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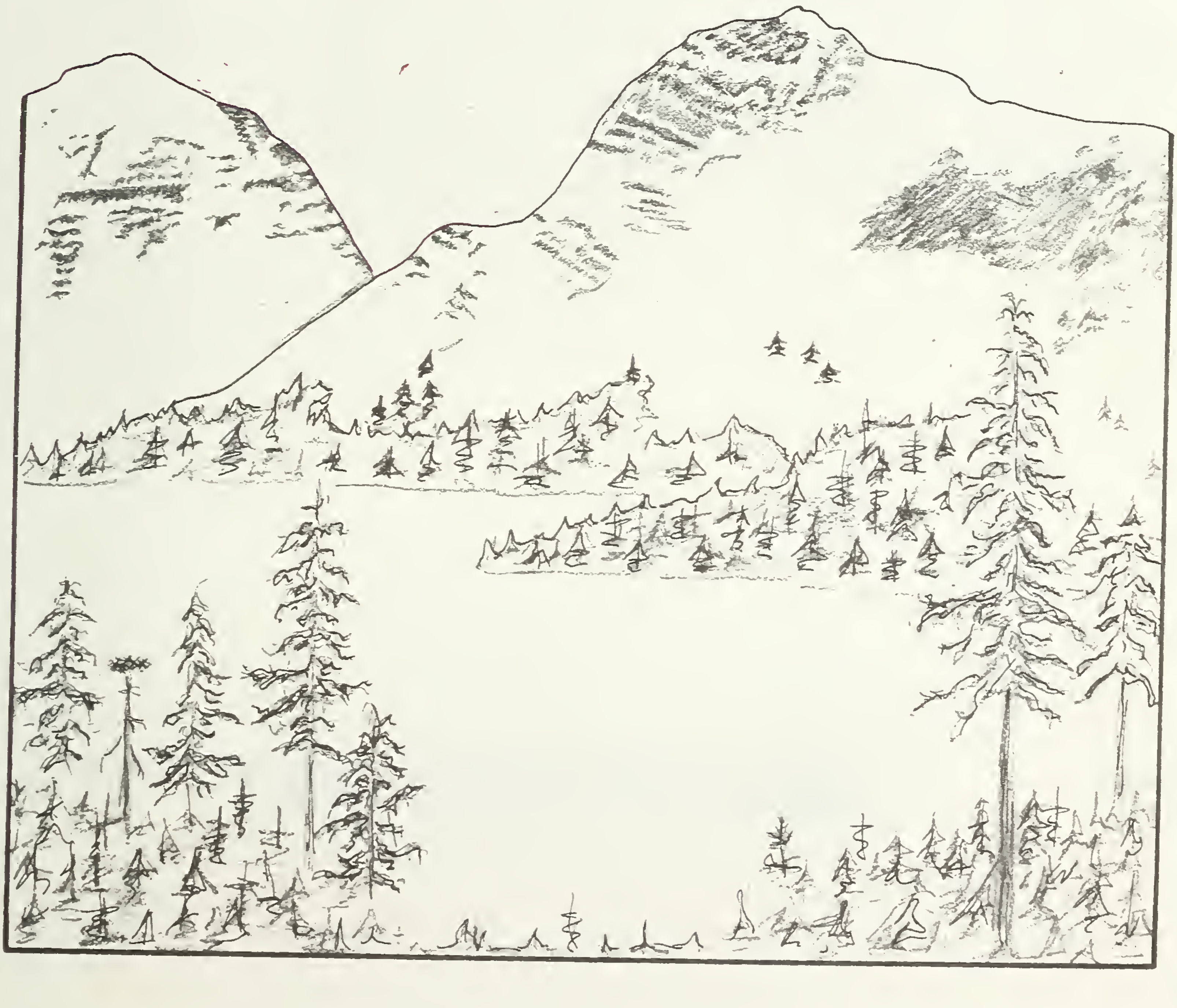
Timber Productivity of Seven Forest Ecosystems in Southeastern Alaska

Willem W.S. van Hees



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Abstract

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Observations of growth on Alaska-cedar (*Chamaecyparis nootkatensis*), mountain hemlock (*Tsuga mertensiana*), Sitka spruce (*Picea sitchensis*), western hemlock (*Tsuga heterophylla*), and western redcedar (*Thuja plicata*) on seven forest ecosystems in southeastern Alaska were used to develop equations relating periodic annual cubic-foot volume growth percent (Pv) to tree diameter at breast height and percentage of live-tree stocking. Results showed differences in productivity between and within forest ecosystem soil groups.

Keywords: Soil productivity, growth rate, growth (plant) -)soil, Alaska (southeast).

Summary

Differences in timber productivity of seven forest ecosystem soils in southeastern Alaska were examined through regression analysis. The analysis attempted to relate tree volume growth percent to aspect, percentage of live-tree stocking, and tree diameter for five tree species growing on the seven ecosystem soils. The tree species were Alaska-cedar, mountain hemlock, western hemlock, Sitka spruce, and western redcedar. Necessary data were extracted from forest resource inventory data bases developed for southeastern Alaska. The regression analysis produced equations for 22 combinations of species and ecosystem soil. Aspect was the only proposed independent variable not statistically significant in any of the equations. Analysis of covariance showed most equations to be unique. The results of this study were consistent with estimates of Sitka spruce site index for each ecosystem made by Stephens and others (1968).

Contents

Introduction

An understanding of the relative differences in productivity among soils is important to forest managers for long-range planning. The most common measure of site productivity is site index: the height of dominant or codominant trees at some chosen age. This measure is commonly used in young, even-aged stands. It generally is not appropriate for estimating site productivity for stands of old-growth timber. Growth percent might be used instead for old-growth stands to rank their potential productivity.

The purpose of this paper is to report results of a study on using growth percent as an estimator of relative future productivity for trees in stands of old-growth timber growing on different forest ecosystem soils. The tree species included were Alaska-cedar (*Chamaecyparis nootkatensis* (D. Don) Spach), mountain hemlock (*Tsuga mertensiana* (Bong.) Carr.), Sitka spruce (*Picea sitchensis* (Bong.) Carr.), western hemlock (*Tsuga heterophylla* (Raf.) Sarg.), and western redcedar (*Thuja plicata* Donn ex D. Don).

Study Area

The study area was the forested area of southeastern Alaska (fig. 1) from near Skagway in the north to Dixon Entrance in the south. The eastern boundary was the border between the United States and Canada, and the western boundary was the Pacific Ocean.

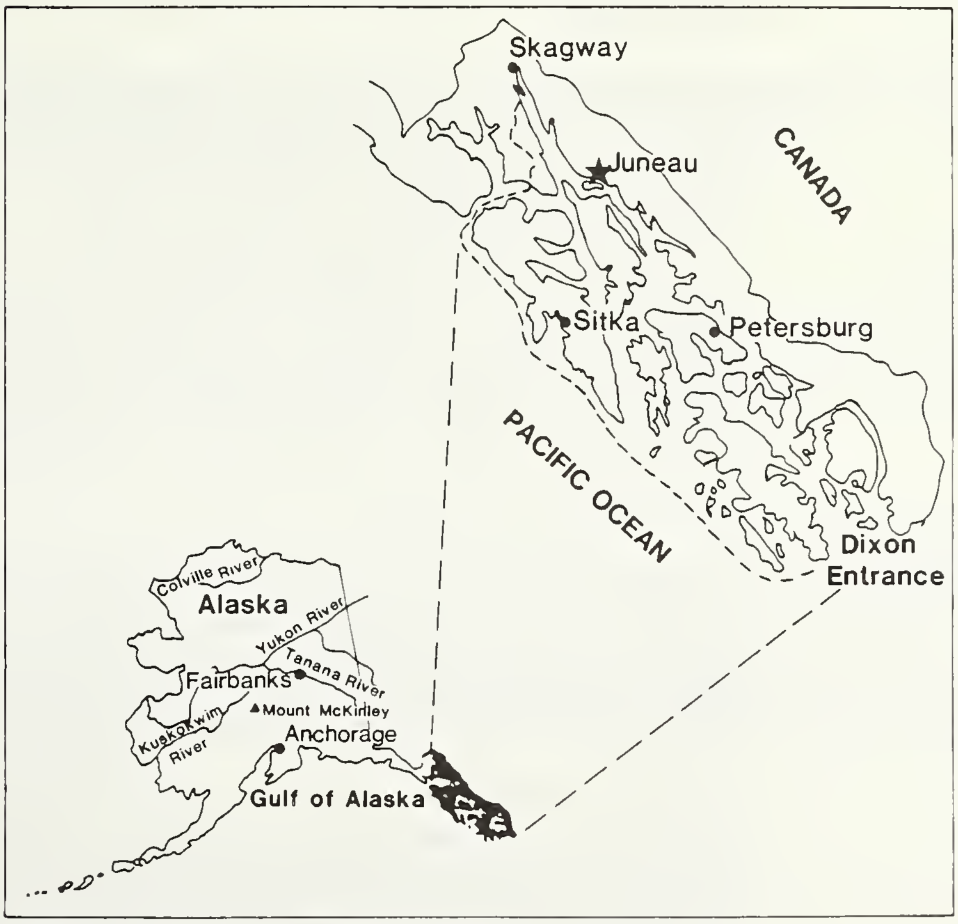

Figure 1—Study area in southeastern Alaska.

Objectives

This study was conducted to evaluate the use of periodic annual cubic-foot volume-growth percent (Pv) as a relative measure of timber productivity on different forest ecosystems in southeastern Alaska.

Volume growth was chosen (instead of diameter or basal area growth) to measure timber productivity because it incorporates growth in diameter and height. Estimates of volume growth are also directly usable in timber-growth models such as TRAS (Alig and others 1982).

Methods

Regression analysis was used to examine the relation between Pv, tree diameter at breast height (DBH), aspect, and percentage of live-tree stocking (LTS) on the sample plot for each tree species and forest ecosystem combination for which there were 30 or more observations. Five tree species on seven forest ecosystems were examined. Analysis of covariance was used to determine if individual equations for each species-ecosystem combination were in fact unique (Neter and Wasserman 1974). F-tests were performed on species equations within and between ecosystems.

Data

Data for this study were from forest resource inventories of southeastern Alaska done from 1970 to 1974. The field portion of the inventory consisted of 962 ten-point, variable-radius (basal area factor = 62.5), 1-acre timberland plots. Observations of tree height and diameter were made on each plot, and increment cores were taken to estimate diameter growth. The forest ecosystem soil (see below) at each plot was also recorded.

The focus of this study was on growth of individual trees. Total stand growth was not determined. To remove effects of age, disease, insect damage, and other physical causes of tree defect from the analysis, only those trees classed as "desirable" (see "Glossary") were selected.

Forest Ecosystems

The ecosystem classes used in this study were those in the forest ecosystem classification developed by Stephens and others (1969). They grouped standard United States Department of Agriculture (USDA) Soil Conservation Service soil series classifications into broader ecosystem categories based primarily on elevation, soil drainage, and soil depth. Further refinement was based on similarities in soil texture, development, and structure. A list of the soil series included in each major ecosystem is included in the glossary.

Dependent Variable

The dependent variable, Pv, is the ratio of periodic annual cubic-foot volume increment during the previous decade to tree volume at the beginning of the year prior to measurement, in percent. Periodic annual cubic-foot tree-volume increment was subtracted from current volume to obtain an estimate of the previous year's tree volume. Thus, Pv is an estimate of tree-growth percent during the year before measurement.

A measure of diameter growth and an estimate of height growth were needed to estimate Pv. Ten-year diameter increment was measured from a single increment core taken at breast height on the uphill side of the tree. The increment was divided by 10 to obtain an estimate of mean annual diameter increment.

Table 1—Cubic-foot volume equations used for the timber resource inventories of southeastern Alaska, 1970-74

Species	Volume equation[a]	Source
Sitka spruce:		
Poletimber	$V = 0.0022D^2H_T - 7.32683/D^2$	Embry and Haack 1965
Young-growth sawtimber	$V = 0.048534D^2H_L + 507.72/D^2$	Embry and Haack 1965
Old-growth sawtimber	$V = 16.30566 - 3.09606H_L + 0.04983D^2H_L$	Bones 1968
Western and mountain hemlock:		
Poletimber	$V = -2.85632 + 0.0633H_T + 0.00202D^2H_T$	Embry and Haack 1965
Young-growth sawtimber	$V = 5.2132 + 0.045805D^2H_L$	Embry and Haack 1965
Old-growth sawtimber	$V = 0.04915D^2 + 0.03912D^2H_L + 269.92685/D^2$	Bones 1968
Alaska-cedar:		
Poletimber	$V = 0.0316H_T + 0.001911D^2H_T - 28.78/D^2$	Farr and LaBau 1971
All sawtimber	$V = 2.0180H_L + 0.040236D^2H_L$	Farr and LaBau 1971
Western redcedar:		
Poletimber	$V = 0.04578D^2 + 0.001266D^2H_T - 27.17/D^2$	Farr and LaBau 1971
All sawtimber	$V = 0.5088D + 0.040668D^2H_L$	Farr and LaBau 1971

[a] V = cubic-foot volume (1-ft stump to 4-in top inside bark),
D = DBH,
H_T= total tree height, and
H_L= log height to a top diameter outside bark equal to 40 percent of DBH.

Height growth was estimated using an equation previously developed for use by the Forest Inventory and Analysis for Alaska (FIA) research unit in its ALCAL[1] program:

$$\text{HEIGHT GROWTH} = -0.454985 - 0.070728(\text{DBH}) + 0.192886\left(\frac{\text{SITE INDEX}}{10}\right);$$

where: HEIGHT GROWTH = annual growth in feet,
DBH = diameter at breast height in inches, and
SITE INDEX = estimate of plot site index.

Height growth as estimated with this equation was used to estimate total height at the end of the previous year. Tree volumes (current and 1 year ago) were estimated using species-specific volume equations relating tree volume to tree height and DBH (table 1).

Independent Variables

Aspect—Physical characteristics of forest sites, including slope, elevation, and aspect, affect tree growth. The ecosystem classification by Stephens and others (1969) is based, in part, on drainage (slope) and elevation. Because these variables are components of the ecosystem classification, they were not included as possible independent variables. Aspect was examined, however, for inclusion as an independent variable in regression. Sine and cosine transformations of aspect were evaluated along with sine and cosine transforms weighted by percentage of slope (Stage 1976).

[1] ALCAL is one of a series of software packages used to compile Forest Inventory and Analysis data. ALCAL is on file at the Forestry Sciences Laboratory, USDA Forest Service, 201 East Ninth Avenue, Suite 303, Anchorage, Alaska 99501.

Percentage of live tree stocking—The effect of stand density on tree growth is well known. The percentage of live-tree stocking (LTS) was used as a measure of the space available to live trees. The sum of LTS values for all individual trees on a plot was used to estimate stand density in the area around each sample tree.

The percentage of individual tree stocking was estimated by using the equation:

$$\text{Stocking percent} = \frac{(\text{basal area factor})(100)}{(\text{basal area standard})(\text{np})} \;;$$

where: np = number of variable-radius sample points in the ground plot; and
basal area standard = the tree spacing, expressed as basal area per acre, needed to capture the full growth potential at a given age and site index.

It was assumed that 60 percent of the normal yield-table basal-area stocking values for western hemlock and Sitka spruce (Taylor 1934) would provide a satisfactory estimate of full stocking and would serve as the basal area standard in computing LTS.

DBH—Both DBH and DBH^2 were tested for inclusion in the volume growth prediction equations. Tree age was not used because age was not available for all trees in this study.

Equation Form

Volume growth percent was expected to decrease curvilinearly for increases in LTS and DBH. A reciprocal function was used to express this relation. The equation form tested was:

$$Pv = a(\text{aspect}) + b\left(\frac{1}{\text{LTS}}\right) + c\left(\frac{1}{\text{LTS}^2}\right) + d\left(\frac{1}{\text{DBH}}\right) + e\left(\frac{1}{\text{DBH}^2}\right) \;;$$

where: a, b, c, d, e = regression coefficients.

Results and Discussion

Equations and Tests of Significance

Regression analysis produced equations for 22 combinations of species and ecosystems. Analysis of covariance showed most equations to be unique. The final equations are shown in tables 2 and 3. Differences in Pv are evident both within and between soil groups. Ecosystems F2r and F5 show lower values of Pv than do the other ecosystems. Within ecosystems, the greatest difference in estimates of Pv between species occurs on F2 soils. With the exception of Alaska-cedar, mountain hemlock, and western hemlock on F2r soils, and Alaska-cedar and western hemlock on F5 soils, all equations within and between ecosystems were found to be significantly different from each other (where models were similar). Dissimilar models could not be tested against each other and were assumed unique.

Table 2—Regression equations of Pv for desirable trees growing on the F1, F2, and F4 forest ecosystems, by species, southeastern Alaska

Forest ecosystem and tree species	Regression equation	Number of trees	r^2	s.e.
F1:				
Sitka spruce	$Pv = -0.008 + 64.705(1/LTS) - 1977.936(1/LTS^2) + 461.279(1/DBH^2)$	244	0.801	0.69
Western hemlock	$Pv = -0.308 + 108.005(1/LTS) - 8635.503(1/LTS^2) + 535.278(1/DBH^2)$	424	.809	1.17
F2:				
Alaska-cedar	$Pv = -0.21 + 351.69(1/LTS) - 44567.148(1/LTS^2) + 218.692(1/DBH^2)$	48	.688	.55
Sitka spruce	$Pv = -0.164 + 21.633(1/DBH) + 67.225(1/DBH^2)$	153	.768	.49
Western redcedar	$Pv = -0.651 + 35.072(1/DBH)$	34	.813	.49
Western hemlock	$Pv = -0.987 + 229.156(1/LTS) - 14952.607(1/LTS^2) + 402.644(1/DBH^2)$	318	.709	1.32
Mountain hemlock	$Pv = -3.667 + 700.856(1/LTS) - 45186.505(1/LTS^2) + 783.045(1/DBH^2)$	57	.618	3.97
F4:				
Alaska-cedar	$Pv = -0.943 + 30.516(1/DBH) + 123.41(1/DBH^2)$	126	.818	.68
Sitka spruce	$Pv = 0.240 + 218.736(1/DBH^2)$	156	.640	.48
Western redcedar	$Pv = -0.618 + 38.004(1/DBH)$	90	.657	.63
Western hemlock	$Pv = -0.034 + 304.59(1/DBH^2)$	355	.848	.69
Mountain hemlock	$Pv = -1.045 + 506.282(1/DBH^2)$	103	.874	1.35

Table 3—Regression equations of Pv for desirable trees growing on the F5, F6, F2r, and f1 forest ecosystems by species, southeastern Alaska

Forest ecosystem and tree species	Regression equation	Number of trees	r^2	s.e.
F5:				
Alaska-cedar and western hemlock	$Pv = -0.487 + 74.072(1/LTS) - 3008.739(1/LTS^2) + 178.035(1/DBH^2)$	169	0.803	0.53
Sitka spruce	$Pv = -0.251 + 159.392(1/LTS) - 8020.865(1/LTS^2) + 98.981(1/DBH^2)$	40	.662	.50
Mountain hemlock	$Pv = 0.049 + 89.393(1/DBH^2)$	42	.676	.18
F6 Mountain hemlock	$Pv = -0.549 + 40.485(1/LTS) - 796.785(1/LTS^2) + 398.8(1/DBH^2)$	71	.926	.44
F2r:				
Alaska-cedar, western hemlock, and mountain hemlock	$Pv = -0.03 + 185.837(1/DBH^2)$	238	.811	.51
Sitka spruce	$Pv = 0.244 + 197.410(1/DBH^2)$	92	.649	.65
f1 Sitka spruce	$Pv = 0.588 + 54.810(1/DBH)$	59	.806	.69

F2r soils consist of duff over bedrock and tend, at times, to become very dry. Western hemlock grows best on deep, internally well-drained soils; Alaska-cedar attains its best development near the upper elevational limits of merchantable timber where the soils are shallow to bedrock with groundwater seeping from higher elevations; and mountain hemlock shows its best development on loose, coarse-textured, well-drained, moist soils (Fowells 1965). The combined equation likely represents "poor" growth for western hemlock and mountain hemlock and "good" growth for Alaska-cedar.

F5 soils are essentially a duff layer over black muck or mucky peat, which in turn overlies sedge or sphagnum peat. The combined equation for Alaska-cedar and western hemlock represents generally poor growth of both species on these soils. A unique equation is needed to represent Sitka spruce growth on F5 soils probably because Sitka spruce grows well on soils high in organic matter that often have heavy accumulations of raw humus or moss (Fowells 1965).

Table 4—Comparison of estimates of site index[a] (100 years) of Sitka spruce with values of Pv for Sitka spruce, by ecosystem and 5-in diameter class (% LTS = 150)

Forest ecosystem	Site index (100 years)	Diameter class (inches)				
		5	10	15	20	25
	Feet			*Pv*		
F1	152	19.7	5.0	2.4	1.5	1.1
F2	118	6.9	2.6	1.6	1.1	.8
F2r	89	8.1	2.2	1.1	.7	.6
F4	118	9.6	2.6	1.3	.8	.7
F5	73	4.6	1.4	.8	.6	.5
f1	150	11.6	6.1	4.2	3.3	2.7

[a]From Stephens and others 1968.

For Sitka spruce, the results of this study are consistent with estimates by Stephens and others (1968) of site index for each ecosystem. Table 4 shows those estimates of Sitka spruce site index by ecosystem along with estimates of Pv by 5-in diameter class. For 5-in trees on F2 and F2r soils, the Pv values do not rank the same as the site index values; however, these differences diminish in the larger diameter classes.

Responses of Variables

Aspect, hypothesized to be significantly related to Pv, did not have statistical significance in any of the regression equations. A number of factors may contribute to this: First, aspect, as measured in the inventories, was recorded to the nearest 15 degrees. Second, tree growth is influenced by a large number of daylight hours on all aspects during the growing season in Alaska, and this, in combination with a measure of aspect that may be insensitive, could result in nonsignificant relations between Pv and aspect.

Live-tree stocking was not retained in all equations for two reasons. The Student's t-value associated with the coefficient of the variable was low, and most importantly, inclusion resulted in a meaningless response surface. The ambiguity of response of LTS likely derives from two sources: an insufficient number of observations in some cases and an inadequate range in magnitude of the observations in other cases.

Limitations

Height growth—Use of a single equation to estimate height growth for all tree species is questionable. The equation used was developed for stands of young-growth western hemlock and Sitka spruce. Because stands of western hemlock and Sitka spruce, both mixed and pure, account for almost 76 percent of the timberland in southeastern Alaska and nearly 81 percent of the cubic-foot volume (van Hees 1988), bias introduced by using one height growth estimator is likely less noticeable in the context of a large-scale timber inventory than in the narrower scope of this study. Height-growth equations for species other than western hemlock and Sitka spruce in southeastern Alaska are lacking, so it is not possible to estimate bias created by using this equation.

Diameter increment—Single increment cores are likely not a sufficient sample for estimating diameter growth of individual trees. Trees measured in the inventory occurred on a variety of slopes and aspects, so sampling bias introduced by using only one core sample should have been minimized.

Tree growth versus stand growth—No attempt was made in this study to estimate stand volume growth. Estimates of Pv derived from measurements made on only desirable trees should more closely approximate potential productivity than if all trees, including damaged, rough, rotten, and cull trees, had been included in the analysis. Although these equations were not developed from data collected from trees growing in young, even-aged stands, they do provide a relative comparison of growth among species and ecosystems.

Although stand growth was not estimated, it is reasonable to assume that stand growth will differ among ecosystems in a manner similar to that found for individual trees.

Inventory data—Using a large timber inventory data base as the source of data for a study such as this presents problems. The inventories conducted in southeastern Alaska by FIA were designed to produce estimates of overall timberland area and volume within certain error limits. They were not specifically designed to provide data for studies of narrow scope.

All forest ecosystems were sampled, but no control on sample size (number of trees) by ecosystem was exercised in design of the inventory. For this reason, only those species-ecosystem combinations for which there were at least 30 observations were selected for analysis. Other species were sampled on ecosystems F6 and F1 for instance, but the number of observations tended to be low (generally less than 20).

Glossary

Desirable trees—Trees greater than 5.0 in DBH having no serious defects in quality to limit present or prospective use, having relatively high vigor, and hosting no pathogens that could result in death or serious deterioration before rotation age.

Ecosystems (from Stephens and others 1969)—

F1: Extensive, well- to moderately well-drained soils with at least 10 in of mineral soil over bedrock. They occur from sea level to about 1,500 ft elevation, vary widely in parent material, and are sandy loam to silt loam in texture. Soils series included in this category are Farragut, Gunnuch, Karta, Kupreanof, Liesnoi, Rynda, Salt Chuck, Sokolof, Tolstoi, Tuxekan, Ulloa, Tokeen, and Sarkar.

F2: Freely drained soils, generally less than 10 in deep, and shallow to bedrock. As with the F1 soils, these are found from sea level to 1,500 ft elevation, but there is generally no water table. Only one soil series is included in this category: Mosman.

F2r: Essentially a duff layer over bedrock. These soils tend to become drier than many other soils. Only one soil series is included in this category: McGilvery.

F4: Somewhat poorly drained soils that vary widely in parent material and generally overlie some type of drainage restriction. Soil textures range from sandy loam to silt loam, and usually a seeping water table is present within 18 inches of the duff layer. Soil series included in this category are Mitkof, Sloduc, and Wadleigh.

F5: These soils are extensive in southeastern Alaska. They have 3 in to 1 ft or more of duff over a layer of black muck or mucky peat, which in turn usually overlies a layer of sedge or sphagnum peat. These soils usually have a water table within 1 ft of the base of the duff layer. Soil series included in this category are Kaikli, Karheen, and Maybeso.

F6: These soils are stony, somewhat poorly drained, and occur just under the alpine zone between 1,500 and 2,000 ft elevation. The soils are generally shallow to bedrock and rock outcrops are common. Only one soil series is included in this category: St. Nicholas.

f1: These soils are young, immature, alluvial soils and occur up to about 1,000 ft elevation. The soils lack well-developed horizons and have relatively thin O-horizons. Beneath the O-horizon is 8-30 in of dark brown silt loam to fine sandy loam, which overlies several feet or more of grayish, stratified gravels and sands. Only one soil series is included in this category: Tonowek.

Old-growth sawtimber trees—Live trees at least 11.0 in DBH and at least 150 yr old.

Poletimber trees—Live trees 5.0-10.9 in DBH.

Timberland—Forest land producing, or capable of producing, crops of industrial wood and not withdrawn from timber utilization. Areas qualifying as timberland can produce in excess of 20 ft^3/acre per year of industrial wood, under management. In old-growth stands along coastal Alaska, this is equated to stands that can produce 8,000 bd ft/acre (net International 1/4-in rule).

Young-growth sawtimber trees—Live trees at least 11.0 in DBH and less than 150 years old.

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