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The Relationship of Site Index to Synoptic Estimates of Soil Moisture and Nutrients for Western Redcedar (*Thuja plicata*) in Southern Coastal British Columbia

Abstract

We described the pattern of mean site index and the associated variation in site index of western redcedar (*Thuja plicata* Donn. ex D. Don.) in relation to categorical variables of soil moisture and nutrients as identified by the field-procedures of the biogeoclimatic ecosystem classification. Additionally, we compared the site index of western redcedar to that of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.). We sampled 105 plots from stands having western redcedar as the major tree species. The plots were distributed within each of two climates, a drier and a wetter cool mesothermal climate in south coastal British Columbia. Sixty-three plots had both western redcedar and western hemlock available for comparisons. Heights and ages were measured on five dominant trees on a 0.04 ha plot, and the height at a base age of 50 years was calculated to give site index. The highest western redcedar site index occurred on sites identified as having no moisture deficit or excess and high nitrogen availability. Site index decreased on sites identified by field procedures as being outside this optimum moisture and nutrient condition. The mean site index was significantly greater in the drier cool mesothermal climate than the wetter cool mesothermal climate on sites identified as having similar soil moisture and nutrient conditions. Climate appears to have a large effect on site index, therefore, on similar soil conditions the site index of western redcedar may be higher in the southern portion of its range in the United States; and lower in north coastal B.C. and southeastern Alaska. On sites where both western redcedar and western hemlock were sampled, the site index of western redcedar was consistently lower. Based on a northward trend, we may predict that in southeastern Alaska the site index values may be larger for western redcedar compared to western hemlock, while in Washington and Oregon there may be an even greater site index of western hemlock over western redcedar than reported here.

Introduction

Where timber production is the management objective, knowledge of the relationship between the potential productivity of possible tree species to various levels of light, heat, nutrient, moisture and aeration is necessary for decision making on a species- and site-specific basis (Klinka and Feller 1984). For example, foresters need to decide which tree species to use as regeneration for a particular harvested area to obtain maximum sustainable productivity. Similarly, when making decisions whether to apply various silvicultural treatments such as spacing or fertilizing, foresters need to decide whether the potential productivity of a particular site warrants the cost.

In British Columbia, site index (height of specified dominant trees at a reference age, and the most widely accepted indirect estimate of potential forest productivity; Mader 1963; Tesch 1981), is used to develop productivity relationships with site units derived from the biogeoclimatic ecosystem classification (BEC) (Pojar et al. 1987). This classification is currently used as an ecological foundation for all silvicultural activities, and the categorical measures of soil nutrient and moisture conditions have been used to describe and predict site index for Douglas-fir (*Pseudotsuga menziesii*) (Klinka and Carter 1990), western hemlock (*Tsuga heterophylla*) (Kayahara and Pearson 1996) and Sitka spruce (*Picea sitchensis*) (Kayahara and Pearson 1996). These investigations provide a description of mean site index, inferring potential timber productivity, and associated variation in site index for various combinations of soil moisture and soil nutrient conditions. This paper reports the results for western redcedar (*Thuja plicata* Donn. ex D. Don.).

The objectives of this study were to (1) describe the pattern of mean site index and the associated variation in site index of western redcedar in relation to soil moisture and nutrient classes as identified by the field-procedures of the biogeoclimatic ecosystem classification; (2) compare the site index trends for western redcedar between a drier and wetter cool mesothermal climate; and (3) compare the site index of western redcedar to that of western hemlock (*Tsuga heterophylla* (Raf.) Sarg.)

Methods

Study Area

The study sites were located in southern coastal British Columbia (latitude 49°20'N, longitude 122°35' to 123°05'W, elevation 160 to 295 m). Plots were located in dry maritime and wet maritime cool mesothermal climates as delineated by the Dry Maritime and Very Wet Maritime Coastal Western Hemlock subzones (CWHdm and CWHvm respectively) of the biogeoclimatic ecosystem classification (Klinka et al. 1991). The climate of the two areas in this study is characterized by cool wet summers and mild wet winters, although hot dry spells are more frequent in the drier area (CWHdm) (Meidinger and Pojar 1991). Mean annual precipitation is 1827 mm for the drier area (CWHdm) and 2787 mm for the wetter area (CWHvm); the mean annual temperature is 9.8°C for the drier area and 8.2°C for the wetter area (Environment Canada 1982). The stands in both subzones originated from logging during the early 1900's followed by fires. The natural regeneration that followed resulted in relatively extensive areas of even-aged western redcedar stands with a minor component of Douglas-fir and western hemlock. Natural regeneration of a large component of western redcedar after fire is unusual for coastal British Columbia where post-fire regeneration includes primarily Douglas-fir and/or western hemlock.

Sampling and Statistical Analyses

The population sampled consists of all naturally established, unmanaged, immature, even-aged stands with western redcedar as a dominant species which are accessible (500 m on each side of access roads with a 20 m buffer strip adjacent to roads). Potential candidate stands were previously identified by an established map for the drier area (Klinka and Krajina 1986) or by a pre-sample reconnaissance for the wetter area. The study stands ranged widely in age (Table 1) and were uniformly stocked with a relatively uniform, single tree layer which featured dominants of one or both study species. In order to avoid observer bias in choosing sample plots, we walked through the candidate stands, and the first plot meeting the criteria for site index determination (relatively uniform in soil, understory vegetation, and tree layer characters, uniformly stocked without a history of damage or suppression) was chosen for sampling. Results thus apply to the population of all plots meeting the criteria for site index with western redcedar as the dominant species within 500 m of either side of access roads in these two particular areas.

TABLE 1. Range and mean of stand age at breast height (years) and site index (m at 50 years breast height age) of the study stands.

Species Characteristic	Range		Mean
Western redcedar		(n = 105)	
Stand age (years)	37-88		56
Site index (m @ 50 years b.h. age)	13.0-33.8		25.8
Western hemlock		(n = 63)	
Stand age (years)	40-112		56
Site index (m @ 50 years b.h. age)	19.1-36.5		28.8

One hundred and five sample plots 0.04 ha in area (20 m x 20 m) were established in the candidate stands; 42 plots had western redcedar only and 63 plots had in addition to western redcedar a component of western hemlock suitable for site index estimates. The distribution and sample size of the plots is given in Table 2. Topography, understory vegetation, and soils of each sample plot were described using the site diagnosis procedure outlined in Green and Klinka (1994). Sites were identified to one of seven soil moisture regimes (SMR) – classes framed along a soil moisture gradient ranging from sites having a prolonged water deficit (very dry) to sites having no water deficit (fresh) to sites having a water excess (wet) – and one of five soil nutrient regimes (SNR) – classes framed along a soil nutrient gradient ranging from sites having low amounts of available nitrogen (very poor) to sites having high amounts

TABLE 2. Distribution and sample size of study stands by species and biogeoclimatic subzone.

	Subzone		
Species	CWHdm	CWHvm	Total
Western redcedar	35	70	105
Western hemlock	19	44	63

of available nitrogen (very rich). The combination of SMR and SNR forms a cell on an edatopic grid (see Table 3 for an example). Identification of SMR and SNR was based on a heuristic synthesis of topographic and soil morphological properties, augmented by indicator plant analysis (Klinka et al. 1989).

In each sample plot, the five largest diameter trees of each of the study species with no obvious evidence of growth abnormalities and damage were measured for age at breast height, using an increment borer, and height, using a clinometer. Site index was taken from height growth tables of Kurucz[1] reported in Mitchell and Polsson (1988) for western redcedar and Wiley (1978) for western hemlock.

For western redcedar, the mean, 95% confidence intervals for the mean, standard deviation, and 95% confidence intervals for the standard deviation (using a χ^2 statistic) were calculated for each subzone and each combination of the SMR and SNR, and summarized on an edatopic grid. For comparison of the two subzones, the mean site index of the plots having the same SMR/SNR combinations were tested for differences using a t-test. A comparison of site index between western redcedar and western hemlock utilized the subset of 63 plots where both species were measured on the same plot. The Pearson correlation was used to relate the site index of the two species and a paired comparison t-test was used to test for differences between the means. The difference in site index of each species on the same plot was calculated and summarized.

Results

In both subzones, the maximum site index occurred on sites identified by field procedures as having no moisture deficit or excess and high nitrogen availability (moist/rich sites). Site index decreased on sites identified as having (1) either an inferred moisture deficit (very, moderately, or slightly dry SMR) or moisture excess (very moist, wet, and very wet SMR), and (2) inferred less nitrogen availability (very poor, poor, medium SNR) (Tables 3 and 4). The estimated population variation in site index associated with various combinations of SMRs and SNRs indicated that although the estimated standard deviation was small, the confidence intervals were large for most cells on the edatopic grid. The mean site index was significantly greater ($p < 0.05$) in the CWHdm subzone compared to the CWHvm subzone on most sites with the same SMR/SNR combination (slightly dry/medium, fresh/medium, moist/medium, moist/rich). Significant differences were not detected on the very moist/rich combination.

Comparisons of the site index of western redcedar and western hemlock growing on the same plot showed: (1) the Pearson correlation coefficient was 0.82; (2) the mean site index for western redcedar was 26.3 m and for western hemlock 28.8 m, and the means were significantly different ($p < 0.001$); and (3) on only one of the 63 plots the site index of the two species was the same, and on only seven of the plots the site index of western redcedar was greater than western hemlock (Figure 1).

Discussion

Due to a small sample size, the results reported here should be considered as preliminary until a larger data base is collected. However, in the meantime until such a data base is generated, operational needs must be addressed. Thus for operational use we present estimates of mean and standard deviation, and respective 95% confidence intervals of measured site index for various combinations of SMR and SNR for two subzones (Tables 3 and 4). For preliminary use in areas south and north of the vicinity of Vancouver, users should consider the influence of even a small difference in climate on the site index of western redcedar growing on the same soil conditions. Therefore, on similar soil conditions site index of western redcedar may be higher in the southern portion of its range in the United States and considerably lower in north coastal B.C. and southeastern Alaska.

A larger sample size is necessary in some cases to gain a more precise estimate of the population mean, and in most cases to gain a more precise estimate of the population standard deviation. However, extensive even-aged stands of western redcedar are rare in British Columbia. Where the sample size is five or greater, the mean estimates are relatively precise, the mean confidence intervals being generally less than one meter, with a few exceptions. However, for sample sizes less than five there is a dramatic loss of precision with relatively large confidence intervals. Although estimates of the population standard deviation were

Actual soil moisture regime	Soil nutrient regime				
	very poor	poor	medium	rich	very rich
very dry	13.4±5.4 0.6 0.3 – 19.1 n = 2				
moderately dry		22.2±7.2 0.8 0.4 – 25.5 n = 2			
slightly dry		24.4±0.6 0.5 0.3 – 1.4 n = 5	26.7±1.4 0.9 0.5 – 3.4 n = 4		
fresh			29.7±0.8 1.0 0.7 – 1.9 n = 9		
moist			30.3±2.7 1.1 0.6 – 6.9 n = 3	32.2±3.5 1.4 0.7 – 8.8 n = 3	29.0 n = 1
very moist				29.1±1.5 0.6 0.3 – 3.8 n = 3	32.0 n = 1
wet			16.5 n = 1	25.4 n = 1	

TABLE 3. Mean site index (m @ 50 years breast height age), ±95% confidence interval (m), standard deviation (m), 95% confidence interval for the standard deviation (m), and sample size for each combination of SMR and SNR for western redcedar in the dry maritime Coastal Western Hemlock (CWHdm) subzone.

Actual soil moisture regime	Soil nutrient regime				
	very poor	poor	medium	rich	very rich
very dry					
moderately dry					
slightly dry		20.9 n = 1	22.0±6.3 0.7 0.3 – 22.3 n = 2	24.8±0.5 0.2 0.1 – 1.3 n = 3	
fresh		23.0±0.6 0.5 0.3 – 1.4 n = 5	24.7±0.8 0.8 0.5 – 2.0 n = 6	26.2±0.7 0.8 0.5 – 1.8 n = 7	
moist			26.3±0.6 0.5 0.3 – 1.4 n = 5	28.3±0.5 1.0 0.7 – 1.5 n = 16	
very moist		21.8 n = 1	25.2 n = 1	27.9±1.6 1.7 1.1 – 3.7 n = 7	27.5±0.6 0.5 0.3 – 1.4 n = 5
wet			17.8±1.9 2.1 1.4 – 4.6 n = 7	22.5±0.5 0.2 0.1 – 1.3 n = 3	26.2 n = 1

TABLE 4. Mean site index (m @ 50 years breast height age), ±95% confidence interval (m), standard deviation (m), 95% confidence interval for the standard deviation (m), and sample size for each combination of SMR and SNR for western redcedar sampled in the very wet maritime Coastal Western Hemlock (CWHvm) subzone.

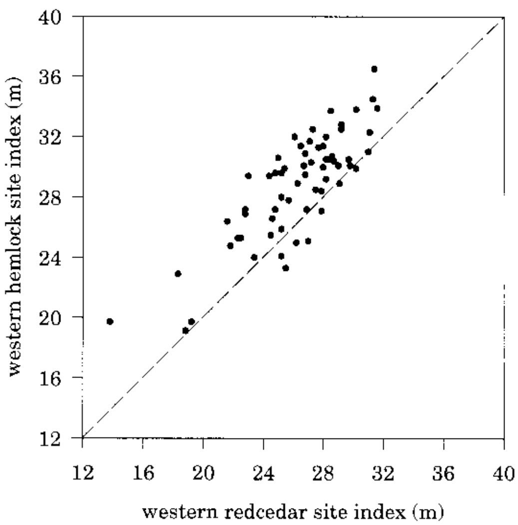

Figure 1. Site index comparisons between western redcedar and western hemlock (n = 63). The dashed line represents a line of equal site index.

generally less than 1.5 m, and all less than 2.0 m (Tables 3 and 4), the upper confidence interval showed that the population variation could be much more, and again especially where the sample size is less than five. At present if users wish to know the consistency of the estimate of site index on an individual site basis, the upper confidence value on the estimate of the population standard deviation may make such an inquiry less reliable.

A shortfall of this study lies in the identification of SMR and SNR from field measurable properties rather than directly with soil chemical measures. However, during the development and refinement of the edatopic grid concept, SNR classes were derived from actual soil chemical measures (Courtin et al. 1984; Kabzems and Klinka 1987; Klinka and Carter 1990), and SMR classes were derived from a water balance model (Klinka and Carter 1990; Wang and Klinka 1996). Further, Klinka et al. (1994) have demonstrated a relationship between the field-derived SNRs with measures of soil nitrogen in the central interior of British Columbia.

For forest management scenarios where timber production is the primary objective, practitioners may consider that the site index of western redcedar was consistently less than western hemlock for western redcedar values from 13.8 to 31.6 m. However, unlike intraspecific comparisons of site index, interspecific comparisons can not be extrapolated to comparisons of productivity. The values are to be used in a growth and yield model to generate comparative productivity between the two species. The consistently lower site index for western redcedar compared to western hemlock differs from that of the Queen Charlotte Islands in B.C. (53°N latitude), where Green (1989) found the site index of western redcedar to be greater than western hemlock at site index values between 11 and 19 m, and the same between 19 and 24 m. Based on this northward trend, we may predict that in southeastern Alaska the site index values will be larger for western redcedar over western hemlock, while in Washington and Oregon the site index of western hemlock will be larger than western redcedar by an amount even greater than reported here.

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