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Trembling Aspen Site Index in Relation to Environmental Measures of Site Quality

Introduction

Trembling aspen (*Populus tremuloides* Michx.) is one of the most common tree species in the boreal and temperate forests of North America. It grows on many different sites and associates with a variety of tree species. In BC, aspen is frequent throughout all submontane and montane continental forested zones. Relationships between environmental factors and forest productivity have been the subjects of many studies. Most of these studies, using various topographic, soil, physical and chemical properties as independent variables, had limited success in accounting for the variation in SI over a large geographic area. The objectives of this study were (1) to quantify relationships between aspen SI and environmental factors at two spatial scales, and (2) to develop predictive SI models from easily measurable environmental factors.

Study Stands and Methods

Study stands were deliberately selected to capture the widest range of climatic, soil moisture, and soil nutrient conditions supporting aspen growth throughout BC. 142 plots were situated in naturally established, unmanaged, fully stocked, even-aged aspen stands older than 50 years @ 1.3 m on a variety of sites across BC in the BWBS, SBS, ICH, MS, IDF, and ICH zones. Each plot, 20 x 20 m in size, was uniform in stand and environmental characteristics.

Biogeoclimatic maps were used to identify the subzone in which each plot was located. Topographic maps were used to identify the latitude and longitude of each plot; elevation was measured with an altimeter, and aspect with a compass. Soil and vegetation were described at each study site. Site index (SI) for each plot is calculated as the average top height of the sampled trees at breast-height age 50, with top height calculated from stem analysis data.

Study stands were stratified according to selected variables of site quality, and one-way analysis of variance and Tukey's test were used to detect differences in SI among the strata. To predict SI from environmental measures, multiple regression models were developed. SI was individually regressed on climatic (spatial) variables (latitude, longitude, elevation, and zone), topographic variables (aspect, slope gradient), and edaphic variables (soil moisture and nutrient regimes). Then topographic and edaphic measures were combined with climatic variables in an all-factor model to test whether climatic variables improve the model's predictive power.

Results and Discussion

Effect of spatial (climatic), topographic, and edaphic gradients on site index

Aspen SI varied from a minimum of 5.5 m, on a moderately dry, nutrient-poor site on a ridge crest in the BWBS zone, to a maximum of 30.7 m, on a moist, very rich site, on a flat in the ICH zone. On zonal sites, mean SI was the highest in the ICH and MS zones (21 and 23 m, respectively), and the lowest in the BWBS and SBS zones (17 and 16.5 m); SI in the IDF zone was intermediate (19 m) (p <0.0001) (Figure 1).

As the pattern of the influence of environmental factors on SI varied with spatial scale, we examined productivity - site relationships at two spatial scales: (1) **provincial**, including the data from all 6 zones and (2) **zonal** (regional), including data specific to each of the 6 zones. Relationships between SI and climate surrogates (longitude, latitude, and elevation) differed with spatial scale. On zonal sites, at the provincial scale, SI decreased with increasing longitude and latitude, but no relationship between SI and elevation was found (Figure 2). At the zonal scale, SI decreased with increasing longitude in the

BWBS and IDF zones, but not in the MS, SBS, and ICH zones. It also decreased with increasing latitude in the BWBS, IDF and MS zones, but not in the SBS and ICH zones (Figure 3). With increasing elevation, SI decreased in the BWBS and MS zones, but increased in the IDF and ICH zones, while no change was detected in the SBS zone (Figure 3).

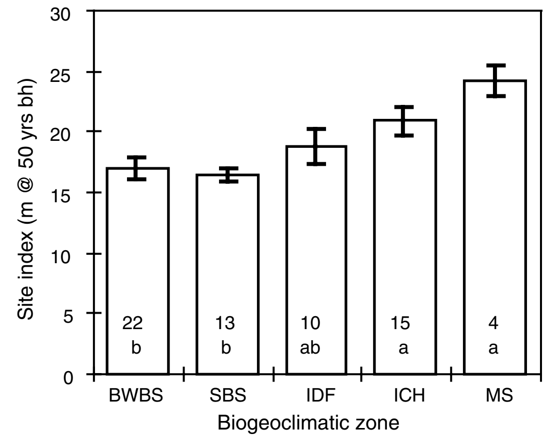


Figure 1. Mean site index of aspen on zonal sites in relation to biogeoclimatic zones. Error bar represents one standard error of the mean; numbers in the bases of bars are the numbers of plots; different letters in bars indicate significant difference in site index between zones (p <0.05).

Figure 2. Scattergrams and fitted regression lines of aspen site index on zonal sites in relation to (A) longitude (SI = 93.468 – 0.610 (LON), $R^2 = 0.41$, SEE = 3.50, $p < 0.0001$), (B) latitude (SI = 54.012 – 0.660 (LAT), $R^2 = 0.24$, SEE = 3.95, $p < 0.0001$), and (C) elevation (SI = 16.699 + 0.002 (ELE), $R^2 = 0.0$, SEE = 4.56, P = 0.425).

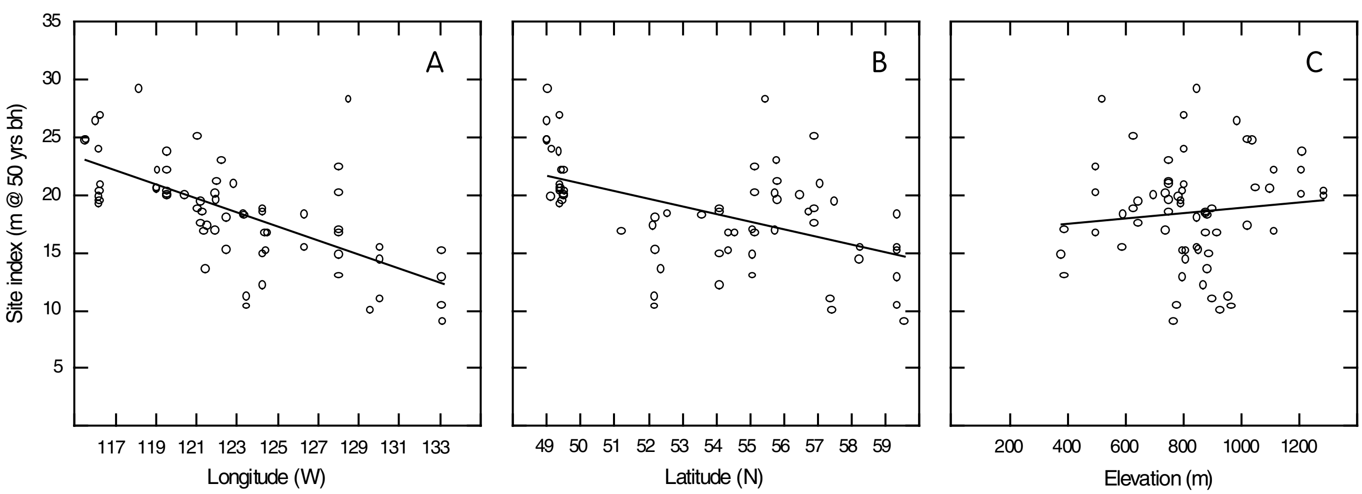
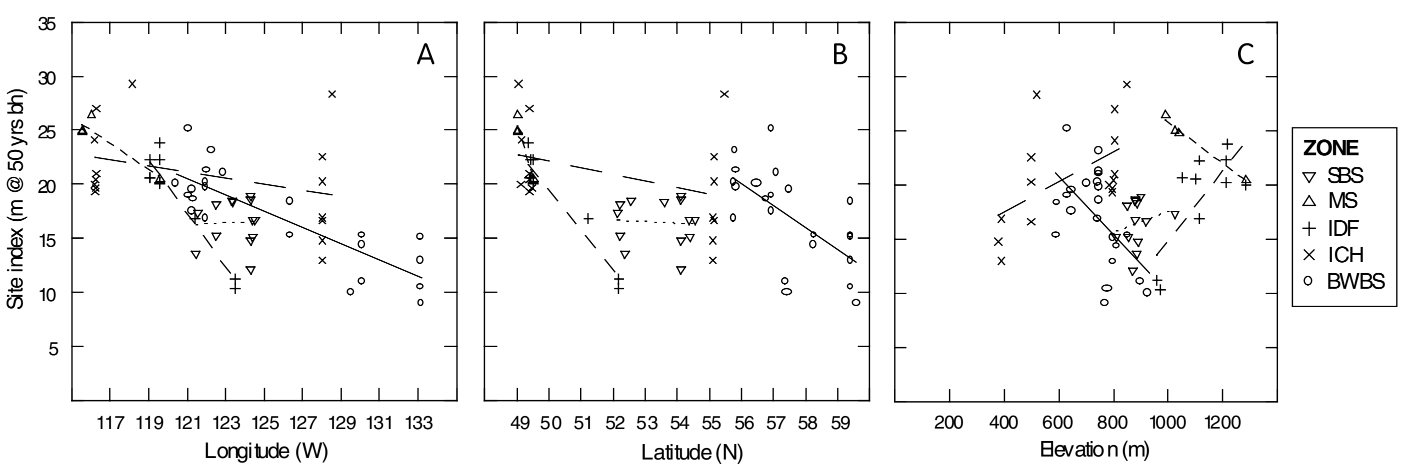


Figure 3. Scattergrams and fitted regression lines of aspen site index on zonal sites in relation to (A) longitude, (B) latitude, and (C) elevation. Regression lines were developed for each biogeoclimatic zone.



The effect of aspect on SI varied among zones. In the BWBS zone SI was lower on north-aspect slopes than on south-aspect slopes; the opposite was found in the MS and ICH zones, while aspect had no effect on SI in the SBS and IDF zones. A similar relationship was observed in relation to drier and wetter portions (subzones) of study zones. On north-aspect slopes, SI in drier climates were significantly higher than in wetter climates, while the opposite trend was observed on the south-aspect slopes. This implies that SI is affected by complex interactions, and compensatory effects among latitude, elevation, and slope-aspect determine differences in the length of growing season and soil moisture conditions on a particular site.

SI varied greatly with edatope at the provincial scale (Table 1). On slightly dry and fresh sites, SI increased from 7.8 m on very poor sites to 18.5 m on very rich sites. On medium and rich SNR sites, SI increased from 13.7 m on moderately dry sites, to 23.9 m on moist sites, and then decreased to 16.1 m on very moist sites. At the zonal scale, the relationships between SI and SMR and SNR were consistent with those at the provincial level.

Table 1. Mean aspen site index, standard error (in parentheses), and sample size for each soil moisture regime (SMR) - soil nutrient regime (SNR) combination. Different superscript letters indicate significant differences in site index values in rows (Tukey's test; p <0.05).

	VP	P	M	R	VR
VD	14.8 n = 1		13.1 n = 1		
MD	12.6 n = 1	16.3^{a} (4.97) n = 8	13.8^{b} (4.81) n = 16	13.4^{b} (5.68) n = 6	
SD	7.8^{c} (0.94) n = 6	13.6^{b} (5.68) n = 14	16.9^{ab} (5.09) n = 13	17.3^{ab} (4.84) n = 19	19.4^{a} (1.13) n = 2
F		15.1^{b} (3.12) n = 6	18.7^{a} (2.80) n = 13	19.9^{a} (4.17) n = 14	17.8^{ab} (6.72) n = 3
M		10.2 n = 1	25.1^{a} (2.09) n = 4	23.3^{a} (4.55) n = 9	26.2^{a} (3.93) n = 3
VM			12.2 n = 1	20.0 n = 1	

Site index predictions

At the provincial scale, although significant ($\alpha = 0.05$), multiple linear regression models based on individual environmental factors explained little of the variation in aspen SI (12%< R^2 <37%). When spatial (latitude, longitude, elevation) gradients were combined with slope-aspect, predictive power was increased (R^2 = 52%); however, the spatial gradients combined with edatope explained still more variation (R^2 = 61%).

Since the zone gives an ecologically meaningful pattern of regional climates across the province and spatial gradients reflect general climatic trends, further regression models were developed by nesting measured environmental factors within zones. The nesting of spatial gradients, slope-aspect, and edatope within zones resulted in models with high accountability of SI variation (Table 2). From a practical point of view, Eqs. [1] and [2] are especially useful because they allow relatively precise SI predictions based on information that can be easily obtained from maps (*i.e.*, latitude, longitude, elevation, zone, and slope-aspect).

The model combining all measured variables nested within zones (Eq. [3], Table 2) accounted for 81% of SI variation, markedly exceeding that of any other model; however, predictors varied with zones. In the BWBS zone, SI in the BWBS zone decreased with increasing elevation, decreasing soil nutrients and moisture, and on the northern and western slopes. In the SBS zone a weak, positive relationship between SI and elevation was observed, likely due to the drier climate of the area where sampling was conducted. In the IDF zone, decreases in aspen SI were associated with increasing latitude and with the southern slope-aspect, and the most productive growth occurred on slightly dry (the 'wettest' sites supporting aspen growth in this zone) and very rich sites. In the MS zone SI was the lowest on water-deficient sites and south-aspect slopes, and the highest on nutrient very rich sites. SI on north-aspect slopes in the MS zone were higher than that on south-aspect slopes, due to the reduced angle of solar incidence and decreased summer temperatures and soil water deficit. Flat topography in the ICH zone is associated with increased SI, likely due to the enhanced capacity of these sites to retain water relative to slopes. The all-variable zone model (Eq. [3]) is recommended when all environmental factors within zone are inexpensively obtained, or when the value of increased model precision is greater than the cost of obtaining appropriate predictor data.

Table 2. Zone-specific prediction models for aspen site index at the zonal scale. ELE - elevation, LAT - latitude, LON - longitude; N - north, E - east, S - south, W - west, R - ridge, F - flat; SEE - standard error of the estimate.

No.	Predictor	Model
[1]	Zone; spatial gradients	SI = 16.9511 + BWBS × [2.3011 (LAT) – 1.0725 (LON)] + IDF × [-7.4875 (LAT) + 3.1224 (LON)] + MS × [-14.7737 (LAT) + 7.0683 (LON) – 0.0858 (ELE)] + ICH × [-4.6229 (LAT) + 2.0057 (LON)] Adjusted R^2 = 0.58, SEE = 3.70, p <0.0001
[2]	Zone; slope-aspect	SI = 16.5897 + (BWBS) × [-3.7219 (N) - 8.7921 (RG) - 3.5586 (W) – 4.3651 (STR)] + (IDF) × [3.9371 (E) - 6.6050 (RG) - 7.0756 (W)] + (MS) × [9.4117 (E) + 10.4150 (F) + 8.7259 (N)] + (ICH) × [10.9098 (F) + 9.6138 (N) + 4.2418 (S)] Adjusted R^2 = 0.58, SEE = 3.69, p <0.0001
[3]	Zone; all-predictors	SI = [29.4764 – 0.0191 (ELE) - 7.3582 (VP) - 2.1196 (P) – 3.5947 (N) – 2.6742 (W) + 3.1232 (F - BWBS × SMR) + 6.2063 (M - SMR)] + SBS ×[-10.9565 + 0.0311 (ELE)] + IDF ×[21.7516 – 4.0038 (LAT) + 2.1517 (SD - SMR) + 5.6432 (VR) – 6.4011 (S)] + MS ×[24.2986 – 4.3168 (MD - SMR) + 3.9359 (R) + 2.7436 (N) – 5.2927 (S)] + ICH × [12.5709 + 0.0109 (ELE) + 4.6104 (M - SMR) + 5.3712 (F)] Adjusted R^2 = 0.81, SEE = 2.50, p < 0.0001

Conclusions

Aspen SI varied (1) along spatial gradients (latitude, longitude, and elevation), used as surrogates for climate, and with (2) zone, each delineating a regional climate, (3) slope-aspect, (4) actual soil moisture regime, and (5) soil nutrient regime. The pattern of variation and the strength of relationships between SI and environmental factors, however, varied with spatial scale, specifically with climate. The variation in SI followed unique trends depending on the climatic conditions of each zone. At the provincial scale, these relationships were weaker than on the zonal (regional) scale. High-elevation, north-aspect slopes compensate for relatively warm climates at low latitudes, while low-elevation, south-aspect slopes compensate for relatively cool climates at high latitudes. Aspen SI is predictable across a large area from a combination climatic (spatial), slope-aspect, edatope variables.

Reference

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