, D04, D05, S03, S04, S13, S15, U01

Results of stepwise regression to predict SI_{20} using data set two (selected B master horizon and solum variables) were more favorable. The coefficient of determination for this equation was 0.53 (p=0.0012).

[4] $$SI_{20} = 15.90 + (10.06 * K) - (0.91 * Al+H) - (0.08 * \%\ clay) + (0.02 * solum\ thickness)$$

Biological significance is suggested from the positive relationship between SI_{20} and the concentration of K, an essential element and solum thickness, an indication of the amount of soil available for root exploitation. Negative relationships between SI_{20} and the concentration of Al+H, an indicator of soil acidity and clay (%), negatively correlated with soil drainage class, reinforce the biological significance of this equation.

Results of stepwise regression to predict SI_{20} using data set three (selected solum soil variables) had a coefficient of determination of 0.48 (p=0.0001).

[5] $$SI_{20} = 16.50 - (1.57 * Al+H) - (0.03 * \%\ silt)$$

The negative relationship between SI_{20} and the concentration of Al+H was similar to that observed in [4]. The negative silt coefficient may suggest a higher site potential for lighter textured soils and/or may be related to the higher percentage of silts and clays found on PD plots.

Model [4] requires data obtained from chemical analyses of the B master horizon, while [5] requires data obtained from all solum horizons in order to predict SI_{20}. Since fewer chemical analyses would be required, and [4] has a coefficient of determination higher than [5], the use of [4] to predict SI_{20} from chemical data obtained from the B master horizon and the solum thickness is recommended.
It is important to note that stepwise regression is merely a tool, with limitations. This procedure does not guarantee the choice of optimum subsets from the group of variables examined (Draper and Smith 1966). The interaction among variables (not examined in this study because of the limited sample size) may eventually prove to be an important factor in predicting site index for European larch.

Both of the models constructed to predict the site index of European larch in Maine using stepwise regression had low precision. This, however, was not unexpected. Recent soil-site sites (Parsonage 1989; Monserud *et al.* 1990; Steinman 1992) incorporating multiple regression prediction techniques for other species also had low precision. Using data collected from 52 plots located throughout Pennsylvania, Parsonage (1989) constructed several alternative models for the prediction of site index for Japanese larch and obtained results with coefficients of determination similar to those in this study.

Monserud *et al.* (1990) conducted a soil-site study for inland Douglas-fir (*Pseudotsuga menziesii* var. *glauca* (Beissn.) Franco) with data collected from 133 plots located across northern Idaho and northwestern Montana. Despite their relatively large sample size in comparison to other studies (Parsonage 1989; this study), they were unable to explain over half of the variation encountered in site index. They attributed the low precision of their results to their inability to examine important site factor interactions encountered in an extensive study area with a limited data base, and a failure to measure the true causes of site productivity.

Steinman (1992) assembled an extensive data base, from soil-site studies conducted over a twenty year time period for spruce-fir in Maine, and was able to account for 40 to 70% of the variability encountered in site index. His precision improved when soil chemical data were included in the analyses.

Discriminant Analyses

Results of the stepwise discriminant analyses (Tables 2.15 and 2.16) complemented those of stepwise regression. For data set two, the concentration of Mg was selected by

Table 2.15. Variables selected by stepwise discriminant analyses from Data Sets 2 and 3 to predict SI_{20} group (low, medium or high) membership.

Data Set 2 B Master Horizon	Data Set 3 Weighted Solum
solum thickness	solum thickness
Mg	Mg
K	K
% clay	% clay
	Ca

Table 2.16. Variables selected by stepwise discriminant analyses from Data Sets 2 and 3 to predict good (medium + high) or poor (low) SI_{20} group membership.

Data Set 2 B Master Horizon	Data Set 3 Weighted Solum
solum thickness	solum thickness
% clay	% clay
K	K

stepwise discriminant analysis in place of the concentration of Al+H (selected using stepwise regression) as a discriminator to classify sites into low, medium or high SI_{20} categories. A subset of the variables in [1] (solum thickness, concentration of K) were selected as discriminators to classify sites into poor or good SI_{20} categories. From data set three, the concentration of Mg was selected by stepwise discriminant analysis in place of the concentration of Al+H (selected using stepwise regression) and, silt (%) (selected using stepwise regression) was replaced by the concentration of Ca as discriminator to classify sites into low, medium or high

SI_{20} categories. A set of variables, comparable to those from the B master horizon, solum thickness and the concentration of K, were selected from the solum to classify sites into poor or good categories of SI_{20}.

Biological significance was suggested by solum thickness, an indicator of the region available for root exploitation; and the concentrations of Mg, K, and Ca, essential elements. Clay (%), which is negatively correlated with silt (%) ($r=-0.54$, $p=0.002$), implies the importance of soil texture.

Solum thickness, when used alone, had a 43% rate of misclassification when attempting to assign membership into low, medium, or high groupings of SI_{20}. When the variable solum thickness was used to assign membership to poor and good groupings of site index, its classification ability improved (Table 2.17). The discriminant functions are provided in Table 2.18. Cross-validation showed an overall misclassification rate of 29% with plots in the poor SI_{20} category being correctly classified 88% of the time.

Cross-validation of the discriminant functions (Table 2.19) for data set two to classify into high, medium, or low SI_{20} groupings showed an overall misclassification rate of 32%. The ability of the discriminant functions to correctly classify SI_{20} groups declined with decreasing site potential (Table 2.20).

Table 2.17. Results of a jackknife cross-validation procedure for classification into good (medium + high) and poor (low) SI_{20} groupings using solum thickness as the single discriminator.

From Group	Number of observations and Percent Classified Into: good	poor	n
good	12 55%	10 45%	22
poor	1 12%	7 88%	8

Table 2.18. Discriminant function coefficients for assignment of good (medium + high) and poor (low) SI_{20} group membership using solum thickness as the single discriminator.

Group	cm Solum thick.	Constant
good	0.076	-2.884
poor	0.048	-1.154

Table 2.19. Discriminant function coefficients for assignment of SI_{20} group (low, medium or high) membership from selected B master horizon variables and solum thickness.

Group	cm Solum	% Clay	meq/100g K	meq/100g Mg	Constant
high	0.143	-0.282	68.453	-0.727	-7.662
medium	0.139	-0.063	76.033	-6.720	-8.669
low	0.069	-0.001	42.551	-2.139	-2.991

Table 2.20. Results of a jackknife cross-validation procedure for classification into low, medium and high SI_{20} groupings for the discriminant functions (Table 2.19) from the B master horizon.

	Number of observations and Percent Classified Into:			
From Group	high	medium	low	n
high	6 100%	0 0%	0 0%	6
medium	4 27%	9 60%	2 13%	15
low	2 29%	0 0%	5 71%	7

Cross-validation of the discriminant functions (Table 2.21) for data set two to classify into good or poor SI_{20} groupings showed an overall misclassification rate of 17%. Their ability to correctly classify good and poor sites was nearly equal (Table 2.22).

Cross-validation of the discriminant functions (Table 2.23) for data set three to classification into high, medium, or low SI_{20} groupings showed an overall misclassification rate of 27%. Their predictability improved with decreasing site potential (Table 2.24).

Table 2.21. Discriminant function coefficients for assignment of good (medium + high) and poor (low) SI_{20} group membership based upon selected B master horizon variables and solum thickness.

Group	cm Solum thick.	% Clay	meq/100g K	Constant
good	0.146	-0.248	67.340	-7.823
poor	0.073	-0.061	40.586	-2.951

Table 2.22. Results of a jackknife cross-validation procedure for classification into good (medium + high) and poor (low) SI_{20} groupings for the discriminant functions (Table 2.21) from the B master horizon.

	Number of observations and Percent Classified Into:		
From Group	good	poor	n
good	17 81%	4 19%	21
poor	1 14%	6 86%	7

Table 2.23. Discriminant function coefficients for assignment of SI_{20} group (low, medium, high) membership based upon selected solum variables.

			meg/100g			
Grp	cm Solum thick.	% Clay	K	Mg	Ca	Constant
high	0.122	-0.140	44.371	-3.832	2.624	-9.183
med.	0.142	-0.017	53.638	-7.423	1.451	-9.761
low	0.064	0.060	26.186	-2.135	0.606	-3.149

Table 2.24. Results of jackknife cross-validation procedure for the classification into low, medium or high SI_{20} grouping for the discriminant functions (Table 2.23) of the solum.

From Group	Number of observations and Percent Classified Into: high	medium	low	n
high	4 57%	3 43%	0 0%	7
medium	1 7%	11 73%	3 20%	15
low	1 13%	0 0%	7 87%	8

Cross-validation of the discriminant functions (Table 2.25) for data set three to classify into good and poor SI_{20} groupings showed an overall misclassification rate of 13%. Their ability to correctly classify good and poor SI_{20} grouping was nearly equal (Table 2.26).

Solum thickness is an important factor in the evaluation of site quality. Its greatest value as a solitary discriminator (Table 2.18) is that it has identified poor sites as having a solum thickness ≤ 62 cm (24.5 in) correctly 7 out of 8 times (Table 2.17).

The coefficients of the discriminant functions for the comparable variables in the B master horizon (Tables 2.19 and 2.21) and solum (Tables 2.23 and 2.25) were similar. The fluctuating importance of the concentrations of K and Mg in the B master horizon and solum upon their respective classification rules (Tables 2.19 and 2.23), while interesting, has no simple explanation. The interaction of

Table 2.25. Discriminant function coefficients for assignment of good (medium + high) and poor (low) SI_{20} group membership based upon selected solum variables.

Group	cm Solum	meq/100g K	Constant
good	0.126	47.145	- 7.515
poor	0.059	24.755	- 2.822

Table 2.26. Results of a jackknife cross-validation procedure for classification into good (medium + high) and poor (low) SI_{20} groupings for the discriminant functions (Table 2.25) of the solum.

	Number of observations and Percent Classified Into:		
From Group	good	poor	n
good	19 86%	3 14%	22
poor	1 13%	7 87%	8

K and Mg with other variables not included in this analysis may be a factor in these results.

Application

The results of these discriminant analyses may be applied at different levels and with different objectives in mind. If the primary objective of a forest manager were to avoid poor planting sites, the results presented in Tables 2.18 and 2.23 would be most applicable. It should be noted, however, that these results require data collected at 2 different levels. The results from Table 2.18 can be applied to a single variable, solum thickness. The results from Table 2.23 require chemical and textural analyses from all solum horizons and provide no increase in predictive ability.

Suppose the objective is to classify a planting site for European larch according to site group (high, medium, or low), and prime planting sites are of primary interest. Lesser sites will be removed from consideration. Assume a solum thickness of 80 cm, 2% clay, 0.12 meq/100g of K and 0.08 meq/100g of Mg in the B master horizon, predict the most likely site category.

In this case, the discriminant functions provided for the B master horizon would be the most useful. To predict group membership, assign a score by multiplying the soil variables by the coefficients from each group and adding them to the constant term. Group membership is then assigned to the group having the highest score. Applying the coefficients (Table 2.17) for each group, the following scores are obtained: high - 11.37; medium - 10.91; and low - 7.46. Therefore, this planting site is expected to be in the high SI_{20} category.

SUMMARY

The null hypotheses testing the effects of soil drainage class upon the rate of early height growth, and SI_{20}, were not rejected for European larch in Maine. This contrasts with results obtained for European larch in southern New York (Aird and Stone 1955), and Japanese larch in Pennsylvania (Parsonage 1989). A relationship between height and soil drainage class may become apparent when differences in potential rooting depth and/or moisture availability become more important.

Multiple regression models constructed to predict SI_{20} from selected soil-site variables had low precision. This was not unexpected given the results of other soil-site studies (Parsonage 1989; Monserud *et al.* 1990; Steinman 1992) and may result from a failure to measure the true causes of site productivity (Monserud *et al.* 1990), or simply the use of a technique that may be inadequate for site assessment. Because of differences in methodology, the results of this study were not comparable with those of Parsonage (1989). Parsonage (1989) incorporated the interaction terms between main effects in his multiple regression analyses. Given the small sample size (30 plots) and the large number of potential soil-site variables (61) in this study, the inclusion of interaction terms in the stepwise analyses was inappropriate.

Using discriminant analysis, solum thickness was found to be an important factor in the assessment of site quality as expressed by site index. This is consistent with results reported by Aird and Stone (1955) in southern New York where they reported a linear relationship between site index and free rooting depth (logarithmically transformed) for European and Japanese larch. The variable free rooting depth was eliminated in favor of solum thickness, in this study, because: 1) of the high correlation between the two variables, 2) the ease in which solum thickness can be measured relative to free rooting depth, and 3) to reduce the number of variables to be included in exploratory analyses. Results from both this study and those of Aird and Stone (1955) indicate that European larch performs better on sites having a deep root exploitation zone.

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SUMMARY

The first portion of this study (Chapter 1) focused on the development of mathematical models to: predict individual tree volume, generate site curves, and predict site index from early height growth information.

The second portion of this study was exploratory in nature and examined the relationship between site productivity (as expressed by site index) and soil-site variables (Chapter 2). The relationship between soil drainage class and early height growth, and site index was examined. Surprisingly, soil drainage class did not have a significant impact upon the rate of early height growth, or site index. This relationship may change as plantations age, but the paucity of plantations located on poorer drained sites in Maine may hinder the future assessment of this relationship.

Stepwise methods of variable selection were utilized in an attempt to predict site index (using stepwise regression) and classify sites (using stepwise discriminant analysis) into two different patterns of site index potential: 1) low, medium and high; and, 2) poor and good. Separate analyses were performed on independent variables included in three data sets created using soil-site variables and requiring successively more laboratory analyses: 1) no laboratory analysis, 2) laboratory analysis of the B master horizon, and 3) laboratory analysis of the solum.

Results of stepwise regression to predict site index using variables from the B master horizon, and solum

thickness, produced a model that explained 53% of the variability encountered in site index. Using the solitary discriminator solum thickness, poor categories of site index potential were correctly classified 88% of the time.

Further research on the growth and yield of European larch in the Northeast is clearly needed. Only a limited amount of information, however, may be obtained from plantations established without regard to specific research objectives. Future research efforts should focus on establishing European larch plantations which incorporate an experimental design to address fundamental biological questions. Only then, will it be possible to properly assess the biological performance of this species.

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APPENDICES

Appendix A. Individual tree volumes[a].

PLOT	TREE	DBH	HT	OBTVOL	IBTVOL	MHT	OBMVOL	IBMVOL
		cm	m	m^3	m^3	m	m^3	m^3
B01	1	19.5	12.8	0.18	0.16	7.9	0.17	0.17
B01	2	20.5	13.7	0.21	0.18	8.3	0.19	0.19
B01	3	16.1	10.7	0.11	0.10	5.7	0.10	0.10
B02	1	24.5	12.0	0.23	0.20	7.0	0.21	0.21
B02	2	16.3	10.5	0.11	0.09	5.2	0.09	0.09
B02	3	19.7	11.7	0.15	0.14	6.4	0.14	0.14
B03	1	20.4	9.9	0.14	0.12	4.9	0.13	0.13
B03	2	17.2	9.6	0.11	0.09	4.8	0.09	0.09
B03	3	17.5	10.8	0.13	0.11	5.2	0.11	0.11
B04	1	16.9	10.1	0.11	0.09	5.2	0.09	0.09
B04	2	19.9	12.0	0.18	0.16	7.1	0.16	0.16
B04	3	20.8	9.8	0.16	0.15	5.7	0.15	0.15
D01	1	25.3	21.3	0.50	0.44	15.7	0.48	0.48
D01	2	28.5	22.7	0.71	0.63	17.8	0.70	0.70
D01	3	26.6	19.6	0.44	0.39	14.4	0.43	0.43
D02	1	10.9	7.9	0.04	0.04	.	.	.
D02	2	8.1	8.2	0.02	0.02	.	.	.
D02	3	12.9	7.0	0.05	0.04	.	.	.
D03	1	13.5	7.4	0.05	0.04	.	.	.
D03	2	15.0	8.5	0.08	0.07	.	.	.
D03	3	12.5	8.1	0.05	0.04	.	.	.
D04	1	13.9	8.2	0.05	0.05	.	.	.
D04	2	12.1	7.9	0.05	0.04	.	.	.
D04	3	11.7	7.7	0.04	0.04	.	.	.
D05	D	16.4	20.2	0.19	0.17	10.8	0.15	0.15
D05	1	19.6	19.0	0.24	0.21	12.0	0.22	0.22
D05	2	23.0	20.1	0.36	0.32	13.8	0.34	0.34
D05	3	27.5	22.2	0.65	0.58	16.8	0.64	0.64
D06	A	15.2	16.9	0.12	0.10	5.1	0.08	0.08
D06	X	19.3	19.9	0.27	0.24	13.1	0.25	0.25
D06	1	26.7	22.8	0.58	0.52	17.5	0.57	0.57
D06	2	23.6	21.3	0.42	0.37	15.9	0.40	0.40
D06	3	28.0	22.6	0.62	0.55	16.7	0.60	0.60
D07	1	10.2	6.2	0.03	0.02	.	.	.
D07	2	8.7	5.6	0.02	0.02	.	.	.
D07	3	7.3	5.5	0.01	0.01	.	.	.
D08	1	13.7	7.6	0.05	0.05	.	.	.
D08	2	12.8	6.1	0.04	0.04	.	.	.
D08	3	10.9	6.6	0.03	0.03	.	.	.
D09	1	8.8	5.7	0.02	0.02	.	.	.
D09	2	10.9	7.0	0.04	0.03	.	.	.
D09	3	10.0	6.8	0.03	0.02	.	.	.
S01	1	20.9	14.1	0.21	0.19	8.5	0.20	0.20
S01	2	18.7	13.6	0.16	0.14	7.4	0.14	0.14
S01	3	22.9	14.2	0.23	0.21	8.4	0.22	0.22
S02	1	20.2	14.1	0.20	0.17	8.3	0.18	0.18
S02	2	15.4	12.6	0.11	0.10	6.4	0.09	0.09

Appendix A. (continued).

PLOT	TREE	DBH	HT	OBTVOL	IBTVOL	MHT	OBMVOL	IBMVOL
		cm	m	m^3	m^3	m	m^3	m^3
S02	3	20.0	13.3	0.18	0.16	8.0	0.17	0.17
S03	1	33.5	24.0	0.96	0.85	20.0	0.95	0.95
S03	2	31.4	23.2	0.86	0.76	19.4	0.85	0.85
S03	3	30.0	23.5	0.79	0.70	18.8	0.77	0.77
S04	B	14.0	18.6	0.18	0.16	11.2	0.16	0.16
S04	1	39.2	27.9	1.62	1.44	24.0	1.61	1.61
S04	2	32.9	23.7	0.91	0.81	19.3	0.90	0.90
S04	3	36.0	26.3	1.24	1.10	22.7	1.23	1.23
S05	1	36.9	28.5	1.48	1.32	24.8	1.47	1.47
S05	2	47.2	20.9	2.23	1.99	26.6	2.22	2.22
S05	3	37.5	28.9	1.46	1.30	25.0	1.45	1.45
S06	1	42.8	29.3	1.83	1.63	25.2	1.82	1.82
S06	2	47.0	30.3	2.08	1.85	26.2	2.06	2.06
S06	3	47.4	32.5	2.25	2.00	28.4	2.24	2.24
S07	1	40.5	29.8	1.48	1.32	25.2	1.47	1.47
S07	2	42.3	29.8	1.91	1.70	25.7	1.90	1.90
S07	3	46.8	30.4	2.27	2.01	27.0	2.26	2.26
S08	1	43.4	32.7	2.15	1.91	28.0	2.14	2.14
S08	2	38.1	29.3	1.49	1.32	25.0	1.48	1.48
S08	3	47.5	29.8	2.35	2.09	26.5	2.34	2.34
S09	1	45.8	30.9	1.96	1.74	27.1	1.95	1.95
S09	2	38.0	30.3	1.53	1.36	26.1	1.52	1.52
S09	3	41.8	29.5	1.78	1.58	25.0	1.77	1.77
S10	1	50.7	33.2	2.75	2.44	29.0	2.74	2.74
S10	2	39.9	32.3	1.75	1.56	27.9	1.74	1.74
S10	3	52.2	33.5	2.63	2.34	29.5	2.62	2.62
S11	X	19.7	23.7	0.32	0.28	15.8	0.29	0.29
S11	1	40.1	32.4	1.98	1.76	28.0	1.96	1.96
S11	2	39.3	31.3	1.68	1.49	26.0	1.67	1.67
S11	3	43.8	32.6	2.14	1.90	28.0	2.13	2.13
S12	1	38.1	31.5	1.61	1.43	26.3	1.59	1.59
S12	2	36.1	30.2	1.10	0.97	24.9	1.08	1.08
S12	3	37.3	31.6	1.49	1.32	27.2	1.46	1.46
S13	1	42.7	24.0	1.47	1.31	20.3	1.46	1.46
S13	2	33.9	22.1	0.89	0.79	18.2	0.88	0.88
S13	3	42.5	23.7	1.50	1.33	19.2	1.49	1.49
S13	4	43.5	22.2	1.56	1.39	18.8	1.55	1.55
S14	1	43.0	30.2	1.74	1.55	24.6	1.73	1.73
S14	2	41.5	28.4	1.46	1.30	24.2	1.44	1.44
S14	3	34.1	26.5	1.08	0.96	21.8	1.07	1.07
S15	1	31.9	25.4	1.05	0.93	22.2	1.04	1.04
S15	2	43.7	26.0	1.49	1.33	21.9	1.48	1.48
S15	3	43.0	24.3	1.40	1.24	20.4	1.39	1.39
S16	1	22.9	14.4	0.25	0.22	9.1	0.23	0.23
S16	2	18.0	14.0	0.17	0.15	8.6	0.16	0.16
S16	3	18.3	13.5	0.17	0.15	8.7	0.16	0.16

Appendix A. (continued).

PLOT	TREE	DBH	HT	OBTVOL	IBTVOL	MHT	OBMVOL	IBMVOL
		cm	m	m^3	m^3	m	m^3	m^3
S17	1	14.1	10.6	0.08	0.07	4.6	0.06	0.06
S17	2	14.3	10.8	0.08	0.07	4.4	0.06	0.06
S17	3	14.1	10.3	0.07	0.06	.	.	.
U01	X	12.9	17.1	0.11	0.10	6.1	0.07	0.07
U01	1	23.3	19.4	0.40	0.36	14.3	0.39	0.39
U01	3	23.5	18.2	0.42	0.37	13.5	0.40	0.40
U01	4	28.4	20.8	0.63	0.56	16.0	0.62	0.62
U01	5	26.4	19.2	0.45	0.40	14.1	0.44	0.44

a OBTVOL = outside bark total volume
IBTVOL = inside bark total volume
OBMVOL = outside bark merchantable volume (min. 10 cm top dia. outside bark at 4 m)
IBMVOL = inside bark merchantable volume (min. 10 cm top dia. inside bark at 4 m)

Appendix B. Averaged soil variables by plot and master horizon.

										Soil pH		Texture[b]			
Plt	Horz.	P	ECEC	Al+H	Ca	K	Mg	Na	OM[a]	H_2O	KCl	SD	ST	CY	TK[c]
		ppm	----------		meq/100g			----------	%			%	%	%	cm
B01	solum	10.61	1.15	0.64	0.41	0.03	0.06	0.01	1.14			83	4	13	102
B01	A	10.77	2.73	1.91	0.63	0.08	0.10	0.01	3.72	4.70	4.07	54	18	28	21
B01	B	12.41	1.04	0.53	0.42	0.03	0.06	0.01	0.87	5.11	4.44	88	0	12	80
B02	solum	19.57	1.92	0.38	1.35	0.06	0.09	0.03	0.96			37	38	25	160
B02	A	14.01	4.12	0.53	3.18	0.10	0.26	0.05	3.57	5.39	4.49	39	35	27	24
B02	B	11.91	2.01	0.40	1.47	0.04	0.06	0.04	0.97	5.94	4.76	33	40	26	31
B02	BC	23.13	1.39	0.35	0.90	0.06	0.06	0.03	0.35	6.02	4.71	37	38	25	105
B03	solum	13.35	2.09	0.31	1.48	0.09	0.18	0.04	1.16			44	29	27	142
B03	A	13.50	6.58	0.28	5.60	0.07	0.60	0.03	3.99	5.56	4.79	41	32	28	24
B03	B	14.51	1.92	0.40	1.29	0.05	0.13	0.05	1.36	5.93	4.70	31	43	26	40
B03	BC	12.72	0.84	0.28	0.34	0.11	0.08	0.03	0.21	6.09	4.71	52	21	27	79
B04	solum	18.59	2.72	0.12	2.14	0.10	0.34	0.03	0.81			57	26	17	160
B04	A	11.07	6.11	0.11	5.46	0.12	0.41	0.01	2.99	6.11	5.11	47	28	25	22
B04	B	12.15	4.06	0.05	3.28	0.11	0.59	0.03	1.05	6.61	5.42	53	21	26	48
B04	BC	23.92	1.16	0.16	0.70	0.09	0.18	0.04	0.13	6.44	4.70	62	28	10	90
D01	solum	25.65	2.19	1.29	0.62	0.15	0.10	0.03	1.03			28	42	30	56
D01	A	32.82	2.45	1.38	0.81	0.12	0.13	0.01	2.00	5.07	4.24	41	33	26	23
D01	B	16.32	0.94	0.64	0.16	0.08	0.05	0.01	0.61	4.98	4.48	72	2	25	3
D01	BC	21.05	2.10	1.27	0.53	0.18	0.07	0.05	0.35	5.26	4.15	14	53	34	30
D02	solum	23.38	2.70	0.11	2.17	0.07	0.32	0.03	0.28			81	0	19	32
D02	A	19.23	8.96	0.38	6.91	0.26	1.37	0.04	3.79	5.17	4.37	73	0	27	1
D02	B	20.58	2.53	0.11	2.03	0.07	0.29	0.03	0.16	6.30	4.51	80	0	20	25
D02	BC	36.42	2.06	0.05	1.75	0.03	0.22	0.01	0.05	6.52	4.48	88	0	12	6
D04	solum	12.06	5.37	0.74	2.45	0.19	1.94	0.05	0.24			33	16	51	84
D04	B	12.06	5.37	0.74	2.45	0.19	1.94	0.05	0.24	5.56	3.97	33	16	51	84
D05	solum	18.15	2.03	0.31	1.26	0.10	0.33	0.03	1.23			57	28	14	50
D05	A	22.71	4.52	0.29	3.22	0.15	0.81	0.05	2.55	6.05	4.85	54	26	21	17
D05	B	13.65	0.86	0.40	0.26	0.09	0.08	0.03	0.69	5.79	4.67	55	33	12	20
D05	BC	18.96	0.49	0.19	0.18	0.05	0.06	0.01	0.30	5.69	4.90	66	24	9	13

Appendix B. (continued).

										Soil pH		Texture^b			
Plt	Horz.	P	ECEC	Al+H	Ca	K	Mg	Na	OM^a	H_2O	KCl	SD	ST	CY	TK^c
		ppm	---------	meq/100g			----------		%			%	%	%	cm
D06	solum	20.23	1.62	0.34	1.02	0.10	0.14	0.03	1.46			58	34	8	80
D06	A	25.41	3.04	0.42	2.16	0.14	0.29	0.04	2.85	5.81	4.67	59	31	10	34
D06	B	10.98	0.62	0.32	0.19	0.07	0.03	0.01	0.64	5.72	4.77	57	36	7	26
D06	BC	23.52	0.55	0.21	0.20	0.06	0.05	0.03	0.21	6.05	4.84	57	36	7	20
D07	solum	27.07	1.84	0.54	0.83	0.25	0.14	0.07	1.71			30	59	11	44
D07	A	41.52	3.42	0.69	2.17	0.46	0.07	0.03	2.78	5.69	4.50	32	56	12	15
D07	B	21.72	1.18	0.64	0.39	0.11	0.01	0.03	1.73	5.75	4.61	28	64	8	13
D07	BC	18.60	0.99	0.32	0.01	0.19	0.32	0.15	0.76	5.78	4.75	30	57	13	17
D08	solum	32.64	1.75	0.85	0.52	0.31	0.02	0.03	1.64			29	60	11	69
D08	A	45.15	2.61	1.14	0.93	0.48	0.03	0.03	2.40	5.33	4.19	29	58	12	27
D08	B	27.72	1.40	0.77	0.34	0.22	0.02	0.05	1.67	5.46	4.37	29	60	11	24
D08	BC	21.18	0.97	0.56	0.18	0.20	0.02	0.02	0.56	5.56	4.43	28	63	9	19
D09	solum	24.40	2.23	0.32	1.52	0.35	0.02	0.02	1.08			30	63	7	54
D09	A	35.76	4.63	0.19	3.75	0.62	0.04	0.03	1.94	6.18	4.94	31	64	5	20
D09	B	15.78	1.29	0.64	0.40	0.22	0.02	0.01	1.13	5.67	4.48	25	69	7	7
D09	BC	18.00	0.65	0.35	0.12	0.18	0.00	0.01	0.42	5.61	4.62	31	61	8	27
S01	solum	11.01	6.33	0.12	5.53	0.12	0.52	0.05	2.06			35	64	1	46
S01	A	7.56	8.62	0.13	7.52	0.16	0.76	0.05	3.06	5.78	4.68	35	65	0	22
S01	B	8.85	4.60	0.11	4.02	0.09	0.34	0.04	1.40	6.19	4.75	32	66	2	13
S01	BC	19.92	3.94	0.11	3.43	0.09	0.26	0.06	0.92	6.15	4.85	37	60	2	11
S02	solum	15.45	5.36	0.16	4.49	0.13	0.52	0.06	2.23			27	73	0	43
S02	A	9.06	8.09	0.16	6.88	0.18	0.80	0.07	3.82	5.62	4.63	21	79	0	24
S02	BC	23.55	1.89	0.15	1.47	0.06	0.16	0.05	0.23	6.27	4.63	35	65	0	19
S03	solum	11.44	1.11	0.89	0.09	0.05	0.04	0.04	1.95			34	66	0	51
S03	A	16.20	2.07	1.70	0.13	0.12	0.07	0.05	3.87	4.78	4.16	35	65	0	18
S03	B	11.10	0.95	0.77	0.08	0.03	0.03	0.04	1.72	5.28	4.42	29	71	0	24
S03	BC	13.89	0.64	0.42	0.12	0.04	0.03	0.03	0.54	5.38	4.49	40	59	1	9

Appendix B. (continued).

										Soil pH		Texture[b]			
Plt	Horz.	P	ECEC	Al+H	Ca	K	Mg	Na	OM[a]	H_2O	KCl	SD	ST	CY	TK[c]
		ppm	---------	---------	meq/100g	---------	---------	---------	%			%	%	%	cm
S04	solum	22.07	1.96	1.54	0.24	0.07	0.07	0.04	3.74			42	58	0	38
S04	A	17.58	2.35	1.83	0.28	0.10	0.10	0.04	5.05	4.87	4.17	46	54	0	15
S04	B	26.19	1.79	1.43	0.22	0.05	0.05	0.04	3.05	5.06	4.28	39	61	0	19
S04	BC	18.63	1.22	0.90	0.18	0.06	0.03	0.05	1.84	5.16	4.48	35	65	0	3
S05	solum	15.49	1.16	0.65	0.34	0.09	0.05	0.04	1.71			39	59	1	84
S05	A	13.47	2.38	1.25	0.83	0.14	0.13	0.04	4.13	4.96	4.22	37	63	0	10
S05	B	14.52	1.13	0.66	0.34	0.05	0.04	0.04	2.12	5.37	4.51	39	60	1	42
S05	BC	17.37	0.82	0.45	0.18	0.12	0.03	0.04	0.43	5.59	4.58	40	57	2	32
S06	solum	21.13	3.68	0.52	2.29	0.17	0.62	0.08	1.62			38	61	1	86
S06	A	9.51	5.06	0.72	3.11	0.28	0.85	0.10	5.05	5.26	4.27	38	62	0	24
S06	B	8.90	1.44	0.69	0.49	0.11	0.10	0.05	0.82	5.53	4.37	39	61	0	18
S06	BC	32.16	3.85	0.35	2.58	0.14	0.71	0.08	0.13	5.78	4.07	38	61	1	44
S07	solum	24.89	2.24	0.61	1.22	0.14	0.22	0.06	0.99			36	63	1	86
S07	A	8.25	3.72	0.45	2.31	0.24	0.65	0.07	3.23	5.31	4.23	32	68	0	17
S07	B	7.17	1.71	0.93	0.53	0.10	0.11	0.04	1.07	5.36	4.22	32	68	1	20
S07	BC	37.32	1.96	0.53	1.12	0.12	0.13	0.06	0.23	5.89	4.33	39	59	1	50
S08	solum	20.92	1.74	0.89	0.60	0.13	0.09	0.03	1.24			28	68	3	70
S08	B	14.37	1.61	0.95	0.46	0.10	0.07	0.03	1.75	5.20	4.39	28	71	1	47
S08	BC	34.02	2.00	0.77	0.88	0.18	0.13	0.04	0.24	5.78	4.40	29	63	8	24
S09	solum	14.72	1.55	0.65	0.66	0.11	0.09	0.03	1.69			33	66	1	58
S09	A	9.33	1.99	0.74	0.93	0.12	0.17	0.03	2.51	5.41	4.32	29	71	0	24
S09	B	14.75	1.36	0.66	0.54	0.08	0.05	0.04	1.82	5.44	4.57	36	64	0	18
S09	BC	22.38	1.11	0.50	0.42	0.12	0.03	0.04	0.38	5.48	4.55	35	60	4	17
S10	solum	12.46	3.77	0.46	2.51	0.18	0.56	0.06	1.73			34	62	3	60
S10	A	10.53	6.61	0.66	4.90	0.25	0.76	0.04	4.83	5.29	4.34	43	57	0	10
S10	B	9.12	2.10	0.50	1.20	0.12	0.24	0.04	1.72	5.73	4.48	33	67	0	17
S10	BC	16.14	3.70	0.32	2.37	0.19	0.73	0.09	0.18	5.82	4.22	31	61	8	20

Appendix B. (continued).

										Soil pH		Texture^b			
Plt	Horz.	P	ECEC	Al+H	Ca	K	Mg	Na	OM^a	H_2O	KCl	SD	ST	CY	TK^c
		ppm	----------	----------	meq/100g	----------	----------	----------	%			%	%	%	cm
S11	solum	12.73	1.96	0.58	1.08	0.12	0.16	0.04	1.51			38	62	0	53
S11	A	8.19	3.31	0.69	2.07	0.15	0.37	0.04	3.17	5.31	4.30	31	69	0	15
S11	B	13.35	1.41	0.53	0.69	0.09	0.07	0.03	0.98	5.75	4.58	41	59	0	22
S11	BC	16.26	1.42	0.53	0.66	0.12	0.07	0.04	0.64	5.89	4.57	39	61	1	16
S12	solum	9.83	2.28	0.60	1.39	0.08	0.17	0.04	2.00			48	44	8	51
S12	A	6.93	4.14	0.88	2.70	0.13	0.37	0.07	3.67	5.40	4.36	37	56	8	17
S12	B	9.12	2.35	0.77	1.33	0.06	0.16	0.03	2.05	5.66	4.52	39	53	8	23
S12	BC	12.54	1.15	0.31	0.68	0.07	0.06	0.04	1.00	5.87	4.79	59	33	8	28
S13	solum	9.21	1.54	1.15	0.26	0.07	0.04	0.02	1.62			63	25	12	51
S13	A	9.75	2.34	1.80	0.35	0.09	0.07	0.03	2.47	4.87	4.11	60	29	11	18
S13	B	8.04	1.14	0.88	0.19	0.06	0.02	0.01	1.18	5.19	4.44	65	22	12	21
S13	BC	10.47	0.99	0.61	0.26	0.07	0.02	0.03	1.07	5.43	4.52	65	22	13	11
S14	solum	12.74	3.41	2.19	0.90	0.14	0.13	0.05	2.19			27	63	10	47
S14	A	8.64	4.68	2.90	1.22	0.22	0.29	0.05	4.43	5.30	3.86	21	67	12	15
S14	B	11.84	3.23	2.25	0.74	0.13	0.06	0.05	1.47	5.38	3.99	24	65	11	21
S14	BC	20.76	1.90	1.00	0.76	0.06	0.04	0.04	0.35	5.90	4.22	43	53	4	10
S15	solum	10.46	2.46	2.15	0.16	0.06	0.05	0.04	2.06			33	63	5	50
S15	A	11.04	3.89	3.50	0.20	0.07	0.08	0.04	3.79	4.83	3.89	23	72	5	18
S15	B	9.33	1.78	1.55	0.13	0.04	0.02	0.04	1.47	5.17	4.29	34	62	4	19
S15	BC	11.31	1.51	1.20	0.16	0.06	0.05	0.04	0.59	5.32	4.32	44	52	4	13
S16	solum	14.77	1.38	0.59	0.55	0.08	0.11	0.04	2.05			51	47	2	64
S16	A	13.23	2.46	1.25	0.81	0.14	0.21	0.05	3.78	5.42	4.29	43	54	4	20
S16	B	10.50	0.81	0.35	0.28	0.07	0.07	0.04	1.47	5.71	4.69	52	46	2	31
S16	BC	28.68	1.01	0.10	0.80	0.03	0.05	0.03	0.59	6.16	4.92	64	35	1	12
S17	solum	11.44	2.06	0.77	1.05	0.08	0.12	0.04	1.93			41	52	7	65
S17	A	13.13	3.83	1.55	1.88	0.15	0.22	0.04	3.68	5.54	4.26	37	50	13	22
S17	B	9.66	1.54	0.55	0.82	0.05	0.08	0.04	1.55	5.92	4.65	36	61	4	25
S17	BC	11.82	0.57	0.10	0.34	0.05	0.05	0.03	0.26	6.28	5.04	55	42	3	18

Appendix B. (continued).

										Soil pH		Texture[b]			
Plt	Horz.	P	ECEC	Al+H	Ca	K	Mg	Na	OM[a]	H_2O	KCl	SD	ST	CY	TK[c]
		ppm	---------	meq/100g			---------		%			%	%	%	cm
U01	solum	18.47	3.29	2.51	0.41	0.12	0.17	0.07	2.39			14	44	43	31
U01	A	13.13	3.68	2.76	0.50	0.14	0.22	0.07	3.39	4.72	3.91	14	46	40	16
U01	BC	24.12	2.87	2.25	0.33	0.10	0.12	0.07	1.33	4.93	4.07	13	41	45	15

[a] organic matter
[b] SD = sand, ST = silt, CY = clay
[c] TK = thickness

Appendix C. Merchantable volume equations to a 3 in top diameter.

The coefficients obtained for Spurr's (1953) weighted model to predict OBMVOL and IBMVOL (cu ft) with merchantability limits of a: minimum 4 in butt diameter, minimum 3 in top diameter, and minimum 12 ft length are provided below.

$$\text{OBMVOL} = 3.73\text{E-}3 + 2.40\text{E-}3(D^2H)$$

$$\text{IBMVOL} = -0.041 + 2.13\text{E-}3(D^2H)$$

where D = dbh (in), and H = total height (ft)

BIOGRAPHY

Daniel William Gilmore was born in Rome, New York on February 15, 1958 the son of Theresa D. Gilmore and the late William M. Gilmore. He attend public schools in Utica, New York and was graduated from Utica Free Academy with a New York State Regents Scholarship in 1976. He entered Paul Smith's College of Arts & Science in 1976, and was graduated with an Associate in Applied Science degree in Forestry in 1978.

While attending Paul Smith's College, he met Debra Jean Williams whom he married in 1979. They lived in the Saranac Lake Region of New York for 10 years. While there, Daniel found employment in a variety of capacities related to forestry throughout the northeastern Adirondacks.

He became a field forester for the northern New York subsidiary of Montreal based Domtar in 1984. In 1987, he was awarded the Wood Manager's Award from the Eastern Ontario Division of Domtar Forest Products for his contribution in the development of a timber cruising procedure.

From 1984 to 1988 he attended college part-time and received an Associate in Science in Business Administration from North Country Community College, Saranac Lake, New York; and a Bachelor of Science with a concentration in Forest Management, from the State University of New York, Empire State College, Saratoga Springs, New York.

He served on the Paul Smith's College Forest Technician Advisory Board from 1987 to 1989. He is a Licensed Professional Forester in the State of Maine, a member of the Society of American Foresters, the Canadian Institute of Forestry, the International Society of Tropical Foresters, and the Soil Science Society of America.

In September of 1989, he was enrolled for graduate study at the University of Maine. He has been a teaching assistant from 1989 through 1991 for various forestry courses including silviculture, forest biometry, and aerial photography. He was the 1990 recipient of the Charles E. Schomaker Memorial Award, and in 1991 he became a member of the Gamma Chapter of XI Sigma Pi. He is a candidate for the Master of Science degree in Forestry from the University of Maine, Orono, in May of 1992.

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