FOREST MANAGEMENT NOTE

Note 57 *Northwest Region*

COMPETITION INDEX FOR JUVENILE MIXED STANDS OF LODGEPOLE PINE AND ASPEN IN WEST-CENTRAL ALBERTA

Regeneration surveys in the boreal mixedwood forests containing trembling aspen (*Populus tremuloides*) have indicated that many conifer-regenerated areas are reverting to hardwood and mixedwood stands (Samoil 1988). A survey of juvenile stands on 11- to 20-year-old conifer cutovers throughout Alberta has shown that 66% of the cut blocks changed from predominantly conifers to predominantly hardwoods or mixedwoods,[1] confirming that heavy aspen competition is the major limiting factor in coniferous growth.

The increased component of aspen on mixedwood and lodgepole pine (*Pinus contorta*) cut blocks is caused by both root suckering and natural seeding. On lodgepole pine cut blocks in west-central Alberta, sucker regeneration resulting from the root system of a single aspen tree could cover up to 0.05 ha, and the density of aspen seedlings on 5- to 16-year-old lodgepole pine cut blocks ranged from 1000 to 42 00 stems/ha (Navratil 1991).

To improve juvenile conifer regeneration, performance expectations for juvenile conifers have been incorporated into the new free-to-grow regeneration standards for Alberta,[2] and similar standards are being considered for adoption by other jurisdictions in the prairie region.[3] Sizable conifer release programs are implemented annually in the prairie region to bring regenerated stands to provincially targeted standards. Selecting stands for the best response to and economic return from release treatments is difficult because of the high cost of treatment and limited information available on biological efficacy. Current treatment decisions are generally subjective or arbitrary, and foresters therefore require quantitative tools to assist in these decisions.

The objective of this study was to select or develop a competition index for quantifying the level of aspen competition that could best predict lodgepole pine growth. An index was required that would be both easy to use in the field and applicable to release decisions. This study is part of a larger Forestry Canada project aimed at formulating competition models for juvenile mixed stands in the prairie region.

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[1] Transcript of talk, March 26, 1991, by C.J. Henderson to the 72nd annual meeting of the Canadian Pulp and Paper Association, Woodlands Section, held in Montreal, Quebec.

[2] Unpublished report, 1990, by Reforestation Branch, Alberta Forest Service.

[3] Personal communication, May 1991, from L. Yarn, Forestry Branch, Manitoba Natural Resources.

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MEASUREMENT OF INTER-SPECIFIC COMPETITION

Various methods have been developed to characterize interspecific competition (i.e., competition between plants of different species). Interspecific competition indexes are often simple and based on easy-to-measure variables, although more complex ones such as those developed by Brand (1986) do exist. Measured variables constitute either stand characteristics or individual competitor and crop tree measurements, or a combination of both. Stand characteristics can include density, percent cover, amount of overtopping by surrounding vegetation, and light interference (Mugasha 1989; MacDonald et al. 1990; Salonius et al. 1991). Individual crop tree-to-competitor measurements may include 1) size ratios of competitor to crop tree, and 2) competitor distance and dispersion around the crop tree.

To date there are no known competition indexes available for the specific assessment of competition in aspen–lodgepole pine regeneration. Furthermore, lodgepole pine and aspen are both shade-intolerant (Burns and Honkala 1990) and their competitive interactions are probably different from those of other combinations of shade-tolerant and shade-intolerant species. For these reasons, a number of competition indexes were tested for possible selection in quantifying competition levels.

FIELD SAMPLING

Data used in the study were collected in the summers of 1989 and 1990 from young mixed lodgepole pine–aspen stands in west-central Alberta, between Grande Prairie and Rocky Mountain House. The sample sites were all on well-drained soils with a subxeric-to-mesic moisture regime; they were located in the Upper and Lower Boreal Cordilleran ecoregions (Corns and Annas 1986) at elevations between 915 and 1200 m. Twenty plots were sampled in each cut block, based on a 40-m survey grid. At each grid point a 1.8-m-radius circular plot (10 m^2) was established around the nearest lodgepole pine tree (i.e., crop tree); a pine tree with recognizable damage such as browse was replaced in the survey by the closest undamaged pine.

In each sample plot, all aspen trees were measured for height, quadrant direction (NE, SE, SW, NW) from crop pine, stem-to-pine stem distance, closest crown edge-to-pine stem distance, and farthest crown edge-to-pine stem distance. The crop pine and the tallest and closest aspen were also measured for root collar diameter and height increments (through internode counts). Crop pine crown radius was estimated from an average of two measurements. Stem disk samples were taken at ground level. General site characteristics (i.e., slope, aspect, elevation, soil drainage, and texture) were recorded for each cut block. In the laboratory, annual radial increment and total age were determined from the stem disks.

ANALYSIS

Data from each cut block were randomly split into two subsets: the first (373 plots) for model building, and the second (145 plots) for model validation. This analysis is based on the first subset.

Based on a literature review and on preliminary work by Navratil et al. (1990), four pine growth response variables, four single competition variables, and six competition indexes were selected for the analysis. Pine growth response variables used in the analysis were height, basal area, height increment, and basal area increment. Single competition variables consisted of aspen density, percent aspen cover, total tree density, and percent total tree cover. Five of the competition indexes of this analysis were selected from the literature: Braathe (1989: page 270), Brand (1986: pages 25–26), Wagner and Radosevich (1987: page 26), Daniels (1976: page 456), and Lorimer (1983: page 358). In some cases a modified version of the published competition index was used to conform to the characteristics of sampled species and stands, and also to correspond to affordable data collection.

Competition Index Formulation

In the formulation of all competition indexes used in this analysis, aspen competition is related to a single crop pine tree in a 1.8-m-radius (10 m^2) plot, and the subscript i indicates individual tree measurements for the competitor aspen. The n values differ between competition indexes because not all published indexes include all the aspen stems in the plot. In the appropriate competition indexes, basal diameter refers to the stem diameter measured just above the root collar.

Braathe (eq. 1) and Brand (eq. 2) use all aspen stems in the plot to formulate the competition index (CI):

$$[1] \quad CI = \sum_{i=1}^{n} \frac{aspen_i \ height - pine \ height}{aspen_i \ stem \ to \ pine \ stem \ distance}$$

$$[2] \quad CI = \frac{avg \ aspen \ height}{pine \ height} \times \left(\frac{avg \ aspen \ stem \ to \ pine \ stem \ distance}{pine \ crown \ radius} + 1 \right)^{-1} \times \% \ aspen \ cover$$

Wagner and Radosevich (eq. 3), in the extensive model 22, use the aspen stem closest to the crop pine in the plot:

$$[3] \quad CI = \frac{\% \ aspen \ cover}{(distance \ to \ closest \ aspen \ stem)^2}$$

Daniels (eq. 4) and Lorimer (eq. 5), both cited by Mugasha (1989), use both the tallest aspen and the aspen closest to the crop pine in the plot:

$$[4] \quad CI = \sum_{i=1}^{n} \frac{\left(\frac{aspen_i \ basal \ diameter}{pine \ basal \ diameter} \right)}{aspen_i \ stem \ to \ pine \ stem \ distance}$$

and

$$[5] \quad CI = \sum_{i=1}^{n} \frac{aspen_i \ basal \ diameter}{pine \ basal \ diameter}$$

The sixth competition index, or "Basal Diameter (BD) Ratio" (eq. 6), was developed for this analysis by the authors. It is a simplification of Lorimer's competition index because it uses only the tallest aspen stem in the plot:

$$[6] \quad CI = \frac{tallest \ aspen \ basal \ diameter}{pine \ basal \ diameter}$$

All competition indexes were calculated for the previous year's conditions by subtracting the most recent height and radial increments, because the regression models for predicting pine growth are designed to predict current year's growth based on previous year's competition.

Correlations

A Spearman rank-order correlation (r_s) analysis (Zar 1984) and a ranking method modified from Mugasha (1989) were used to correlate the four pine growth response variables with the six competition indexes and four single competition variables. The all-possible-regressions procedure (Neter et al. 1989) was used to determine which of the competition variables accounted for a significant proportion of the variation in the pine growth response. The final form and parameter estimates of the regression model were selected on the basis of highest coefficient of determination (r^2), most homogeneous variance, and lowest relative mean square residual. In support of this study, further analyses (not reported here) were conducted to determine the effects on the aspen–pine competition relationship of aspen density, lodgepole pine density, and stem-to-stem distance and location (in cardinal quadrants) of the tallest aspen within the plot (Navratil and MacIsaac n.d.).

SELECTION OF BEST COMPETITION INDEX

In the comparison of competition indexes shown in Table 1, the BD Ratio competition index had the highest ranking and most significant correlation with the four pine growth response variables. Lorimer's competition index was consistently second in the ranking, with significant correlations ($P < 0.001$) and slightly lower absolute r_s values (Table 1), followed by the competition indexes of Daniels and Braathe. Single competition variables such as aspen density and percent aspen cover did not perform well in the correlation ranking (Table 1). Absolute r_s values were usually less than 0.30 and the relationships less significant ($P > 0.01$ in some cases) when compared to most of the competition indexes.

A Spearman's correlation analysis of the relationship between the BD Ratio and lodgepole pine growth showed the significant, strongly negative correlations for all pine growth response variables in all lodgepole pine age groups tested (5–7, 8–10, 11–13, and 14–16 years). Additional analyses were conducted to alleviate a concern that the high correlation ranking of the BD Ratio was influenced by the inclusion of crop pine basal diameter in the index. These analyses confirmed that even when other pine growth variables were taken into account, the BD Ratio had a higher coefficient of determination (r^2) than some competition indexes that did not include these variables (Navratil and MacIsaac n.d.).

The BD Ratio not only had the best correlations in this analysis but also required fewer field measurements than Lorimer's competition index,

Table 1. Ranking of Spearman's rank-order correlation (r_s) of competition indexes and single competition variables using lodgepole pine growth variables

Lodgepole pine growth variable	Competition index (CI) or variable	Correlation (r_s)[a]
Height (cm)	Basal Diameter (BD) Ratio CI	–0.65***
	Lorimer CI	–0.62***
	Daniels CI	–0.54***
	Braathe CI	–0.52***
	Aspen density	–0.26***
	% tree cover	–0.18***
	Tree density	–0.17***
	Wagner CI	–0.16**
	Brand CI	–0.16**
	% aspen cover	–0.06
Basal area (cm^2)	BD Ratio CI	–0.83***
	Lorimer CI	–0.79***
	Daniels CI	–0.70***
	Braathe CI	–0.64***
	Aspen density	–0.31***
	Wagner CI	–0.26***
	Brand CI	–0.26***
	Tree density	–0.24***
	% aspen cover	–0.19***
	% tree cover	–0.01
Height increment (cm)	BD Ratio CI	–0.57***
	Lorimer CI	–0.55***
	Braathe CI	–0.47***
	Daniels CI	–0.45***
	Aspen density	–0.24***
	Brand CI	–0.19***
	Wagner CI	–0.17***
	Tree density	–0.15**
	% aspen cover	–0.14**
	% tree cover	–0.01
Basal area increment (cm^2)	BD Ratio CI	–0.79***
	Lorimer CI	–0.75***
	Daniels CI	–0.67***
	Braathe CI	–0.61***
	Aspen density	–0.30***
	Wagner CI	–0.27***
	Brand CI	–0.27***
	Tree density	–0.24***
	% aspen cover	–0.22***
	% tree cover	–0.05

[a] Significance levels: *** = P < 0.001; ** = P < 0.01; based on 373 competition plots.

which had the second best ranking. Consequently, the BD Ratio was selected for use both in the regression models for predicting pine growth and in the estimation of competition thresholds[4] that cause changes in the following year's growth.

Competition Effects

Lodgepole Pine Height Growth

Pine height increments were not affected at the levels of competition resulting in BD Ratio competition index values of 1.5 and 2.0 for lodgepole pine age groups of 5-10 and 11–16 years, respectively (Fig. 1). Competition levels associated with larger BD Ratio values resulted in a decrease in pine height growth of about 20%, with a corresponding unit increase in BD Ratio value.

The competition thresholds producing reductions in pine height growth were relatively high. In practical terms and as suggested by BD Ratio values, on plots where lodgepole pine height growth was significantly reduced, pine diameter was found to be less than half that of aspen. This finding also suggests that pine height growth is relatively insensitive to aspen competition, and it explains the frequent incidence of lodgepole pines with spindly tree form growing under high competition levels.

In the regression model analysis (not shown), the BD Ratio accounted for only 31% of the variation in pine height growth. Because of the weak height-predicting capability of the regression model and the observed great variations in pine height and height increment, it appears that, for lodgepole pine, height growth alone has limited value in quantifying threshold competition levels and consequently in guiding stand tending decisions.

Lodgepole Pine Radial Growth

The relationship of BD Ratio and pine basal area increment was more pronounced than that of BD Ratio and pine height increment. The regression model derived from the BD Ratio accounted for 51 and 55% of the variation in pine basal area increment for lodgepole pine age groups of 5–10 and 11–16 years, respectively (Fig. 2). The BD Ratio and pine basal area increment relationship approximated a negative hyperbolic curve. This curve showed a sharp decrease in the response variable corresponding to increasing BD Ratio values, with no apparent plateau to indicate a competition threshold at low competition levels. The steep slope between BD Ratio values of 0.5 and 1.5 indicated the high sensitivity of pine radial growth to these competition levels; it also suggested that maximum pine radial growth occurs at the competition levels found at BD Ratio values of less than 0.75.

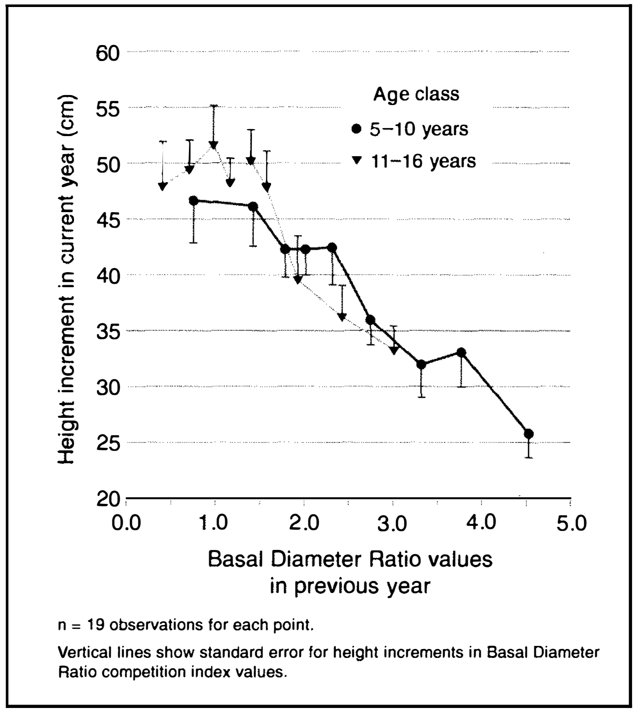

Figure 1. Lodgepole pine height increment over Basal Diameter Ratio competition index.

To verify competition effects on pine radial growth, the mean basal area increments were calculated for five arbitrary BD Ratio competition index classes. The basal area increment of a range of BD Ratio values from 0.25 to 0.75 was used, both as an estimation of the pine growth rate that was presumably either unaffected or slightly affected by aspen competition and as an estimation of relative pine growth losses (Table 2).

From the calculated and model-predicted reductions in basal area increment, it was evident that the range of competition between BD Ratio values of 0.5 and 1.0 was critical in causing decline in pine radial growth: as values increased from 0.5 to 1.0, increased competition levels represented growth losses in mean pine basal area of about 45 and 33% for lodgepole pine age groups of 5–10 and 11–16 years, respectively (Table 2). Stand tending

[4] Competition threshold is defined as a level of competition at which there is an abrupt increase or decrease in the rate of change of a growth response (Simard 1990). It can be estimated from a curve depicting the competition and growth relationship.

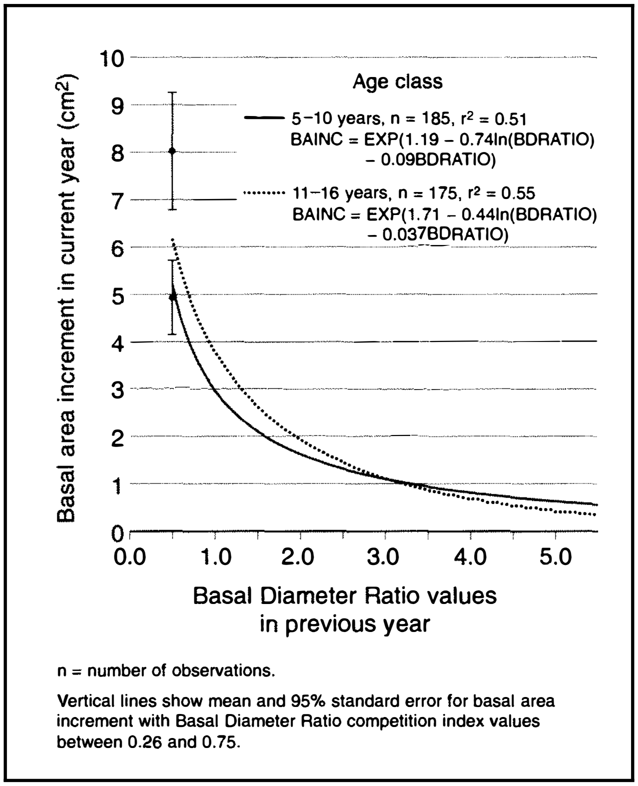

Figure 2. Lodgepole pine basal area increment over Basal Diameter Ratio competition index.

treatments should therefore be directed toward reducing competition before these critical levels are reached; treatment should be implemented before the BD Ratio value reaches 0.75.

Lodgepole Pine Form

For most tree species, shoot growth has a higher priority in photosynthetic allocation than radial growth. As a result, cambial growth of trees under competition is reduced in favor of height growth; one of the first signs of competition is an increase in height-diameter ratios. Increased height-diameter ratios in turn result in the reduced resistance of such trees to wind and snow damage when released from competition. The height–diameter ratio—a slenderness coefficient—has been widely used to estimate the risk of snow and wind damage in coniferous stands in Europe (Abetz 1976; Konopka et al. 1987). As observed in this study and estimated from the BD Ratio values, the increase in slenderness coefficient with increasing competition suggested that aspen competition strongly influenced lodgepole pine form and that the BD Ratio competition index has potential use in estimating lodgepole pine stability after release from aspen competition.

Sensitivity of Basal Diameter Ratio Competition Index and Competition Model to Stand Characteristics

Lodgepole Pine Age

When the regression model based on the BD Ratio was applied to the two lodgepole pine age groups (5–10 and 11–16 years), there were some differences in the shape of the curve. The relationship between pine basal area and BD ratio was stronger for the older age group than for the younger (Fig. 2).

Aspen Density

The regression model form based on the BD Ratio was unchanged over the range of aspen density in this study. The predictive ability of the model improved as aspen density increased, as indicated by a gradual increase in r^2 values: from $r^2 = 0.40$ in the 1000–2000 trees/ha class to $r^2 = 0.67$ in the 9000–42 000 trees/ha class. The BD Ratio competition index can therefore be used for this range of aspen density.

Lodgepole Pine Density

Pine density ranged from 3000–6000 and 4000–6600 trees/ha for lodgepole pine age groups of 5–10 and 11–16 years, respectively. Regression analyses that included pine density and pine cover variables indicated no significant effects from intraspecific (pine–pine) competition on the observed competition and growth relationships (Navratil and MacIsaac n.d.).

Distance Between Lodgepole Pine and Aspen Trees

Correlation of pine growth and distance from the crop tree to the tallest and closest aspen was usually not significant; if significant, the relationship was weak. Furthermore, the inclusion of inter-tree distance in the regression models was of little value in estimating either pine height increment or basal area increment. When the regression model was tested on lodgepole pine samples stratified by distances either greater than 100 cm or less than 100 cm, the form of the model was again unchanged (MacIsaac and Navratil n.d.). In conclusion, the BD Ratio competition index is not dependant on

Table 2. Actual and predicted lodgepole pine basal area increments by Basal Diameter Ratio competition index groups

Basal Diameter (BD) Ratio index values	Basal area increment					
	5–10 years			11–16 years		
	Actual		Predicted from model[c]	Actual		Predicted from model
	Mean[a]	n[b]		Mean	n	
0.25 – 0.75	4.9 a	6	5.3	8.1 a	28	6.3
0.76 – 1.25	2.7 b (–45%)[d]	11	3.0 (–43%)	5.4 b (–33%)	42	3.8 (–39%)
1.26 – 1.75	2.8 b	25	2.1	4.0 bc	41	2.6
1.76 – 2.25	2.1 bc	37	1.6	1.8 cd	18	1.9
2.26 +	1.0 c	105	Not predicted	1.1 d	55	Not predicted

[a] Comparison of means using Hochberg's (1974) GT2-method, where $\alpha = 0.05$.
[b] n = sample size (number of competition plots).
[c] Model form: LNBAINC(t) = a + b*BD Ratio(t-1) + c*LN(BD Ratio(t-1)).
[d] Number in brackets is the percentage of reduction between BD Ratio index values 0.26–0.75 and 0.76–1.25.

distance from crop pine to aspen within the fixed plot radius of 1.8 m.

Aspen Position and Shading Effect

It was possible to assess the potential effect of aspen shading by comparing the strength of the competition relationship in different quadrants (i.e., NE, SE, SW, or NW) of a plot, depending on the location of the tallest aspen in the plot. The relationship was unchanged for each quadrant, indicating that aspen position appears to have no effect on the regression model for the BD Ratio competition index.

CONCLUSIONS

The objective of this study was to develop a competition index for lodgepole pine and aspen,[5] based on measures that were easily obtained and simple to use. These criteria eliminated measures such as multivariable measurements, destructive sampling, and time-consuming tree aging.

The new BD Ratio competition index satisfies the criteria of accessibility and efficacy and offers several advantages:

1. The index does not require aspen-to-pine distance measurements. The tallest aspen on the 1.8-m-radius circular plot can be easily recognized, and basal diameter measurements of only a few trees are required.
2. The index may be easily interpreted for use in stand tending guidelines. Any aspen within 1.8 m of the crop pine stem (based on stem-to-stem distance) with a basal diameter greater than 75–100% of the crop pine's basal diameter should be removed, regardless of aspen-to-pine distance.
3. The index can be used for the wide range of aspen and lodgepole pine densities covered in this study.
4. The index is age-independent for the two tested lodgepole pine age classes (5–10 and 11–16 years).
5. The index requires data from only a limited number of plots. In this study, sample data from 15–20 plots were adequate to describe competition on 10-ha areas of cut blocks; additional plots did not improve the coefficient of determination (r^2).

This study did not include actual release response assessment: lodgepole pine growth responses must be confirmed by field experiments. Nevertheless, the study results indicate that lodgepole pine should benefit from the removal of major aspen competitors within a 1.8-m radius. These results lend additional support to the crop tree-based and the competition-removal definition of free-to-grow performance criteria established in the Alberta regeneration standards. Results show that basal diameter increments are more responsive to competition and a better indicator of growth losses than height measurements. For this reason,

[5] It should be noted that the BD Ratio competition index was developed for lodgepole pine–aspen regeneration in west-central Alberta. It cannot be used for other species and/or regions unless validated for them.

diameter should be used in preference to height when defining free-to-grow performance standards and evaluating the efficacy of release treatments for lodgepole pine. The results also show that aspen within a 1.8-m radius of a crop pine influence lodgepole pine growth, which suggests that the definitions of free-to-grow zones may need to recognize stem-to-stem distances appropriate to different tree species and age classes.

Study results show that individual tree-based competition measures using an estimator such as the new BD Ratio competition index can be very useful in vegetation management prescriptions. Results indicate that concentrating release treatments around individual lodgepole pine crop trees rather than completely removing aspen may be an efficient way to improve conifer growth while at the same time maintaining aspen growth and area productivity. To test these stand tending practices, stand development after release will require further monitoring.

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