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Pacific Silver Fir Site Index in Relation to Ecological Measures of Site Quality

Introduction

Ecosystem-specific forest management requires comprehension of tree species productivity in managed settings, and how this productivity varies with the ecological determinants of site quality, *i.e.*, the environmental factors that directly affect the growth of plants: light, heat, soil moisture, soil nutrients, and soil aeration. A good understanding of this variation is necessary for making species- and site-specific silvicultural decisions to maximize productivity. Productivity of a given species is usually measured by site index (tree height at 50 years at breast height age). Quantitative relationships between site index and these measures of site quality provide predictive models for estimating site index.

Pacific silver fir (*Abies amabilis* (Dougl. ex Loud.) Forbes) is an important timber crop species in the coastal forests of British Columbia. In relation to climate, its range in southwestern British Columbia extends from sea level to almost timberline, and from the hypermaritime region on western Vancouver Island to the subcontinental region on the leeward side of the Coast Mountains. In relation to soils, its range extends from slightly dry to wet sites and from very poor to very rich sites. In view of this relatively wide climatic amplitude, a large variability in productivity can be expected. It is particularly important to consider the growth performance of Pacific silver fir when decisions are made regarding whether or not to cut stands on high-elevation sites. In the study summarized here, relationships between Pacific silver fir site index and selected ecological measures of site quality were examined, and site index models using these measures as predictors were developed.

Study Stands and Procedure

The study area encompassed the entire native range of Pacific silver fir in southwestern British Columbia; Vancouver Island and the adjacent mainland south of the line extending from Port McNeill to Lillooet. The study stands had regenerated naturally after a major disturbance (wind, fire or clearcutting) and were deliberately selected across the widest range of climate (measured by elevation and continentality), soil moisture, and soil nutrient conditions. A 0.04 ha plot was established in each of the 98 study stands, the three largest diameter trees were cut and sectioned, and site index was determined from stem analysis data. We allocated stands into 4 continentality strata according to plot location on biogeoclimatic maps. The strata were: (1) maritime (west Vancouver Island and the leeward side of the Coastal Mountains), (2) less-maritime (east Vancouver Island), (3) submaritime (the leeward side of the Coastal Mountains within the MH zone), and (4) subcontinental (the leeward side of the Coastal Mountains within the ESSF zone). Soil moisture regime (SMR) and soil nutrient regime (SNR) were estimated using a combination of topographic and soil morphological properties, as well as understory vegetation. Only three SNRs were used (poor, medium and rich), since no stands sampled were identified with very poor SNR, and the few very rich sites sampled were combined with rich sites.

Regression analysis was applied to examine the relationship between site index and climate (measured by elevation and continentality) using a climosequence; *i.e.* a data set comprised of 42 sites with fresh and moist SMRs and a medium SNR. Covariance analysis was applied to test the effects of differential availability of soil moisture and nutrients on site index. After adjusting for elevation, differences in mean site index were tested between sites stratified according to (1) SMRs across a hygrosequence, *i.e.*, a data set comprised of 45 sites with medium SNR, and (2) SNRs across a trophosequence, *i.e.*, a data set comprised of 76 plots with fresh and moist SMRs (Table 1).

To develop and test predictive models for Pacific silver fir site index, the data set (98 plots) was randomly split into a calibration data set (67 plots) and a test data set (31 plots). Multiple regression analysis was used to fit predictive models from climate and/or soil variables, and the precision of fitted models was tested against independent data and for bias using the root-mean square prediction error (root-MSPR = the square root of the mean squared differences between predicted and measured site index) and paired t-tests, respectively. The best model was compared to a climate-specific, polymorphic site index model (see ***Scientia Silvica*** Number 19).

Results and Discussion

Pacific silver fir site index decreased rapidly with increasing elevation, but the decrease varied with continentality (Figure 1). There was little difference between the maritime and less-maritime/submaritime strata; for every 100 m increase in elevation, site index decreased 2.0 m and 2.4 m, respectively. In the subcontinental stratum, where Pacific silver fir does not occur below 800 m in elevation, the decrease per 100 m elevation gain was only 0.8 m. However, for the same elevation, site index was much lower in the less-maritime/submaritime strata, compared to the maritime and subcontinental strata. This pattern may reflect drier summers in the less-maritime/submaritime strata compared to the maritime stratum, or a shorter growing season due to higher winter precipitation compared to the subcontinental stratum.

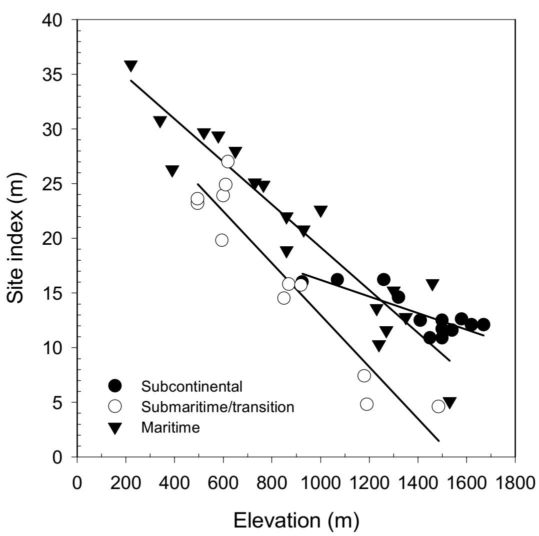

Figure 1. Regression lines showing the relationship between site index and elevation separately for the continentality strata: maritime ($R^2 = 0.89$), less-maritime/submaritime ($R^2 = 0.89$), and subcontinental ($R^2 = 0.69$). All regressions are significant at $p < 0.001$).

After adjusting for elevation, analysis of covariance showed a significant effect of available soil moisture on site index (n = 45, $p = 0.02$). Multiple comparisons of the marginal means using Bonferroni's adjustment indicated that site index on slightly water-deficient sites (slightly dry SMR) was significantly lower than on fresh and moist sites (p = 0.002 and 0.006, respectively; Figure 2A), reflecting the sensitivity of Pacific silver fir to water stress. No significant difference was observed between fresh and moist sites (p = 1.0).

Covariance analysis using the trophosequence showed a trend of increasing site index with increasing nitrogen (N) availability (n = 76, $p < 0.001$). After Bonferroni's adjustment, multiple comparison of the marginal means showed that poor sites had significantly lower mean site index compared to medium and rich sites (p = 0.001 and <0.001, respectively); however, no significant difference was shown between medium and rich sites (p = 0.713) (Figure 2B). This pattern indicates that the poor SNR represents sites with insufficient nutrient supply for the optimal height growth of Pacific silver fir. Thus, for constructing predictive models three groups of sites were considered: (1) water-deficient (WD - slightly dry) sites, nutrient-deficient (ND - fresh and poor) sites, and sites with sufficient soil moisture and soil nutrients (SWSN - remaining edatopes in Table 1).

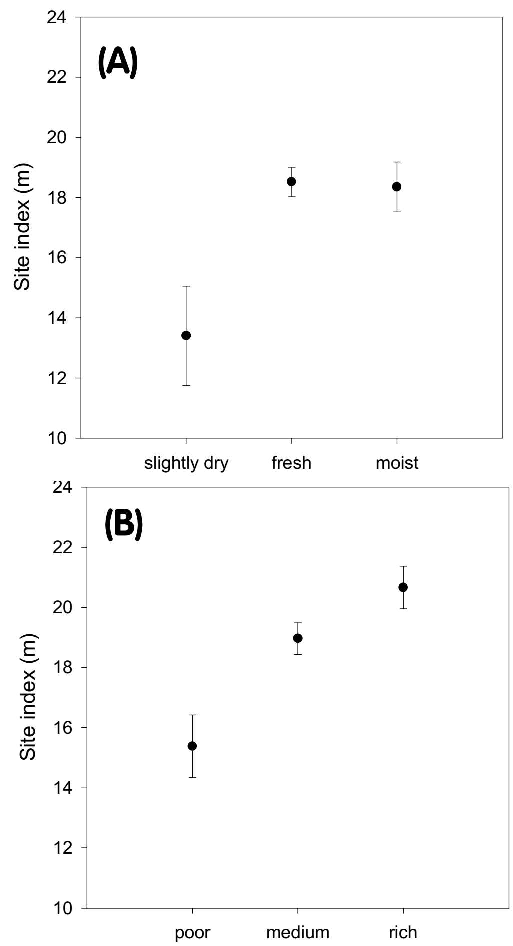

Figure 2. Relationship of site index to (A) soil moisture regimes across a medium hygrosequence (n = 45) and (B) soil nutrient regimes across a fresh and moist trophosequence (n = 76) when adjusting for elevation and continentality. Means represent site index at the elevation of 992 m and 969 m, respectively. Error bars represent one standard error of the mean.

The climate model (Eq. [1]) accounted for a slightly smaller portion of the variation of site index and was less precise (lower root-MSPR) than the combined model using climate and soil variables (Eq. [2], Table 2). Both models were unbiased when tested against independent data, since no significant differences were found using paired t-tests between measured and predicted site index (p = 0.650 and

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0.795, respectively). The precision of the climate model (root-MSPR = 3.73 m) and of the combined model (root-MSPR = 2.93 m) was low, when compared to a model using top height, stand age and continentality strata as predictors, which had a root-MSPR of 0.76 m (Figure 3) (also see *Scientia Silvica* Number 19). Although unbiased site index estimates of Pacific silver fir can be obtained from the models using site variables, their low precision may restrict their application to the forest rather than the stand-level.

Table 1. Number of study stands according to edatopes. The stands used for a climosequence are italicized, for a hygrosequence bolded, and for a trophosequence underlined. Boxes refer to water-deficient (WD), nutrient-deficient (ND), and sites with sufficient water and nutrient supply (SWSN) used in the predictive model [2].

	Poor	**Medium**	Rich	Total
Slightly dry	14 WD	**3**	-	17
Fresh	11 ND	***32*** SWSN	2	45
Moist	-	***10***	21	31
Very Moist	-	**-**	5	5
	25	**45**	28	98

Table 2. Models for predicting site index (SI) from indirect climatic (Eq. [1]), and indirect climatic (elevation and continenality strata as dummy variables) and soil variables (as dummy variables) (Eq. [2]). All models are significant (p <0.001, n = 98). R^2_{adj} is adjusted for the number of independent variables. SEE is standard error of estimate. Root-MSPR is the square root of the mean squared differences between predicted and measured site index using the test data (n = 31). ELE is elevation (m), SC is the subcontinental stratum, M is the maritime stratum, ND and WD are defined in Table 1.

	Regression model	R^2_{adj}	SEE	root-MSPR
Eq. [1]	SI = 34.240 - 0.02105(ELE) + 0.01301(ELE*SC) + 6.0(M) - 11.035(SC)	0.78	3.87	3.73
Eq. [2]	SI = 35.783 - 0.02080(ELE) + 0.01202(ELE*SC) + 4.97(M) - 9.852(SC) - 3.313(ND) - 6.047(WD)	0.84	3.12	2.93

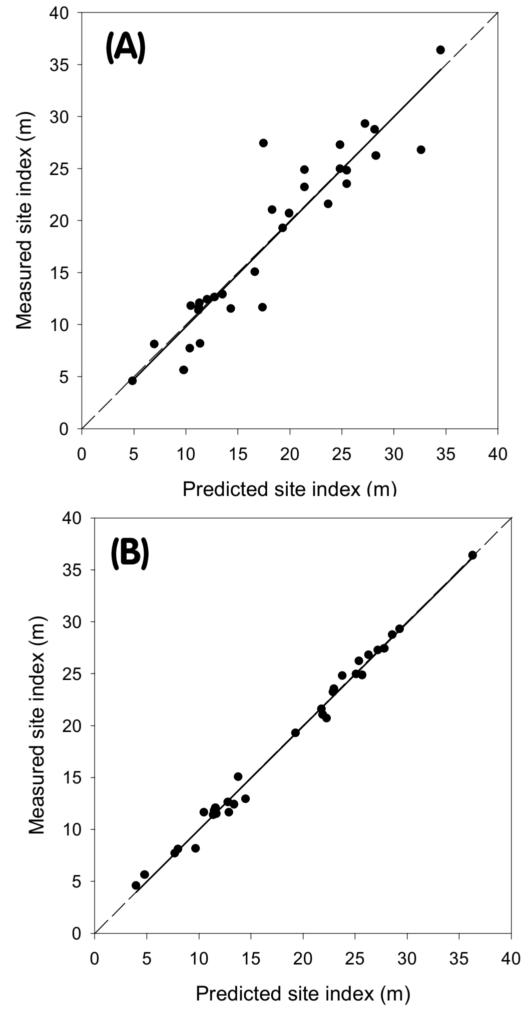

Figure 3. Scattergrams comparing the predicted to measured (from the test data, n = 31) site index using (A) the combined climate-edatope model (Eq. [2]) and (B) the climate-specific site index model that used top height and breast height age as well as continentality strata as predictors. Dashed lines indicate perfect correlation.

Reference

Splechtna, B. 2000. The growth of *Abies amabilis* (Dougl. ex Forbes) in relation to climate and soil in southwestern British Columbia. Ph.D. Dissertation, Forest Sciences Department, University of British Columbia, Vancouver, BC. In progress

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