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Relationships Between Coastal Douglas-fir Site Index and Synoptic Categorical Measures of Site Quality

Introduction

Knowledge of ecological characteristics of trees, sites and tree growth on different sites is fundamental for silvicultural decision-making and planning. With the biogeoclimatic ecosystem classification in place, silvicultural management in British Columbia has been given an ecological foundation; however, relationships between growth and site have not yet been fully investigated. The purpose of this study was to determine how height growth of Douglas-fir within the drier portion of the CWH zone varies with site.

We adopted site index (m @ 50 yr bh) as a species-specific measure of forest productivity, recognizing that it indicates height growth performance at a selected point in time. If forest productivity is correlated with ecological measures of site quality, what site factors should be used to quantify the relationships? Because of compensating effects, the numerous site factors can be reduced to four primary (synoptic) factors that directly affect plant establishment and growth: climate (light and temperature), soil moisture, soil nutrients, and soil aeration (not used in this study).

Materials and Methods

One-hundred and thirty-three plots were located in even-aged immature Douglas-fir stands with a relatively wide age range (18 to 69 yrs) and stocking (400 to 900 stems ha^{-1}), and without a history of damage. All stands had similar management history: slashburning, planting to Douglas-fir, and pre-commercial thinning. The stands were located in the very dry and dry maritime subzones of the CWH zone on Eastern Vancouver Island and the adjacent mainland across a wide range of elevation, aspect, and soil conditions. In each stand, a 20 x 20 m plot was located to represent an individual ecosystem with relatively uniform vegetation and soil. The relative soil moisture regime (SMR) and soil nutrient regime (SNR) of each plot were estimated in the field, and then converted to actual SMRs.

In each plot, the five largest diameter trees of the study species were measured for breast-height age, using an increment borer, and top height, using a clinometer. Site index was taken from height growth tables. On each plot the current year's foliage from the upper crown of 15 dominant trees was sampled and analyzed for total nitrogen. Samples of forest floor and the top 30 cm of mineral soil were taken at each plot, air-dried, and analyzed for a number of nitrogen-related properties. Biogeoclimatic subzone (identified from maps and representing climate), actual SMR, and SNR were used as independent categorical variables in stratification and data analysis. Analysis of variance (ANOVA) and multiple regression analyses were used to examine relationships between site index and climate, actual SMR, and SNR.

Results

Relationship between Site index and Climate

Stratification of study stands by subzones did not indicate any meaningful relationships. By using a soil moisture factor separately from a temperature factor, biogeoclimatic ecosystem classification reduces the role of climate as categorical variable to a temperature factor. Although temperature characteristics of the two study subzones are not the same, their variation is probably too small to exert a significant influence on plant activity via potential evapotranspiration.

Relationship between Site index and Soil Moisture

A strong productivity gradient coinciding with the assumed soil moisture gradient was detected when all study stands (n = 133) were stratified according field-estimated SMRs (Table 1). Douglas-fir site index increased from very dry through moist sites, but the difference between fresh and moist was not significant ($\alpha = 0.05$). The variation of direct (continuous) measures of soil moisture and soil nutrients paralleled this trend but none of them separated the five SMRs from each other.

Table 1. Means and standard deviations (in parentheses) of selected stand and soil characteristics of the study stands stratified according to actual soil moisture regimes. Values in the same row with same superscripts are not significantly different ($p \leq 0.05$; Tukey's test).

Characteristic	Very dry n = 18	Moderately dry n = 56	Slightly dry n = 33	Fresh n = 21	Moist n = 5
Douglas-fir site index	21^{d} (2.5)	27^{c} (2.9)	33^{b} (2.8)	35^{a} (2.3)	36^{a} (1.9)
Actual growing season precipitation (mm)	206^{b} (26)	$219^{a,b}$ (32)	$227^{a,b}$ (32)	$243^{a,b}$ (22)	254^{a} (26)
Water deficit (mm/yr)	97^{a} (48)	$68^{a,b}$ (50)	$39^{a,b}$ (42)	$8^{b,c}$ (13)	0^{c} (11)
Mineral soil (0–30 cm) mineralizable -N (ppm)	6.8^{c} (2.5)	9.8^{c} (4.9)	22.6^{b} (14.0)	27.1^{b} (13.0)	48.0^{a} (30.1)
Foliar N (%)	1.09^{b} (0.13)	1.14^{b} (0.09)	1.20^{a} (0.09)	1.20^{a} (0.09)	1.20^{a} (0.07)
Mass of 100 needles (mg)	434^{b} (44)	480^{b} (67)	501^{b} (64)	497^{b} (82)	636^{a} (102)

Relationship between Site index and Soil Nutrients

Stratification of all study stands according to field-estimated SNRs produced the similar results as for SMRs - a strong productivity gradient coincided with the assumed soil nutrient gradient (Table 2). Douglas-fir site index increased consistently from very poor through very rich sites. The variation in values of direct measures of stand and soil nutrients paralleled this trend, but again none of them separated five SNRs from each other

Table 2. Means and standard deviations (in parentheses) of selected stand and soil characteristics of the study stands stratified according to actual soil nutrient regimes. Values in the same row with same superscripts are not significantly different ($p \leq 0.05$; Tukey's test).

Characteristic	Very poor n = 11	Poor n = 60	Medium n = 39	Rich n = 19	Very rich n = 4
Douglas-fir site index	22^{d} (2.4)	26^{c} (3.7)	32^{b} (2.6)	36^{a} (2.1)	37^{a} (1.4)
Mineral soil (0–30 cm) mineralizable-N (ppm)	7.0^{c} (2.8)	9.5^{c} (4.5)	17.5^{b} (13.5)	31.1^{b} (11.4)	49.6^{a} (37.9)
Foliar N (%)	1.14^{a} (0.06)	1.13^{a} (0.13)	1.19^{a} (0.10)	1.19^{a} (0.15)	1.24^{a} (0.26)
Mass of 100 needles (mg)	470^{b} (61)	469^{b} (69)	479^{b} (64)	552^{a} (87)	610^{a} (28)

Relationship between Site index, Climate, Soil Moisture, and Soil Nutrients

Regression models were developed to quantify relationships between site index and categorical measures of site quality (Table 3) as well as analytical measures of site quality, using actual evapotranspiration or water deficit and mineralizable-N (data not presented). The SMR and SNR models each had strong relationships with site index but the combined SMR & SNR model accounted for the largest proportion of the variation in site index of all models tested. The rate of increase in site index from very dry through moist SMRs was nearly the same as that from very poor through very rich SNRs; however, SMR and SNR were found to exhibit high collinearity. As a categorical variable, biogeoclimatic subzone was found to be significant ($\alpha = 0.05$) but did not improve the performance of any categorical model tested. The models using analytical variables also showed strong relationships with site index. Testing of the models using an independent data set showed that the SMR, SNR, and SMR & SNR models provided the best results compared to analytical models.

Table 3. Models for the regression of Douglas-fir site index (m @ 50 years bh) on soil moisture regimes (SMRs) and soil nutrient regimes (SNRs). All models are significant at $p<0.01$. SEE - standard error of estimates; abbreviations for SMRs: VD - very dry, MD - moderately dry, SD - slightly dry, F - fresh, M - moist; abbreviations for SNRs: VP - very poor, P - poor, M - medium, R - rich, VR - very rich.

[1] SI = 34.6 – 14.0(VD) – 7.7(MD) – 3.0(SD) – 0.01(F) + 0.0(M)
Adjusted $R^2 = 0.74$, SEE = 2.6 m

[2] SI = 35.5 – 13.2(VP) – 9.7(P) – 4.0(M) –0.6(R) + 0.0(VR)
Adjusted $R^2 = 0.66$, SEE = 3.0 m

[3] SI = 35.5 – 7.0(VD) – 1.4(MD) + 0.1(SD) + 3.1(F) + 0.0(M) – 9.4(VP) – 7.4(P) – 4.9(M) – 1.5(R) + 0.0(VR)
Adjusted $R^2 = 0.85$, SEE = 2.0 m

Discussion

Despite a limited representation of certain combinations of SMRs and SNRs (edatopes) in the study, the large amount of variation explained by the models using either categorical or continuous variables suggests the presence of strong relationships between direct as well as indirect measures of ecological measures of site quality. Increases in Douglas-fir site index with decreasing growing-season water deficit and increasing soil nutrient levels were described in other studies, but have not been quantified, particularly over a large area. This study has also given evidence that the mineralizable-N in the mineral soil is a good single measure of a soil nutrient gradient related to potential forest productivity. Insignificant differences in site index between subzones indicated that the two study subzones are climatically equivalent. In consequence, site index - site quality relationships can be examined within the study area without considering a climatic factor. Thus indirect measures (*i.e.*, SMR and SNR) are good estimates of direct measures (water deficit, soil mineralizable-N). In view of difficulties involved in measurements of actual evapotranspiration and nutrient levels in forest soils, it was not surprising to find the performance of the analytical models to be inferior to the categorical models.

The categorical models require only identification of SMR and SNR for each site in a forest without the need for extensive data collection and laboratory analysis. Examination of a few selected topographic and soil properties aided by keys and indicator plant analysis have proved to be an efficient means for identifying ecological quality of forest sites using system of biogeoclimatic ecosystem classification.

Conclusions

There were significant differences in site index and direct measures of soil moisture and nutrients between Douglas-fir stands when stratified according to field-estimated soil moisture and nutrient regimes. Regression models developed showed strong relationships between Douglas-fir site index and field-estimated SMR and SNR. The similarity in the relationships obtained when employing direct measures of soil moisture and nutrients justifies the use of indirect qualitative measures - soil moisture and nutrient regimes - in estimating potential forest productivity within drier cool mesothermal climates of southern coastal BC.

References

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