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Long-Term Basal Area and Diameter Growth Responses of Western Hemlock-Sitka Spruce Stands in Southeast Alaska to a Range of Thinning Intensities

Nathan J. Poage

ABSTRACT

To better understand the long-term basal area and diameter growth response of young, well-stocked, even-aged, mixed-species stands of western hemlock *(Tsuga heterophylla* (Raf.) Sarg.) and Sitka spruce *(Picea sitchensis* (Bong.) Carr.) to a range of thinning intensities (heavy, moderate, light, and unthinned), 20 years of post-treatment (i.e., thinning) data were analyzed from !28 permanent study plots at 32 installations in southeast Alaska. Thinning significantly increased the basal area growth of the thinned plla elative to that of the unthinned plots. Basal area growth of the thinned plots decreased with increasing thinning intensity, likely a consequence of the reduction in growing stock with increating thinning intensity. Diameter growth increased with increasing thinning intensity. Younger stands (typically with smaller pre-treatment basal areas and diameters) responded more vigorously to thinning than did older stands, as did stands growing on more productive sites. The models developed in this analysis can be used by land managerTto make general predictions of how western hemlock-Sitka spruce stands similar to those investigated in southeast Alaska are likely to respond to diffewnt thinning intensities in terms basal area and diameter growth during the first 20 years post-treatment.

Keywords: *Picea sitchensis,* southeast Alaska, thinning, Tongass, *Tsuga heterophylla,* young stand growth.

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INTRODUCTION

The majority of the forests along the North American Pacific Northwest coast are mixed-species stands ntain-ir~ h significant proportion of westftt hemlock (Tsuga *heterophyIla* (Raf.) Sarg.) and, to a lesser degree, Sitka spruce (Picea sitchensis (Bong.) Carr.), western redeedar (Thuja plicata Donn), yellow cedar *(Chamaecparis* noothatensis [D. Don] Spach), and mountain hemlock (Tsuga *mertensi-*ana (Bong.) Carr.). Spanning over 22° of latitude, coastal hemlock-spruce forests occur from northern California to south-central Alaska, a distance of more than 1500 miles (Harris 1990). Low respiration demands associated with cool temperatures and abundant precipitation throug a't the year in these coastal forests have led to some of the hiihest recorded accutnulaticias of above-ground biomass in the world (Waring nd Franklin 1979).

Mixed-species stands of hemlock and spruce regenerate naturally following harvesting and heavy thinning in southeast Alaska (Ruth and Harris 1979, Deal and Farr 1994, Zasada and Packee 1994, Deal and Tappeiner 2002, Deal et at. 2002). In southeast Alaska, harvesting of primary forest has led to the establishment of an estimated 649,000 ac of western hemlock-Sitka spruce young-growth stands since the 1950t(Barbour et al. 2005). Interest in actively managing these-naturally regenerated young-growth standsied, in the early 197ls, to the initiation of t USDA Forest Service's Cgbperative Stand-D#i5ity Study (CSDS; DeMars 2000).

A primary objective of the CSDS is addressed in this paper: to underst fl the long-term basal area and diameter growth responses of young, well-stocked, even-aged, mixed-species_stands of western hemlock and Sitka spruce

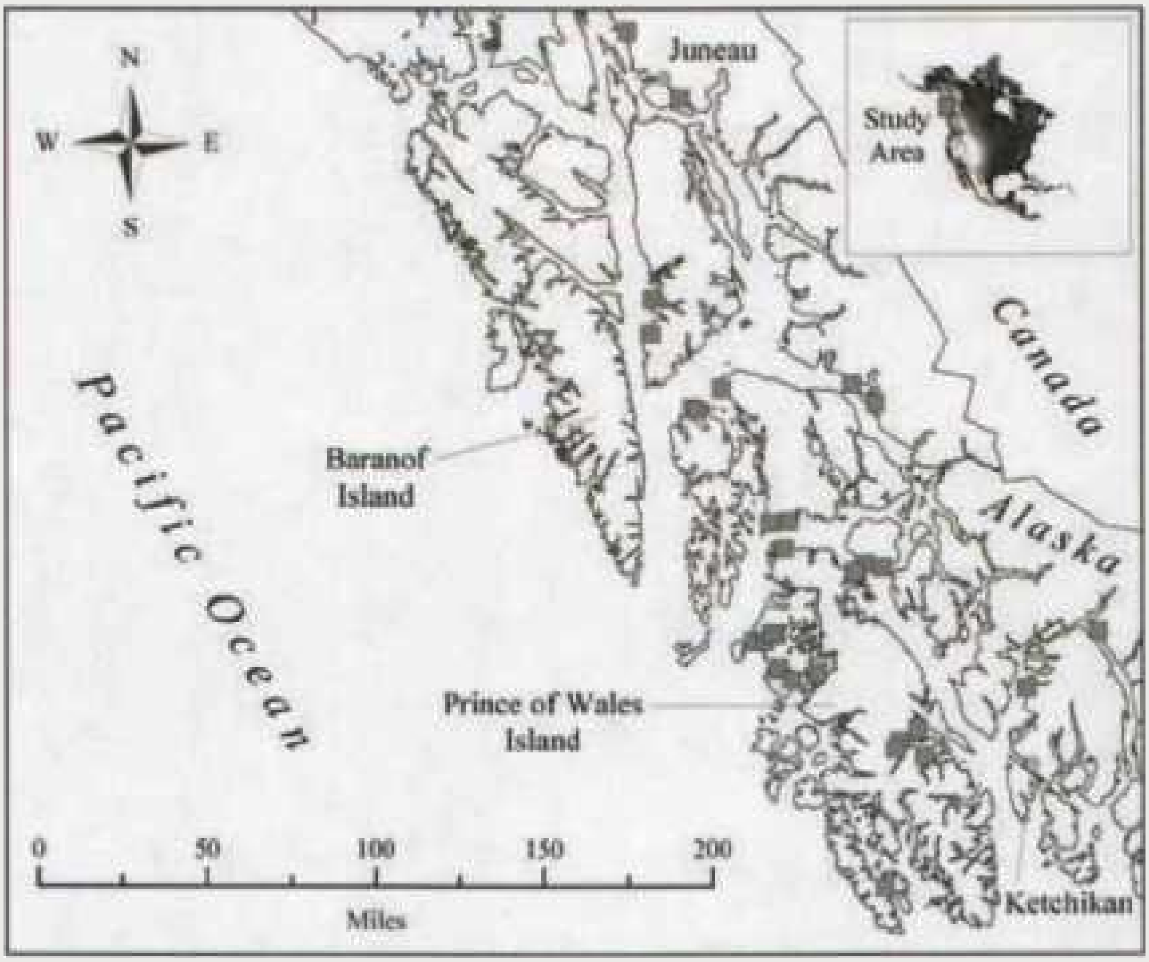


Figure 1- Locations *of the* 32 *Cooperative* Stand Density Study installations *(red* squares) discussed in detail in this *paper*

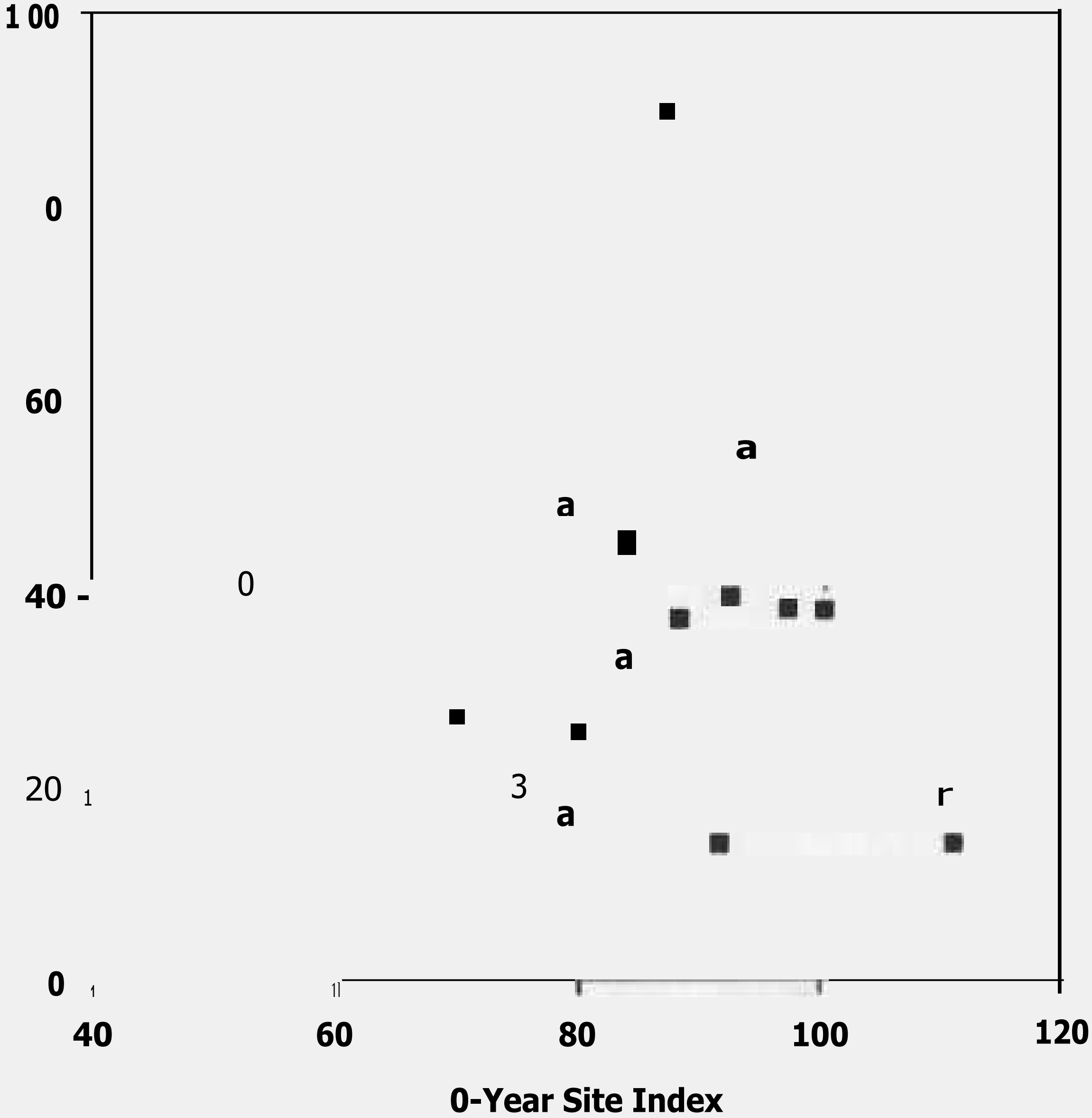


Figure 2– Mean age at treatment over 50year site index (Farr 1984) for 32 installations in southeast Alaska. Gray lines indicate the breaks between the 4 age classes and 3 site index classes defined in the original study plan,tor the Cooperative Stand Density Study (Farr 1976, DeMars 2000). ~t T numbers indicate the number of installations bout of 32) occurring in c ct-df the original 12 combinations of age at treatment class x site index class defined in the original study plan.

in southeast Alaska to a range of thinning intensities (Parr 1976, DeMars 2000). Of particular interest is to better understand how the basal area and diameter growth responses are influenced by age and stand structure at the time of thinning and site productivity (site index).

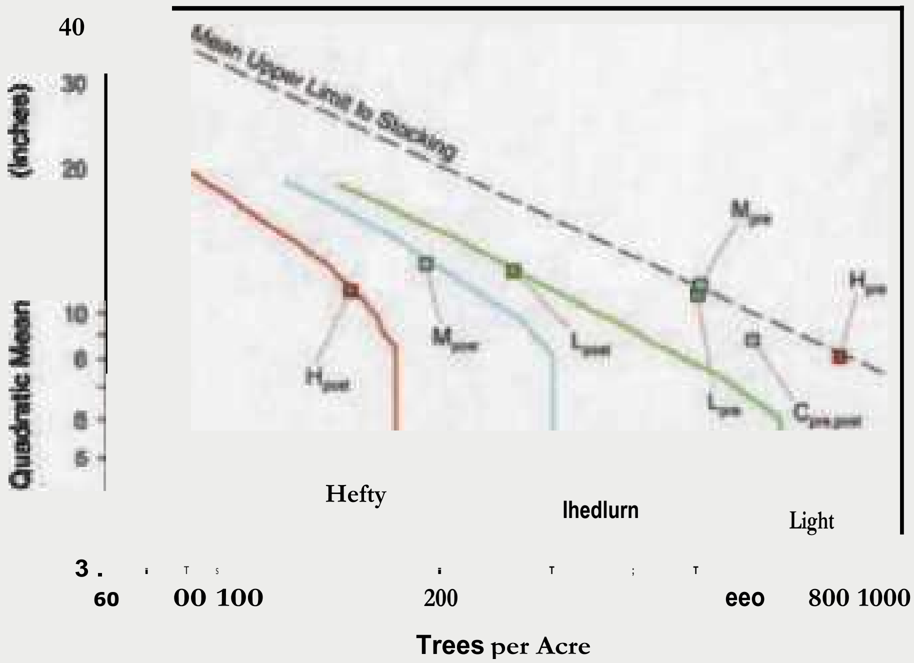
METHODS

Twenty years of post-treatment (i.e. thinning) data were analyzed from 128 permanent study plots (96 thinned plots and 32 unthinned plots) maintained by the USDA Forest Service at 32 sites or installations in southeast Alaska (Figure 1). The north-to-sodfh discs bution of tale plots was approximately 250 mi. Most plots were located close to the coastline at elevations of < 500 ft. All plots were located in the Picea stchensi"-Tsuga heterophylla forest type (Franklin and Halpern 2000). 'More than 95% of total basal area at each plot was made up by hemlock and spruce. The stands containing the plots were between 13 and 94 years old at the time of plot establishment; 50-year site index (Farr 1984) ranged between 49 and 118 (Figure 2). Pre-treatment basal areas (BA) were between 34 and 407 ft2/ac; pre-treatment quadr atic mean diameters (Q D, the diame&r of tree of average basal area) were between 1.2 and 16.3 in. DeMars (2000) provides a more detailed description of the study area.

All installations meeting 2 criteria were selected for analysis. First, the plots at each installation had measurements made on live trees for least 20 years of post-treatment measurements (generally made every 2-4 years). Second, an installation comprised 1 unthinned "control" (C) plot, 1 ghtly (L) thinned pot, 1 moderately (M) thinned plot, and 1 heavily (H) thinned plot. Thirty-two installations (96 thinned and 32 unthinned plots) met these selection criteria.

All plots were square, 0.2 ac in size, and centered in the middle ofa 1.0 ac treated area (Farr 1976, DeMars 2000). Each thinned plot was thinned once from below at plot establishment, generally to a uniform spacing. Pre-treatment QMD and thinning guidelines included in the CSDS study plan (Farr 1976, DeMars 2000) were used to determine post-treatment BA and QMD, average spacing, and number of trees per acre (TPA) for the L, M, and H thinning treatments. Preliminary analysis of the thinning guidelines indicated that the L, M, and H thinning treatments reduced stand density-expressed in terms of either relative density (Curtis 1982) or maximum stand ensity index (Poage et al. 2007)-to approximately 50% ( ), 35% (M), and 25% (H) of full stocking (Figure 3).

Species and diameter at breast height (dbh, the diameter at 4.5 ft above the ground) were recorded for each rive tree with a dbh > 0.5 in within each plot immediately pre- and post-treatment (i.e., At 0 years since treatment). Exceptionally dense young stands (generally greater than 1500 trees/acre) were sub-sampled using nine 0.004 ac circular subplots spaced at 23.3 ft intervals on a 3 x 3 grid. All trees measured at plot establishment were tagged. For each plot, total and species-specific BA, TPA, and QMD were calculated pre- and post-treatment (i.e., at 0 years since treatment) and for the measurements closest to 5, 10, 15, and 20 ye irs since treatment. Stand age and site index were determined at the time of treatment (DeMars 2000). DeMars (2000) provides additional details about the plot design and sampling scheme.



Fi?ure 3- *Thinning* guidelines defined in thOoriginal study plan *for the Cooperative* Stand Density Study *(Farr 1976, DeMars 2000).* Post-treatment quadratic mean diameters and *trees per acre are* shown *for* lightly (L) thinned plots in *green, moderately* (M) thinned plots in blue, and heavily (H) thinned plots in *red.* To illustrate, the squares indicate *the pre-* and post-treatment quadratic mean diameters and *trees per* acre *for* the 4 plots at one installation. The dashed black line labeled Mean Upper Limit to Stocking *represents the* mean Maximum stand density index (SDlmax = 619) *recently* identified *for* western hemlock-Sitka *spruce* stands in southeast Alask`(Poage et al. 2007).

How **BA** and diameter (QMD) growth responses during the 20 years post-treatment were influenced by thinning intensity, age when thinned, pre-treatment BA, pre-treatment QMD, site index, and years since treatment was modeled using a repeated measures approach and the **PROC MIXED** procedure of SAS (2003). Restricted/residual maximum likelihood (REML) was selected as the estimation method.

Backwg-ds, stepwise selection of explanatory variables resulted in the final mixed models for **BA** and QMD shown in Equation 1:

+ f **BAp,,,,** + Jir,QM/) ,,~ + f,S1,, + N_o + .i.N,i + +

time (/ 3_7 + ft QMD_p,,,,,, + + + 1',, M + fi,_2 H_A +

+

where v,,, is **the RA or ()AID** of **plat** k of **installation** j in year:.

EA,, ▾▾ is the pre-treatment BA of plat k on installation J.

Q^MD , is the pre-treatment QMD of **plot k on installation j.**

St, is the 50-year site index of plot k on installation j.

M,,, **and Ho** are **indicator variables that take the value of** I if **plot k** of **installaticxt j owed the light. medium, or heavy thinning treatment,** respectively, **and 0 otherwise,**

time is year t since the thinning treatment.

h, is the random effect of **installation j. and**

e,t, is the random error.

It is **assumed** that h, is **normally distributed** with mean tl **and variance Var(b)** The vector of errors of the **t observations** from plot **k** of installation j. **e,1.** is **assumed** to be normally **distributed** with mean **0** and covariance matrix **Var(e,&)** = I. It is further assumed that **b1 and e)**, **are independent and** that **observations** from different installations **are also independent**

Note that Equation 1 is structured to highlight the variables associated with the immediate post-treatment **BA** or QMD (i.e., the °ntercept term) in the first row, the variables associated with the change in **BA** or QMD over time (i.e., the slope term) in the second row, and the error terms in the third row.

RESULTS AND DISCUSSION

The plots responded to thinning as one might have predicted. Thinning significantYy Increased the basal area **(BA)** growth of the thinned plots relative to that of the unthinned plots, but **BA** growth of the thinned plots decreased with increasing thinning intensity (Figure 4, "Cable 1). The highest **BA** growth was observed in the lightly (L) thinned plots. **BA** growth of the L plots was, on average, 2.18 ft^2/ac/yr greater than that of the unthinned, control (C) plots (see lio, the time × L parameter estimate for the BA mixed model in Table 1). Average **BA** growth of the moderately (M) and heavily (Mrinned plots was 1.68 ft^2/ac/yr and 1.16 ft2/acryr greater, respectively, than that of the C plots (see fn and *ffi2* for the **BA** mixed.rnodel in Table 1). The observed decrease in **BA** growth with increasing thinning intensity was likely a consequence of the corresponding reduction in row stock with increasing thinning intensity. Although the **BA** growth of individual trees was greater in heavier thinnings than in "lighter thinnings, too few trees were retainedn heavier thinnings to generate the same plot-level **BA** growth observed in lighter thinnings.

In contrast to the **BA** growth of plots, diameter (QMD) growth increased with increasing thinning intensity (Figure 5, Table 1). Thinning significantly increased the QMD growth of the thinned M and **H** plots compared to that of

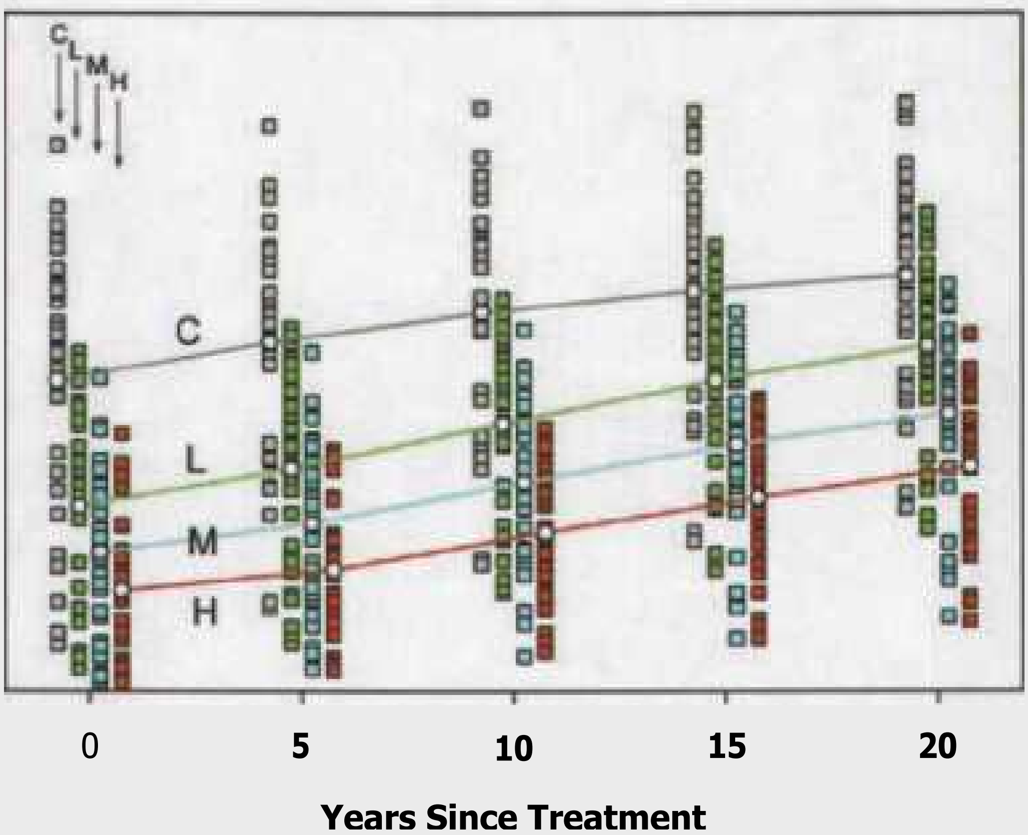


Figure 4- Plot-level basal *area* to shown by *treatment* at 0, 5, 10, 15, *and 20 years* since *treatment.* Data *for* unthinned "control" (C) plots *are* shown in *gray,* lightly (thinned plots *in green, moderately* (M) thinned plots in blue, and heavily (H) thinned plots in *red.* White *circles* indicate the average basal *ch treatment* at 0, 5, 10, 15, and *20 years* since *treatment.*

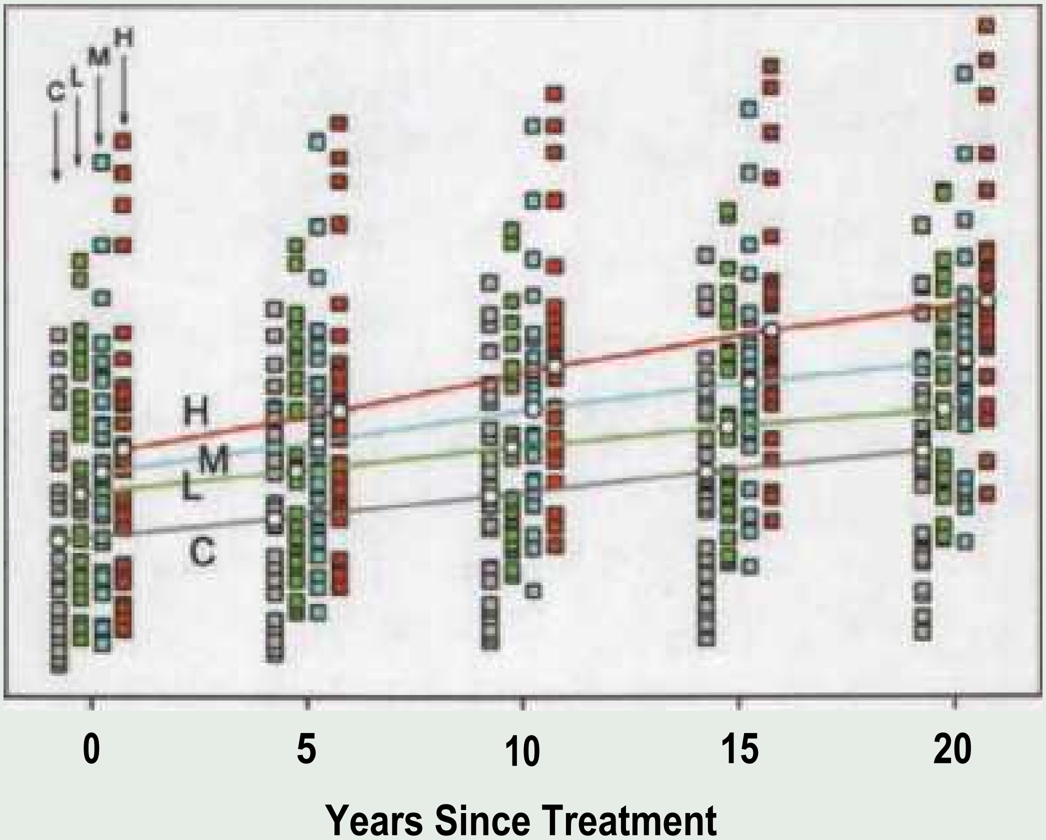


Figure 5. Plot-level quadratic *mean* diameter data shown by treatment at 0, 5, *10,* 15, and 20 *years since* treatment. Data *for* **unthinned** "control" (t plots *are* shown in *gray,* ligttly (L) thinned plots *in green, moderately* (M) thinned plots in blue, **a1** heavily (II) thinned plots in *red.* White *circles* indicate the average quadratic mean diameters *for each* treatment at 0, 5, *10,* 15, *and 20 years* "ice treatment.

the unthinned C plots. Average QMD growth of the M and H plots was 0.03 in/yr and 0.09 in/yr greater, respectively, than that of the C plots (see /311 and f u for the QMD mixed model in Table 1). Average QMD growth of the L plots was not significantly different than that of the C plots.

Younger stands responded more vigorously to thinning than did older stands, as did stands growing on more productive sites. .Both **BA** and QMD growth decreased with increasing pre-treatment QMD, pre-treatment **BA,** and age lien thinned. Age when thinned, pre-treatment QMD, acn e-treatment **BA** were all positively correlated (i.e., an older plot typically hafCl a larger QMD and more **BA** before thinning than a younger plot). The positive correlations between these three explanatory variables resulted in age when thinned being dropped as an explanatory variable„ from the final models for both BA and QMD (Equation 1). Both **BA** and QMD growth increased with increasing site index (see fay for the **BA** and QMD mixed models in Table 1).

The models developed for BA and QMD can be used by land manager&to make general predictions of how western hemlock-Sitka spruce stands similar to these investigated in southeast Alaska are likely to respond to different thinning intensities in terms BA and QMD growth during the first 20 years post-treatment. To illustrate, consider a 40-year-old stand with a pre-treatment BA of 275 ft^2/ac, a pre-treatment QMD of 6.5 in, and an estimated 50-year site index of 85. Equation 1 can be used to compare how, for example, the liA of this stand might develop over 20 years if it were a) lightly thinned and b) heavily thinned.

Table 1. Parameter estimates for the final basal area and diameter mixed models (Equation 1). With the exception of those parameter estimates indicated as not significant by the "n.s." superscript, all parameter estimates were significantly different than zero ($p < 0.05$). L, M, and H are indicator variables for the light, medium, and heavy thinning treatments, respectively.

	Basal A		eter (^ᶠD)	
Variable			E timate	(S.C.)
Intercept	**0**	(17,5970	**-2.4115**	**(0.4505)**
Pre-treatment 13**asal** Area	**0,4803**		**9**	**(um()**
Pre-t tineni **Quadratic** Mean ,Miaam:irl' 4Q:%!O	5	(1]'149)		
; it ,x (Si	**0.8704**	(0,17 '	**0.0167**	(o.
hii ning (L	-92J263	(6.277n	**2.1071**	(o.
Medium. thinning (At)	**-125.3000**	(6.2544)	**2.6730**	(0.1642)
Heavy **thinning (H**		*(r, r,*	3.4786	6
time'	-1,2338	**(0,** Chi	**-0.0104**	**((lf).2)**
time , .), L,..	.3710		**-0.0095**	**(0.0010)**
time SI	**0.0748**	(0.007)	**0.0026**	**o.2)**
time ×	2.1824		-0.017& '	i
time ,4f	L6815			(0.01)
(,fl; time : /I	1.1622	(03277)	0.0940	O 01(}7)

standard error of parameter estimate

^?ᵢlt-year site index (Farr **1984)**

`year' sine treatment (1.e. thinning)

(The following steps are perhaps most easily done using an electronic spreadsheet.) Begin by inserting the parameter estimates for **BA** ir.Table 1 into Equation 1 (e.g., li = 0.4803). Add the pre-treatment **BA** (275 ft^2/ac), pre-treatment QMD (6.5 in), and site index (85) where indicated in Equation 1. When L = 1, M = 0, **H** = 0, and time = 0, Equation 1 predicts a BA of 162 ft^2/ac immediately post-treatment for the lightly thinned stand; 20 years after thinning (i.e., time

= 20) the lightly thinned stand is predicted to be 260 ft2/ac. Similarly, if L = 0 M = 0, H = 1, and time = 0, Equation 1 predicts that the heavily thinned stand will have a **BA** of 104 ft^2/ac immediately post-treatment; 20 years after thinning the heavily thinned stand is predicted to be 182 ft^2 ac. In this scenario, average annual **BA** growth during th~ 20 years post-treatment is predicted to be 25% greater in the lightly thinned stand (4.9 ft^z/ac/yr) than in the heavily thinned stand (3.9 ft^2/ac/yr).

This paper is the first to address the primary objective of the Cooperative Stand-Density Study (CSDS): to understand how young hemlock-spruce stands of different ages and site productivities respond to a range of thinning intensities. The primary reason for this is simply a matter of time. Over a decade was required to establish the study plots (1974-1987). Additionally, if long-term responses to thinning are to be analyzed, decades must pass post-treatment; to analyze 20 years of post-thinning growth response requires that a sufficient number of plots have had 20 or more years pass following treatment. It is sincerely hoped that the CSDS plots-which are now beginning to pay long-term research dividends-continue to be maintained and measured into the future.

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