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Leader Damage in White Spruce Site Trees in Northeastern British Columbia

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Gordon D. Nigh

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ABSTRACT

Anecdotal information suggests that damage in leaders of white spruce (*Picea glauca* (Moench) Voss) is less in the Boreal White and Black Spruce (BWBS) biogeoclimatic zone than was found in a previous study in the Interior Cedar-Hemlock (ICH) and Sub-Boreal Spruce (SBS) zones. The purpose of this project was to confirm or refute this assertion. Forty-six 0.01-ha stem analysis plots were established in managed stands in the BWBS zone and data from those plots were combined with data collected previously from the ICH and SBS zones. The stem of one sample tree per plot was split, and the heights of the nodes demarcating the ends of the annual height growth were measured. Leader damage was noted. The height growth model that was fit to the ICH/SBS data was based on the combined data set. Indicator variables allowed the parameter estimates of the model to vary across the two projects. The analysis indicated that the effect of damage on height growth was the same for both the ICH/SBS and BWBS data, but the growth parameters were different. There were fewer incidents of damage in the BWBS data than in the ICH/SBS data. This should result in less biased site indices in the BWBS zone than in the ICH and SBS zones.

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1 INTRODUCTION

Previous research in the northwestern Interior Cedar-Hemlock (ICH) and Sub-Boreal Spruce (SBS) biogeoclimatic zones (Meidinger and Pojar 1991) of British Columbia shows that leader damage in white spruce (*Picea glauca* (Moench) Voss) site trees is extensive and causes site index to be underestimated (Nigh 2017a). The height growth of a site tree is intended to reflect the productivity of a site; hence, site trees should be undamaged. However, leader damage in many site trees escapes detection when selecting the tree because the damage has been overgrown by radial stem growth, which effectively obscures the damage. Similar damage is also found in the leaders of lodgepole pine (*Pinus contorta* var. *latifolia* Dougl. ex. Loud.) (Nigh 2017b). Anecdotal information suggests that the amount of damage may not be as great in the northeastern part of British Columbia—that is, the Boreal White and Black Spruce (BWBS) biogeoclimatic zone (Meidinger and Pojar 1991)—as it is in the ICH and SBS zones. The purpose of this study was to provide evidence to support or refute the assertion that there is less leader damage in the BWBS zone than in the ICH and SBS zones, and to determine if the effect of leader damage on height growth is the same in the BWBS zone as in the SBS and ICH zones.

2 DATA

The stem analysis data for this study came from two sources. The first source was for the ICH and SBS zones and was the data set used in Nigh (2017a). The other source was stem analysis data for the moist cool, moist warm, and wet cool subzones of the BWBS zone. Details about the ICH/SBS stem analysis data collection are provided in Nigh (2017a) but are identical to the methods for the BWBS data, which are described next.

Forty-six 0.01-ha site index plots were established in managed stands in the BWBS zone that were regenerating with white spruce. Stands between 10 and 40 years of age at breast height (1.3 m) were targeted for sampling. A walk-through of the stand was performed to identify possible site trees. Site trees have height growth that reflects the potential productivity of the site. The characteristics of a site tree are that they must be the largest-diameter tree in a 0.01-ha plot, be dominant or co-dominant, and be free of suppression, damage, and insect or disease attack (B.C. Ministry of Forests and Range 2009).

The selected site trees were sampled by first felling the tree at breast height. The limbs of the tree were then removed, and the stem was split longitudinally to reveal the pith. Pith nodes, which are scars in the pith that demarcate the end of annual height growth every year, were identified, and their height above breast height was recorded along with any leader damage. The observed damage was exclusively crooks (bends in the stem due to damage) and was identified by irregularities in the normal growth pattern of the pith. The data were converted into height–breast height data by adding 1.3 m to the heights and determining the breast height age at each node. The first node above breast height had a breast height age of 1, the second had a breast height age of 2, and so on.

The number of incidences of leader damage in site trees in the BWBS zone was summarized. The percentage of damaging events per tree in the BWBS was compared to that in the ICH/SBS study. The amount of leader damage in the two regions was compared using histograms of the percentage of nodes that were damaged by age class and height class.

The ICH/SBS data and the BWBS data were combined and the same height growth model that was fitted in Nigh (2017a) was fitted to the combined data set to evaluate whether the effect of damage on height growth in the BWBS zone was similar to the effect found in the ICH/SBS zones. The height growth model was based on the Chapman-Richards function, and it tested three different hypotheses about the effect of damage on height growth. This model was modified slightly to test whether the variation in the parameters between the two study areas was statistically significant at a 0.05 significance level. The modified model is:

$$hg_{ij} = D_{ij} \times (a_0 + \Delta a_0 \times \mathrm{BWBS}_i + b_{0i}) \times (a_1 + \Delta a_1 \times \mathrm{BWBS}_i) \times (a_2 + \Delta a_2 \times \mathrm{BWBS}_i + b_{2i}) \times e^{-(a_1 + \Delta a_1 \times \mathrm{BWBS}_i) \times A_{ij}} \times (1 - e^{-(a_1 + \Delta a_1 \times \mathrm{BWBS}_i) \times A_{ij}})^{(a_2 + \Delta a_2 \times \mathrm{BWBS}_i + b_{2i}) - 1} + \varepsilon_{ij}$$

where the subscripts index site tree (i) and observation within tree (j), hg_{ij} is annual height growth (m/yr), a_0, a_1, a_2, Δa_0, Δa_1, and Δa_2 are model parameters, A_{ij} is breast height age (yr), b_{0i} and b_{2i} are random effects, D_{ij} is a modifier to account for the effects of leader damage on height growth, BWBS_i is an indicator variable that takes on the value of 1 if tree i is from the BWBS zone; 0 otherwise, and ε_{ij} is the random error term with the usual regression assumptions (Sen and Srivastava 1990). The random effects parameters b_{0i} and b_{2i} had tree as the subject and were assumed to be multivariate normally distributed with a mean of 0 and with unstructured variances and covariance. These variances and covariance were estimated along with the other parameters. Variable BWBS_i allowed the model to have different values for parameters a_0, a_1, and a_2, for the ICH/SBS and BWBS zones. If parameters Δa_0, Δa_1, and/or Δa_2 were not significantly different from 0, then parameters a_0, a_1, and/or a_2, respectively, were common across both regions of the province.

The following three hypotheses were tested:

(H1) Height growth is affected by the most recent leader damage within the current year and last 2 years, but the effect is contingent upon how long ago the event occurred.
(H2) Height growth is affected by leader damage in the current year and last 2 years, and the effect accumulates multiplicatively.
(H3) Height growth is affected by leader damage in the current year and last 2 years, and the effect accumulates additively.

Variable D_{ij} was formulated as follows to test these three hypotheses:

$$\text{H1:}\quad D_{ij} = \begin{cases} d_0 + \Delta d_0 \times \mathrm{BWBS}_i \text{ if the latest damage occurred in the current year} \\ d_1 + \Delta d_1 \times \mathrm{BWBS}_i \text{ if the latest damage occurred in the previous year} \\ d_2 + \Delta d_2 \times \mathrm{BWBS}_i \text{ if the latest damage occurred 2 years ago} \end{cases}$$

$$\text{H2:}\quad D_{ij} = (d_0 + \Delta d_0 \times \mathrm{BWBS}_i) \times (d_1 + \Delta d_1 \times \mathrm{BWBS}_i) \times (d_2 + \Delta d_2 \times \mathrm{BWBS}_i)$$

$$\text{H3:}\quad D_{ij} = 1 + (d_0 + \Delta d_0 \times \mathrm{BWBS}_i) + (d_1 + \Delta d_1 \times \mathrm{BWBS}_i) + (d_2 + \Delta d_2 \times \mathrm{BWBS}_i)$$

where d_k, $k = 0, 1$, or 2 was the change in height growth due to damage that occurred in either the current year ($k = 0$), the previous year ($k = 1$), or 2 years previously ($k = 2$); Δd_k, $k = 0, 1$, or 2 were parameters that were similar to d_k but represented the difference in the change in growth due to damage between the ICH/SBS zones and the BWBS zone; and BWBS_i was an indicator variable, as described for model (1). For hypotheses 1 and 2, $d_k = 0$ and $\Delta d_k = 0$, $k = 0, 1$, or 2 if no damage occurred in the current year, the previous year, or 2 years previously, respectively. For hypothesis 3, $d_k = 0$ and $\Delta d_k = 0$, $k = 0, 1$, or 2 if no damage occurred in the current year, the previous year, or 2 years previously, respectively. If d_k, $k = 0, 1$, or 2 was not significantly different from 1 (or 0 for hypothesis 3) at $\alpha = 0.05$, then there was no effect of damage on leader growth for that year, and d_k was set to 1 (or 0 for hypothesis 3), which effectively removed that parameter from the model. If Δd_k, $k = 0, 1$, or 2 was not significantly different from 0 at $\alpha = 0.05$, then there was no significant difference in the effect of damage on leader growth between the ICH/SBS zones and BWBS zone, and Δd_k was removed from the model. The fitting was done with procedure NLMIXED in SAS (SAS Institute Inc. 2011).

The residuals (estimates of the ε_{ij}) were tested for meeting the usual regression assumptions (Sen and Srivastava 1990). The mean of the residuals was compared to 0 with a *t* test, a plot of the residuals against breast height age was tested for homoscedasticity, the Kolmogorov-Smirnov KS test and q–q plots were used to test for normality, and serial correlation was tested by tree using the Durbin-Watson statistic (Sen and Srivastava 1990). Since multiple comparisons were made for serial correlation, the Holm step-down Bonferroni adjustment was made to the *p* values for these tests (Bretz et al. 2011). Statistical tests were conducted at $\alpha = 0.05$.

4 RESULTS

Table 1 presents the percentage of sample trees from the BWBS zone that had stem leader damage by the number of incidences of damage; that is, the number of times a site tree had experienced leader damage. The data for the ICH/SBS zones are also presented for comparison. There was less leader damage in sites trees in the BWBS zone than in the ICH/SBS zones. This is evident in histograms of the percentage of nodes with damage by age class and height class for the ICH/SBS and BWBS zones (Figure 1). The BWBS zone had a smaller percentage of nodes with damage in each age class and height class than did the ICH/SBS zones. The percentage of nodes with damage in the ICH/SBS zones was variable across the age and height classes, but no trend was discernable. However, there was a downward trend in the percentage of nodes with damage as age and height increased beyond approximately 20 years and 10 m, respectively, in the BWBS zone.

The results of the analyses for the three hypotheses are presented in Table 2. This table contains the parameter estimates and their standard errors, and the Akaike Information Criterion (AIC) (Burnham and Anderson 2002).

TABLE 1 *Number of incidents of damage per tree as a percentage of the total number of trees sampled in the Boreal White and Black Spruce (BWBS) biogeoclimatic zone. The breast height age range of the trees is also presented. The same information for the Interior Cedar-Hemlock (ICH)/ Sub-Boreal Spruce (SBS) zones data is shown for comparison.*

	BWBS		ICH/SBS	
No. incidences of damage	% of trees	Age range (yr)	% of trees	Age range (yr)
0	15.2	(13–30)	5.2	(10–29)
1	21.7	(14–32)	10.4	(11–21)
2	23.9	(15–33)	15.7	(12–39)
3	21.7	(15–31)	16.5	(15–38)
4	8.7	(16–32)	15.7	(15–38)
5	6.5	(22–37)	14.8	(15–42)
6	–	–	5.2	(19–35)
7	–	–	5.2	(22–33)
8	–	–	3.5	(31–39)
9	2.2	(20)	2.6	(21–28)
10	–	–	0.9	(30)
12	–	–	3.5	(24–36)
15	–	–	0.9	(60)

TABLE 2 *Parameter estimates and their standard errors and Akaike's Information Criterion (AIC). The Var and Cov functions are the variances and covariances of the parameter(s) in the parentheses. Parameter* Δa_2 *was not significantly different from 0* ($\alpha = 0.05$) *and was removed from the model.*

	Hypothesis 1		Hypothesis 2		Hypothesis 3	
Parameter	Estimate	Standard error	Estimate	Standard error	Estimate	Standard error
a_0	31.09	1.078	31.03	1.071	30.98	1.069
Δa_0	−4.489	1.537	−4.450	1.533	−4.412	1.531
a_1	0.03113	0.001359	0.03121	0.001359	0.03122	0.001360
Δa_1	0.004593	0.001940	0.004535	0.001938	0.004502	0.001937
a_2	1.537	0.03093	1.538	0.03092	1.538	0.03091
d_0	0.7097	0.009991	0.7200	0.009791	−0.2756	0.009646
d_1	0.9348	0.01149	0.9427	0.01071	−0.05246	0.01018
d_2	0.9719	0.01244	0.9709	0.01097	−0.02598	0.01039
$\mathrm{Var}(\varepsilon_{ij})$	0.01121	0.0002817	0.01121	0.0002817	0.01122	0.0002820
$\mathrm{Var}(b_{0i})$	15.69	2.651	15.62	2.638	15.54	2.626
$\mathrm{Cov}(b_{0i}, b_{2i})$	0.3419	0.1011	0.3430	0.1010	0.3418	0.1007
$\mathrm{Var}(b_{2i})$	0.04482	0.007408	0.04469	0.007390	0.04460	0.007379
AIC	−5229	–	−5230	–	−5228	–

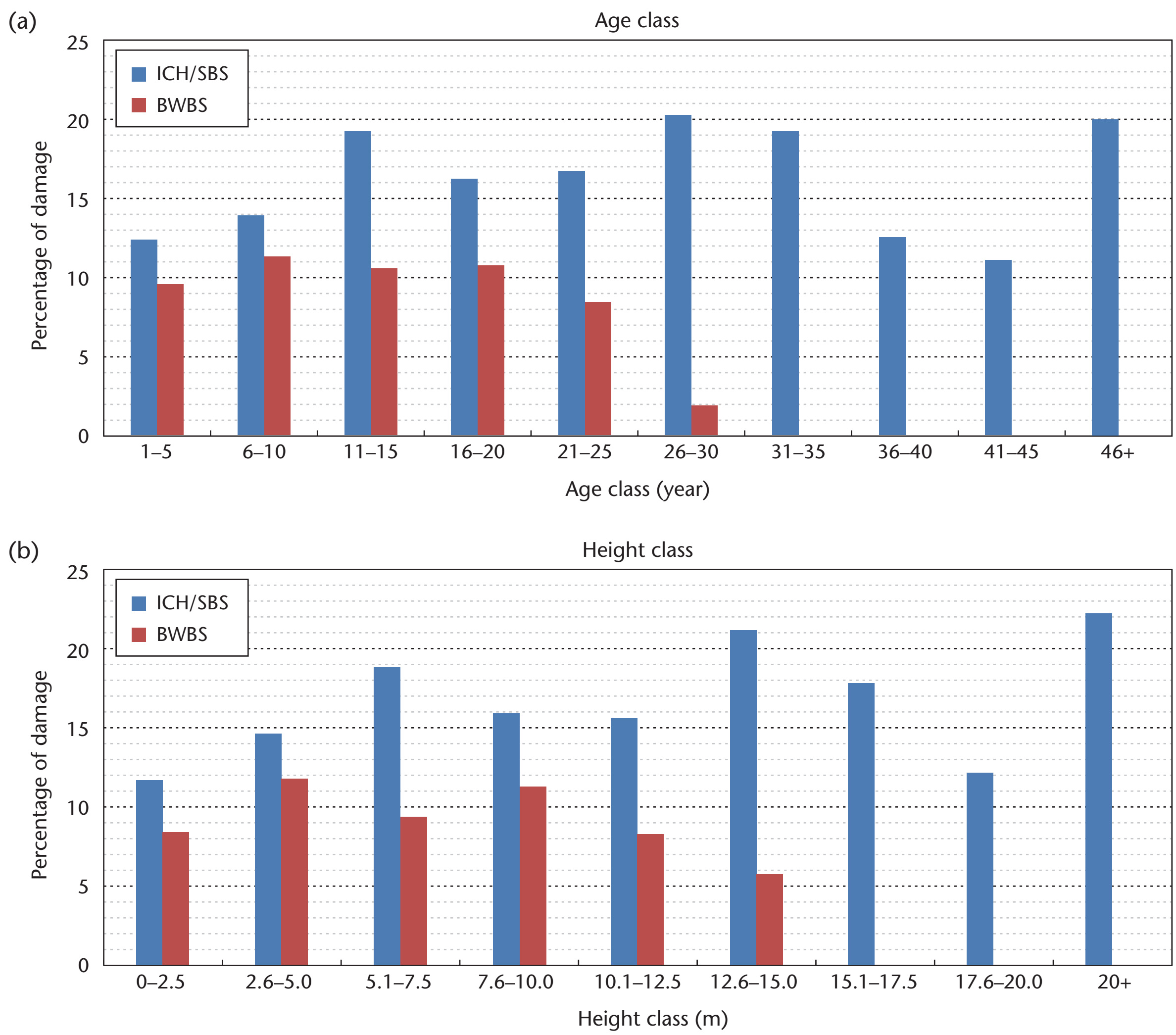

FIGURE 1 *Percentage of nodes with leader damage by (a) 5-year age class and (b) 2.5-m height class (Interior Cedar-Hemlock [ICH]/Sub-Boreal Spruce [SBS], Boreal White and Black Spruce [BWBS] biogeoclimatic zones).*

There was no evidence of heteroscedasticity or serial correlation for the three analyses. The KS statistic for all three analyses indicated that the residuals may not be normally distributed. However, the q–q plots indicated only very minor departures from normality for all the analyses. Therefore, the regression assumptions were believed to have been adequately met.

5 DISCUSSION

The proportion of site trees with no leader damage in the BWBS zone was greater than that in the ICH/SBS zones (Table 1). It is also evident that there were fewer incidents of damage in site trees in the BWBS zone than in the ICH/SBS zones. It is not possible to definitively explain why this is without knowing which biotic or abiotic agent was causing the damage. However, it seems likely that insects or late frosts that occurred after budbreak caused the damage (Nigh 2017a). Speculatively, less damage may be occurring in the BWBS zone because late frosts occur less frequently or the colder temperatures result in fewer insect attacks.

The testing of the three hypotheses showed that when the BWBS and ICH/SBS data were combined, the three mechanisms regarding the effect of leader damage on height growth were about equally likely, as indicated by the AIC. Parameters d_0, d_1, and d_2 indicated that there was approximately a 28% reduction in height growth in the year of the damage event, a 6% reduction in the year following the damage event, and a 3% reduction 2 years after the damage event. Height growth was unaffected more than 2 years after the damage event. Parameters Δd_0, Δd_1, and Δd_2 allowed the height growth modifier D_{ij} to vary by region. Since these parameters were not significantly different from zero ($\alpha = 0.05$), there was no evidence that the effect of leader damage on height growth was any different in the BWBS zone than in the ICH/SBS zones at the individual tree level. Given that the effect of leader damage on height growth was the same in both regions but there was less damage in the BWBS zone, the site indices from site trees in the BWBS should more accurately reflect potential site productivity than do site indices in the ICH/SBS zones.

Parameters a_0 and a_1 varied by region. Parameter a_0 is the asymptote, and it was smaller by approximately 4.5 m in the BWBS zone than in the ICH/SBS zones. Parameter a_1 is related to the rate of growth. Since parameter Δa_1 was positive, it indicated that site trees grow slightly faster in the BWBS zone than in the ICH/SBS zones. It should be noted, however, that the sample trees from both projects were young. Consequently, these parameter estimates may not be applicable for evaluating the height growth of older site trees. As well, the focus of this work and the study in the ICH/SBS zones was on site trees because those trees are critical to the estimation of site index. Therefore, these results apply only to site trees. Other trees may experience different amounts of damage, and the damage may affect height growth differently.

6 CONCLUSION

This study bears out the anecdotal observation that there is less leader damage to white spruce site trees in the BWBS biogeoclimatic zone than in the ICH/SBS biogeoclimatic zones. However, the effect of leader damage on height growth was the same in the two regions. The site index estimates from site trees in the BWBS zone should more accurately reflect potential site productivity than in the ICH/SBS zones due to fewer damaging events.

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