

## Competition Dynamics in Juvenile Boreal Hardwood-conifer Mixtures

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### Abstract

There are concerns about the shift from conifer to mixedwood regeneration in young stands in the Prairie provinces. Aspen and balsam poplar rapidly outgrow spruce and pine and can seriously affect the growth and survival of associated conifers in these regenerating stands. The Canadian Forest Service has conducted three studies in Alberta and Manitoba to quantify the relationship between conifer growth and broadleaf competition levels to assist in stand-tending decision making. These studies are of Alberta lodgepole pine-aspen, Alberta white spruce-broadleaf, and Manitoba conifer-broadleaf mixtures. Results from the three studies are presented. The basal diameter ratio competition index is shown to be most appropriate for the lodgepole pine-aspen in Alberta. Height and distance thresholds were developed for the Manitoba conifer-broadleaf sites. For the Alberta white spruce-broadleaf study, the effects of the spatial distribution of competitors is described. The effects of neighbouring competition on conifer tree growth are discussed along with the development and potential applications of competition indices in mixedwood forests.

### Introduction

Throughout the western boreal mixedwood forests, trembling aspen (*Populus tremuloides* Michx.) and balsam poplar (*P. balsamifera* L.) often dominate regenerating stands. On sites planted to spruce and pine, these fast-growing broadleaf species often negatively affect both the growth rate and survival of the associated conifers. For example, historically up to two-thirds of white spruce (*Picea glauca* [Moench] Voss) plantations in the region have reverted to mixedwood or broadleaf status (Brace and Bella 1988). While it is desirable to manage for conifer-broadleaf associations on these mixedwood

sites, maintaining a sufficient conifer component is a difficult problem in the Prairie provinces. The trembling aspen and balsam poplar competition is seen as one of the major factors limiting coniferous growth in these regenerating stands.

Recent free-to-grow standards developed in Alberta (Alberta Forest Service 1990) and other jurisdictions reflect this concern by incorporating acceptable conifer growth standards, such as a required minimum height for 7–14-year-old seedlings, in their regulations. Conifer release programs are being implemented to bring regenerated stands to the targeted standards. However, selecting stands that are most economical to tend and will have the best potential for good conifer post-treatment response is difficult because of limited information on biological efficacy. Treatment decisions have been (in some cases) arbitrary and quantitative tools are required by foresters to assist in these decisions.

Research scientists with the Canadian Forest Service (CFS) have conducted a series of studies that aim to quantify the effects of broadleaf competition on growth of major commercial conifer species in Alberta and Manitoba, specifically lodgepole pine (*Pinus contorta* Loudon), jack pine (*P. banksiana* Lamb.), white spruce, and black spruce (*P. mariana* [Mill.] BSP). This paper presents some results about the effects of neighbouring competition on conifer tree growth and the effects of site conditions on these interactions. It also gives a brief discussion of the development and potential applications of competition indices in mixedwood forests.

### Concepts of Conifer-broadleaf Competition

In boreal aspen mixedwood forests in the Prairie region, there appears to be a critical period in stand development between 5 and 15 years after harvest (the actual age depending on the site),

during which the conifer component often declines. This decline in conifer growth may be associated with the crown closure of the broad-leaved competitors. Several studies suggest that conifer response to increasing broadleaf competition is species specific and differs for survival, height growth, and diameter growth (e.g., Carter and Klinka 1992; Klinka et al. 1992). For shade-intolerant species such as pine, under increasing competition (shade) levels, radial growth declines before height growth. This is manifested in the elevated height:diameter ratios of spindly stemmed, etiolated lodgepole pine growing under these conditions (Navratil and MacIsaac 1993). For moderately shade-tolerant conifers such as white spruce, height growth is suppressed while the growth of laterals is somewhat maintained. This produces a short seedling with a relatively large crown surface. While the spruce may survive under very low light levels (Sims et al. 1990), their low rate of radial increment makes them susceptible to stem clipping by herbivores or to damage from vegetation press or falling debris.

### Retrospective Neighbourhood Approach

The new free-to-grow standards are based on the concept of a "competition neighbourhood" around a target conifer tree. At this scale, individual tree-based models of competition and growth can be developed. In many cases, microsite effects may be more important than the observed above-ground competition effects and can be incorporated into these neighbourhood models.

Neighbourhood competition analysis has been used to estimate the effects of neighbouring vegetation on tree growth and survival (e.g., Simard 1990; Wagner and Radosevich 1991a, 1991b; Comeau et al. 1993). This approach is useful in situations where species "A" negatively affects the growth of species "B," but species "B" has a lesser or no detrimental effect on the growth of species "A" (described as "asymmetric competition" by Pacala and Weiner [1991]). Because of the rapid growth of young broadleaved trees compared to conifers on boreal mixedwood sites, the above-ground competition is asymmetric in these situations. Neighbourhood analysis is an efficient approach, as it concentrates the study on the species of interest.

**Competition Indices** Several methods have been proposed for describing interspecific competition (between plants of different species) and for estimating the magnitude of its effects. The objective of our studies was to develop or select competition indices which best quantified the relationship between aspen or broadleaf competition and conifer growth response. These indices had to be applicable to release decisions and readily applied in an operational setting.

Interspecific competition indices are based on either stand characteristics, or individual competitor and target tree measurements, or a combination of both. Stand measures can include density, percent cover, amount of overtopping by surrounding vegetation, and light interference (Mugasha 1989; MacDonald et al. 1990). Neighbourhood measurements may include: size ratios of competitor to target tree, competitor size, and distance and dispersion around the target tree. Competition is usually measured within a specific distance from the target tree, using either fixed or variable radius plots.

Most competition indices developed for mixed-wood regeneration are individual-tree centred, and describe "neighbourhood competition" adjacent to the target (crop) tree. They may be distance dependent (spatial) or distance independent (non-spatial), extensive (one measure, many plots) or intensive (many measurements, fewer plots), and based on plotless or fixed/variable radius plots. Competition indices incorporate a wide variety of information on the attributes of neighbouring vegetation. Examples include: available growing space around the target tree, crown, or adjusted crown overlap; competitor tree density or basal area; diameters or distances of neighbouring trees; and measured or inferred shade by competitors (e.g., light transmittance or height ratios). Comprehensive reviews of competition indices, as well as discussions on their utility can be found in Alemdag (1978), Mugasha (1989), and Burton (1993).

### Competition Studies

Three competition studies are presented here. The Alberta lodgepole pine-aspen competition study comprised 518, 10 m<sup>2</sup> (1.78 m radius) plots, measured in 48 blocks 5–16 years after harvest within the Upper and Lower Foothills natural

regions (Anon. 1994). The Alberta white spruce–broadleaf competition study was based on 869, 12.6 m<sup>2</sup> (2 m radius) plots in 19 blocks, 10–15 years after harvest, within the Lower Foothills and Central Mixedwood natural regions. The Manitoba conifer (white spruce, black spruce and jack pine)–broadleaf competition study was based on 1035, 12.6 m<sup>2</sup> (2 m radius) plots, measured in 18 blocks 7–12 years after harvest within the Boreal Mixedwood, Manitoba Lowland and Lower English River forest regions (Rowe 1972). Study locations for the Alberta and Manitoba studies are shown in Figures 1 and 2, respectively. In all cases, the selected blocks were in sites where the dominant competition was broadleaved trees.

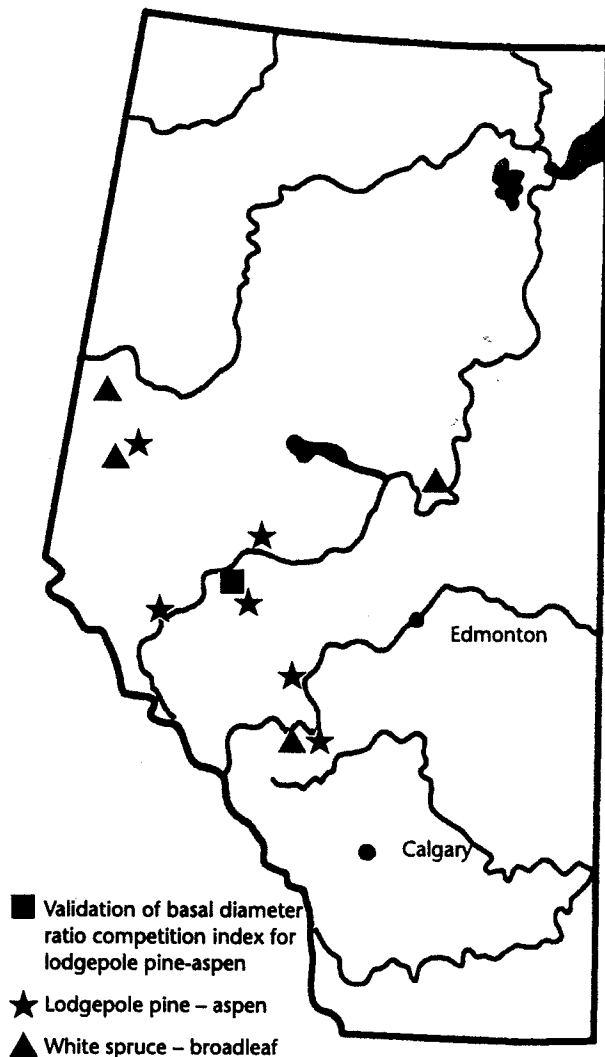


FIGURE 1 Location of conifer-broadleaf studies in Alberta.

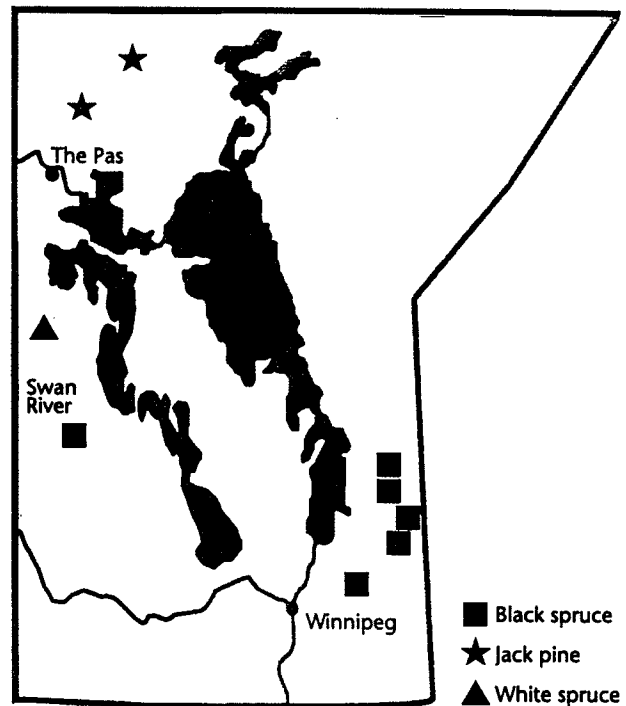


FIGURE 2 Location of sites for the conifer-broadleaf study in Manitoba.

**Field Methods** The field methods and measurements were similar for all three studies. They were all based on target tree-centred circular plots, 1.8 or 2 m in radius. These plots were located along a regular grid pattern, with spacing ranging from 10 × 10 m to 40 × 40 m, with at least 20 plots in each block. In each plot, a “retrospective survey” (Simard 1990) was completed. Target tree growth measurements were taken, along with detailed measurements of broadleaf tree and shrubby competitor stem density, crown cover, proximity, size, and the amount of overtopping of the target tree by surrounding vegetation. Height increments were measured for the target tree and closest and tallest broadleaf and conifer, and then the target conifer and competitors were harvested for radial increment and age measurements. For the Manitoba conifer and Alberta white spruce studies, additional information was collected. This included cover and height information on all trees and other vegetation in the plot, and an evaluation of micro-site conditions, using both subjective classification variables (e.g., moisture class) and continuous measurement variables (e.g., litter depth).

**Selection of Competition and Growth Variables** A limited set of variables was tested in the Alberta lodgepole pine–aspen study. These included six published competition indices, four single competition variables (based on density and cover), and four growth response variables. In the Manitoba conifer–broadleaf study, a much wider range of competition indices and variables were evaluated. They included published and unpublished intensive and extensive competition variables (using ratios, sums, and multivariable indices) and microsite variables. The competition variables were based on stem density, cover, height, distance, shading, and distribution of competitors around the target tree. The growth response variables included simple variables and ratios, both size dependent and size independent. For the Alberta white spruce–broadleaf study, a smaller set of more recently developed competition indices was tested, along with single competition variables based on cover and density.

The competition indices tested in these studies included those by Daniels (1976), Lorimer (1983), Martin and Ek (1984), Brand (1986), Wagner and Radosevich (1987, 1991a, 1991b), Braathe (1989), MacDonald et al. (1990), Delong (1991), Towill and Archibald (1991), Comeau et al. (1993), MacDonald and Weetman (1993), and Navratil and MacIsaac (1993). Specific equations for these indices as used in this research are described in Navratil and MacIsaac (1993), MacIsaac (1995a), and Navratil and MacIsaac (1995).

### Analysis Methods

In general the analytical approach has followed the same pathway for each study, with refinements as indicated by the specific requirements and study objectives. Initial exploratory data analysis was conducted using Spearman's rank-order correlation ( $r_s$ ) analysis (Zar 1984) and multiple linear stepwise regression (Neter et al. 1989). A ranking method modified from Mugasha (1989) was used to determine which growth and competition variables were best suited for more detailed analysis. Model-building with subsets of these variables was completed with multiple linear, curvilinear, and non-linear regression. As well, the parameter estimates and final form of the selected models were derived on the basis of highest coefficient of

determination ( $R^2$ ), lowest relative mean square residual, and most homogeneous variance. Categorical evaluation was also conducted using  $t$ -tests and multiple means tests. Most of the analysis was conducted using SAS statistical software (SAS Institute 1990).

### Competition Index for Lodgepole Pine–Aspen in West-central Alberta

For lodgepole pine–aspen data in Alberta, the basal diameter ratio (*BDR*) competition index had the strongest Spearman's rank-order correlation values of the tested competition indices and variables with lodgepole pine growth. The correlations were strongly negative ( $P < 0.001$ ), with absolute correlation values as high as 0.83 (Navratil and MacIsaac 1993). This index, which is a simplification of Lorimer's (1983) index, is:

$$\text{BDR competition index} = \frac{\text{basal diameter of tallest aspen within 1.8 m of the target tree}}{\text{basal diameter of target pine}}$$

The *BDR* index and basal area increment relationship approximated a negative hyperbolic curve (Figure 3). The steep slope between *BDR* 0.5 and 1.5 indicated high sensitivity of pine radial growth to these competition levels. The regression model accounted for 51 and 55% of the variation in basal area increment, for age groups 5–10 and 11–16 years, respectively. A concern raised by this analysis was that the high correlations and coefficient of determination ( $R^2$ ) values in the regression models may occur because pine size was included in both the competition index and growth response. To address this concern, the regression analysis was rerun with the pine diameters stratified into 5-mm size classes. This caused the variations in *BDR* index to be almost exclusively due to changes in aspen size. Overall, some  $R^2$  values were reduced, but some individual size classes had  $R^2$  values as high as 0.45, which was greater than for the other competition indices.

Pine height increment was not affected at the levels of competition up to *BDR* values of 1.5 for 5–10 year and 11–16 year pine age groups (Figure 4). Competition levels at greater *BDR* values resulted in decreased height growth by about 20% with a unit increase in *BDR*. While this may be partly due to a shorter height:diameter ratio of seedlings, it

may also be because low amounts of aspen cover could be beneficial to pine seedlings (e.g., protection from radiant frost).

Additional regression analyses were conducted to determine the effects of pine and aspen density, and the distance and quadrant location of the tallest aspen within the plot on this competitive relationship. In general, the relationship between *BDR* index and pine growth was consistent for the range of stand characteristics encountered in the study (Navratil and MacIsaac 1993). This research indicated that stand-tending treatments should be aimed at reducing competition before *BDR* index values of 0.75 are reached.<sup>1</sup>

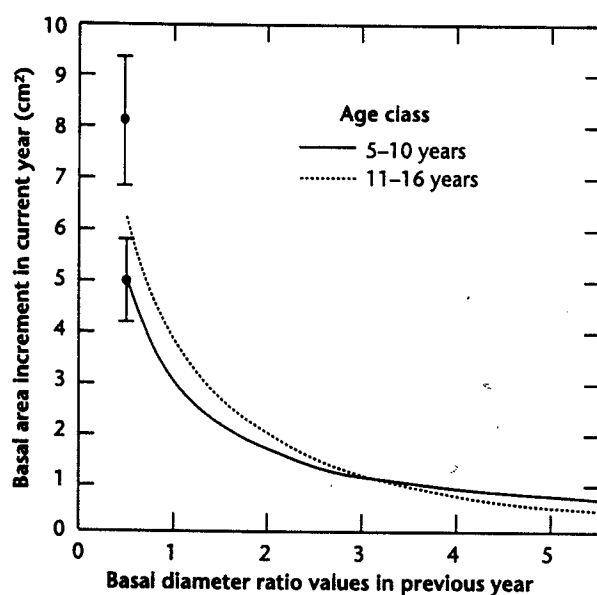


FIGURE 3 Relationship of lodgepole pine radial increment to basal diameter ratio competition index, from the Alberta lodgepole pine-aspen study. For age class 5-10 years the model fit to these data is  $BAINC = \exp(1.19 - 0.74\ln(BDRATIO) - 0.09BDRATIO)$ ;  $n = 185$ ,  $R^2 = 0.56$ ,  $F = 115.2$ . For age class 11-16 years the model fit to these data is  $BAINC = \exp(1.71 - 0.44\ln(BDRATIO) - 0.37BDRATIO)$ ;  $n = 175$ ,  $R^2 = 0.52$ ,  $F = 99.2$ . Vertical lines show mean and 95% standard error for basal area increment with basal diameter ratio competition index values between 0.26 and 0.75 (from Navratil and MacIsaac [1993]).

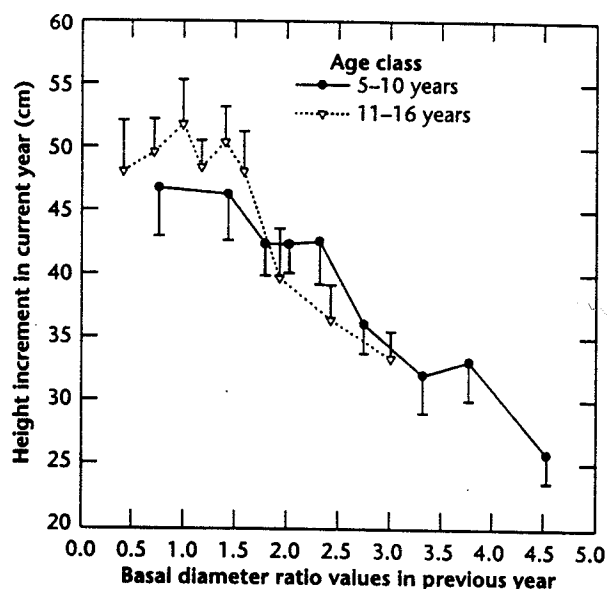


FIGURE 4 Relationship of lodgepole pine height increment to basal diameter ratio competition index, from the Alberta lodgepole pine-aspen study. Each point represents 19 observations. Vertical lines indicate standard error for height increments in basal diameter ratio competition index values (from Navratil and MacIsaac [1993]).

#### Validation of the Basal Diameter Ratio Competition Index for Lodgepole Pine-Aspen in Alberta

A 4-year study was initiated in 1993 in the Foothills Model Forest to test the usefulness of the *BDR* competition index in making stand-tending decisions for regenerating lodgepole pine-aspen blocks in west-central Alberta. Three 7-8-year-old blocks were selected northwest of Edson, Alberta, in the Lower Foothills natural region (see Figure 1). A total of 360 (1.78 m radius) plots in three blocks (120 each) were sampled. A mixed-nested experiment with three blocks and four levels of aspen removal (treatments) was designed. The four treatments (aspen removal within 1.8 m of pine) were defined as follows:

- 1 no aspen removed
- 2 aspen with diameter greater than pine diameter ( $BDR > 1.0$ ) removed
- 3 aspen with diameter greater than three-quarters of the pine diameter ( $BDR > 0.75$ ) removed
- 4 all aspen removed

<sup>1</sup> To determine the predictive ability of the basal diameter ratio, analysis was based on the relationship between *BDR* index values calculated for the previous year versus the conifer growth response in the current year. In an operational setting, both *BDR* and growth would be based on non-destructive, concurrent measurements.

In 1993, initial vegetation competition and conifer measurements were made and then the aspen were removed. These were followed by growth response measurements in 1994. The initial vegetation conditions and first-year growth response have been analyzed and are reported in MacIsaac (1995b).

Table 1 illustrates the levels of aspen competition before and after each treatment in 1993 (the post-treatment results are shown only for the two intermediate treatment levels). The remaining aspen competition was similar in terms of density, height, and cover for the two intermediate treatments (removal with  $BDR > 0.75$  and  $BDR > 1.0$ ). One year after treatment, there were significant differences ( $P < 0.05$ ) in both pine radial increment and pine root collar diameter between no removal and full removal of aspen within 1.8 m of the conifer (MacIsaac 1995b). However, no significant differences occurred in root collar diameter growth response and basal diameter between the two intermediate treatments. This may be because the level of post-treatment aspen competition was similar for both intermediate treatments (Table 1).

Table 2 presents an analysis of covariance (used to control for initial pre-treatment pine size) for first-year radial increment response. The most significant effects in the model were treatment ( $P = 0.0001$ ) and initial pine size ( $P = 0.0155$ ). Even after only 1 year, the pine were responding to release with increased radial growth. Figure 5 indicates how the rate of root collar diameter

growth has accelerated for trees under full release, especially compared to the control (no aspen removal). While these trends were encouraging, they were not statistically significant 1 year after treatment using Ryan's multiple range test (SAS Institute 1990).

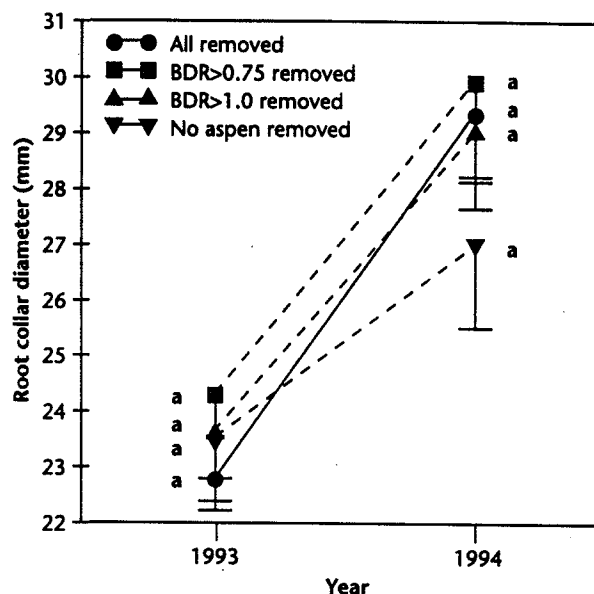


FIGURE 5 First-year radial growth response for lodgepole pine after aspen removal. Standard error shown (lower interval only). Similar letters for the same year indicate means are not significantly different at  $P = 0.05$  using Ryan et al.'s multiple range test (SAS Institute 1990).

TABLE 1 Aspen competition levels before and after aspen removal in 1993 for the basal diameter ratio competition index validation study, Foothills Model Forest. Data are for the three blocks combined ( $n = 320$ ). Values shown are the mean and the standard error of the mean. Number in brackets is % change from pre-treatment levels.

Aspen before removal		Aspen after removal	
		BDR > 0.75 removed	BDR > 1.0 removed
Aspen			
Density (1000s)	25.60 ± 0.71	8.90 ± 0.93 (-65%)	10.50 ± 0.85 (-59%)
Height (m)	2.43 ± 2.56	0.87 ± 3.56 (-64%)	1.01 ± 4.45 (-58%)
Cover (%)	45.80 ± 0.97	4.20 ± 0.48 (-91%)	5.20 ± 0.51 (89%)
Pine			
Height (m)	1.01 ± 2.25		

TABLE 2 Analysis of covariance on first-year post-treatment radial increment response for lodgepole pine in the basal diameter ratio competition index validation study, Foothills Model Forest

Source	df	Mean square	F value	P > F
1993 root collar diameter	1	16.47	6.614	0.0155
Block	2	15.16	3.5579	0.0904
Sub-block (Block)	6	4.52	2.5120	0.0216
Removal	3	14.74	8.1922	0.0001
Block*Removal	6	2.17	1.2059	0.3026
Error	343	1.80	—	—

There were no significant statistical differences in first-year pine height growth response between treatments; however, some graphical trends were noted by MacIsaac (1995b). The response of the height increment may be less pronounced than for radial growth because of the general trend for released trees to respond with accelerated radial growth before height growth. Trends in height growth will be tracked closely in subsequent years.

#### Results of the Manitoba Conifer-broadleaf Competition Study

The Manitoba study permitted analysis over a wider range of competition and growth variables than the Alberta lodgepole pine-aspen study. Table 3 provides a summary of the growth and competition variables and indices that revealed the highest correlation or explained the most amount of variation in conifer tree growth, as shown in the analysis by MacIsaac (1995a). Published competition indices that include target tree size, such as those by Martin and Ek (1984), Comeau et al. (1993), and Navratil and MacIsaac (1993), perform better than those that do not. This finding was consistent even when stratified analysis was performed to control for the effect of target tree size in the indices. Very simple variables such as broadleaf density and cover provided greater correlation with growth response than a variety of more sophisticated competition indices. In general, relative height of the average competitor versus the target tree was the most consistent competition

variable in the analysis (Table 3). Distance to the closest broadleaf competitor stem was more highly correlated with white spruce and jack pine growth than were other distance variables. Of the growth response variables tested, radial increment had the strongest correlation with competition variables. In the regression analysis,  $R^2$  values were not as high for growth variables based on total target tree size (height, root collar diameter, etc.) as for radial increment and height increment variables.

Analysis had shown that competitor height relative to target tree height was one of the best competition variables in "predicting" conifer growth, and that stem-to-stem distance of the closest broadleaf was also important. These two variables were used to test for competitor distance and height thresholds. In determining the distance thresholds the following question was addressed: At what distance from the conifer do broadleaved trees begin to significantly affect conifer growth? (Figure 6). Because the size and location of all the broadleaved competitors in each plot had been recorded, this analysis was possible. Trees were assessed as "open-grown" (relatively free from broadleaf competition) and "not open-grown" (relatively not free from broadleaf competition) using different criteria for broadleaf competitor distance.<sup>2</sup> The average growth difference of the target trees in these classes was compared using a series of *t*-tests and the difference plotted against the tested distances (Figure 7). In each test, a specific distance criterion was used to group the target trees from each plot into "open-grown" and

<sup>2</sup> The term "open-grown" in this analysis labelled trees with greater and lesser competition into two groups based on competitor distance. It did not refer to the actual tree morphology.

TABLE 3 Significant growth and competition variables<sup>a</sup> for the Manitoba conifer-broadleaf competition study

Species/region	Growth variable	Competition variables and competition indices
Black spruce/ Pine Falls	radial increment height increment	<ul style="list-style-type: none"> <li>• relative target tree:broadleaf height</li> <li>• broadleaf cover</li> <li>• Navratil and MacIsaac (1993) basal diameter ratio competition index</li> </ul>
Black spruce/ Duck Mountain	radial increment height increment	<ul style="list-style-type: none"> <li>• relative target tree:broadleaf height</li> <li>• broadleaf density</li> <li>• broadleaf cover</li> <li>• Comeau et al. (1993) competition index<sup>b</sup></li> </ul>
White spruce/ Porcupine Hills	radial increment	<ul style="list-style-type: none"> <li>• relative target tree:broadleaf height</li> <li>• stem-to-stem distance between closest broadleaf and target conifer</li> <li>• broadleaf density</li> </ul>
Jack pine/The Pas	radial increment total diameter	<ul style="list-style-type: none"> <li>• relative target tree:broadleaf height</li> <li>• stem-to-stem distance between closest broadleaf and target conifer</li> <li>• Martin and Ek (1984) competition index<sup>c</sup></li> </ul>

<sup>a</sup> These were variables that consistently had the highest  $R^2$  in the regression analysis.

<sup>b</sup> Comeau's index is the sum of the average cover  $\times$  average height of the competing species, divided by the target tree height.

<sup>c</sup> Martin and Ek's competition index is a distance-weighted, root collar diameter ratio of the target tree and broadleaved competitors.

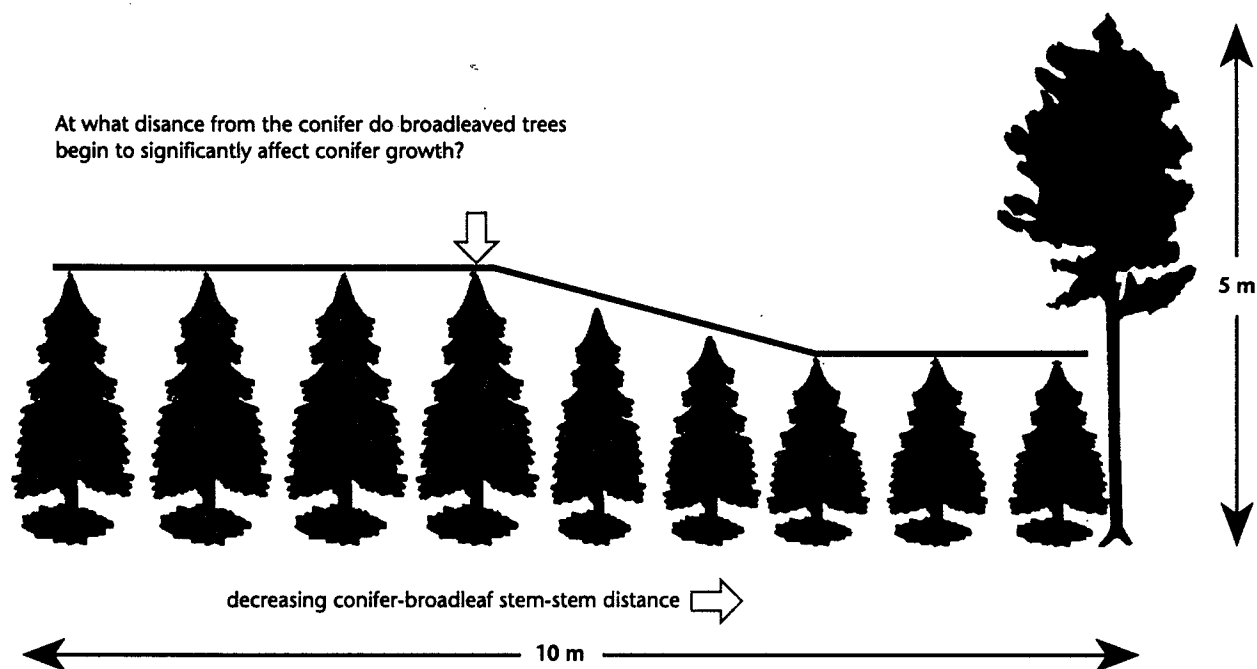


FIGURE 6 Concept of the effect of changes in conifer-broadleaf competitor inter-tree distance on conifer growth. In a young regenerating stand, the conifer seedling is potentially affected by the presence of nearby broadleaf competitors. In upland mixedwood stands on mesic sites, the effects would be mostly due to shading. At a certain distance, the broadleaf tree has little or no effect on the conifer (distance relationships may vary for different conifer-broadleaf orientations).

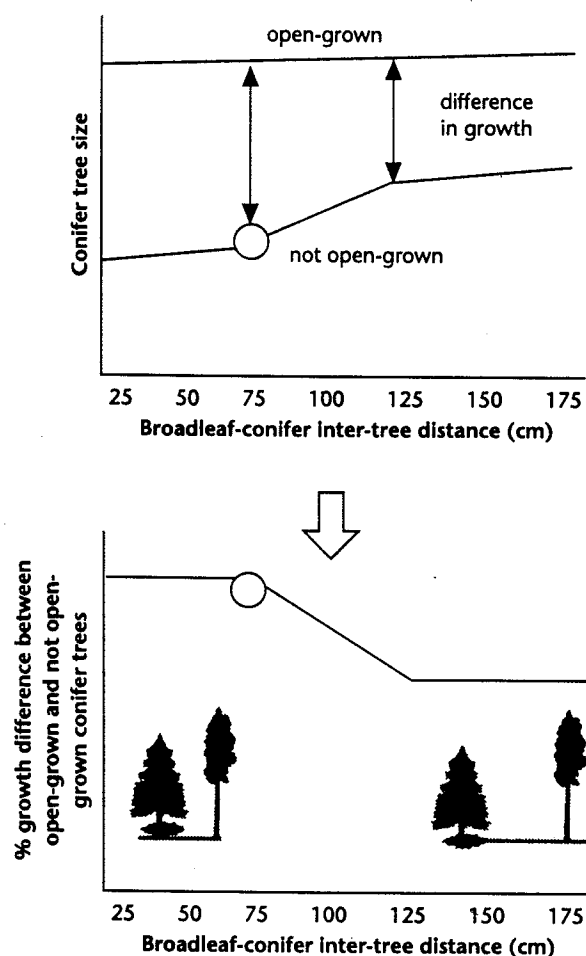


FIGURE 7 Graphical representation of methodology used to determine broadleaf-conifer inter-tree distance thresholds. The top diagram illustrates the average tree sizes for "open-grown" and "not open-grown" trees for each distance threshold based on individual t-test results. The circles in the diagrams represent the critical distance thresholds. The trees in the lower diagram represent the stem distances associated with the x-axis values and a constant competitor-target tree ratio of 0.66 (from MacIsaac [1995a]).

"not open-grown" categories. Each test was run independently of the others. In other words, the grouping of target trees into "open-grown" and "not open-grown" sets was based on the unique competition distance threshold; a tree could be defined as "open-grown" in one test and "not open-grown" in the next.

In the Pine Falls area of Manitoba, the analysis showed that broadleaved trees within 75 cm of the target black spruce seedling had the largest negative impact on conifer growth; in plots where broadleaved trees were at a stem-to-stem distance greater than 75 cm, the impact on conifer growth was less (Figure 8). Seventy-five centimetres is considered to be the critical distance threshold. Similar analysis was done to determine relative conifer:broadleaf height thresholds and is described in MacIsaac (1995a). Table 4 summarizes the overall results of height and distance threshold analyses, for each species in each region, tested with six growth response variables. Additional information on this analysis is found in MacIsaac (1995a).

### Results of the Alberta White Spruce-Broadleaf Competition Study

The results of the Alberta white spruce-broadleaf study show some similarities to the Manitoba work. The complete results are shown in Navratil and MacIsaac (1995). Of the growth response variables tested, radial increment consistently had the highest coefficient of determination in the regression analysis. Published competition indices

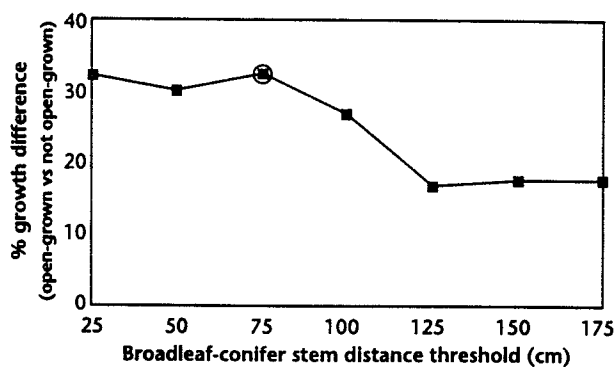


FIGURE 8 Effect of broadleaf-conifer stem distance on growth response between "open-grown" and "not open-grown" black spruce from Pine Falls, Manitoba. Based on overall average of separate t-tests performed for each age class (5-9, 10, 11-15 years) and growth variable (radial increment, root collar diameter, height, and height increment). The critical distance threshold is circled on the line. Tests based on broadleaf-conifer height ratio of 0.66 (from MacIsaac [1995a]).

TABLE 4 Distance and height thresholds for the Manitoba conifer-broadleaf competition study (see MacIsaac [1995a] for details)

Species/ region	Threshold broadleaf:conifer height ratio <sup>a</sup>	Threshold distance (cm) <sup>b</sup>
Black spruce/ Pine Falls	0.66	75
Black spruce/ Duck Mountain	0.66	75–100
White spruce/ Porcupine Hills	0.66	100
Jack Pine/ The Pas	0.66	125

<sup>a</sup> The height thresholds refer to the ratio of broadleaf height to target conifer height.

<sup>b</sup> Distance thresholds are based on stem-to-stem distance between broadleaved trees and target conifer.

that explained the highest amount of variation in regression analysis included:

- ratio of volume of target tree to sum of broadleaf competitor volume (MacDonald 1991, cited by MacDonald and Weetman 1993);
- distance-weighted root collar diameter ratio of the target tree and broadleaf competitor (Martin and Ek 1984); and
- distance-weighted basal area of the broadleaf competitor (MacDonald et al. 1990).

Aspen and broadleaf density were often shown as important competition variables, as was broadleaf and total vegetation cover.

A number of microsite variables were measured for Alberta including moisture class, drainage class, aspect, slope, micro-topography class, slash abundance, and litter depth. Multivariate analysis indicated that three groups of variables added significantly to the competition models for some locations. These were: (1) combined slope and aspect; (2) moisture and drainage; and (3) slash, micro-topography, and litter depth. These groups of variables are important in determining microsite moisture and nutrient status.

The effect of the location of broadleaved competitors around the target trees was tested (MacIsaac and Navratil 1995). The greatest difference in growth of shaded versus unshaded

trees was for seedlings with no competitors to the east and southeast, and was significant for root collar diameter (Figure 9). This growth difference between shaded and unshaded trees was maintained, even with competitors in the west and southwest. Solar radiation received in the morning appears to be more critical than that received in the afternoon, perhaps because of early soil warming in the former case. This may have implications for mixedwood management. Stand tending could remove broadleaved competitors to the east, while retaining those to the west; this would maintain a mixture of broadleaves and conifers in the stand and young conifer growth. Conifer growth could even be enhanced because of the reduced mid-afternoon sunlight, which can lead to desiccation on some sites.

### Conclusions on the Use of Competition Indices in Conifer-broadleaf Competition

Some researchers believe that competition indices have serious limitations, and their use may be overrated (e.g., Caza and Kimmins 1989; Burton 1993). On the spectrum from detailed process models to mensurational empirically based mathematical models, many competition indices are very simplistic. They are empirically based and often developed with only minimal knowledge of underlying causal processes. As such, they must be used with caution. When testing for appropriate indices using regression analysis, the *average*  $R^2$  must be examined rather than the highest  $R^2$ . For example, the relationship between a specific competition index and radial increment is tested for a particular species in various young conifer age classes and sites. It is also very important to recognize when high  $R^2$  results are partly due to size dependence. Notwithstanding the above concerns, competition indices are efficient to use. If an operationally useful and simple competition index has a high correlation with a more physiologically based measurement, then using the index may be more valid. This was DeLong's approach in the development of his light interception index (1991).

In British Columbia, competition indices have been applied successfully to mixedwoods in very young stands (e.g., DeLong 1991; Comeau et al. 1993), where the competitors are mostly herbaceous with high leaf areas. However, use of competition

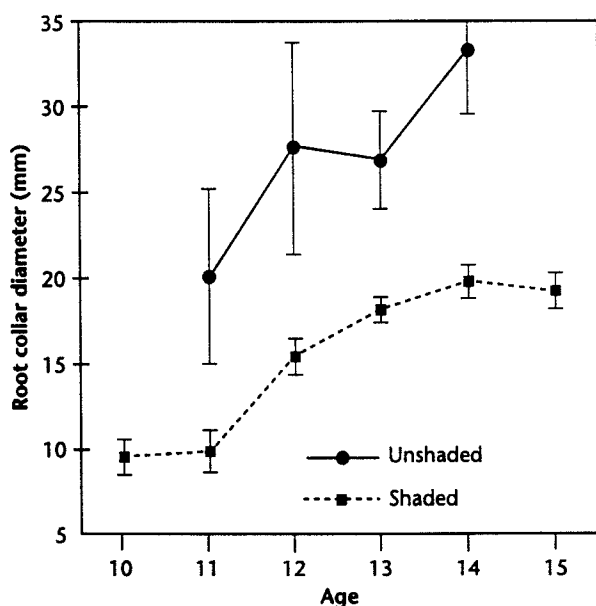


FIGURE 9 Difference in root collar diameter growth between shaded and unshaded white spruce seedlings, Calling Lake, Alberta. Values shown are mean  $\pm$  standard error of the mean. Unshaded trees are those with greater than 40% full sunlight to the south and southeast of the tree (measured with a sunfleck ceptometer in late summer, 1.5 m from the seedlings at mid-crown height). Based on 22 unshaded and 99 shaded trees, respectively.

indices has not been as successful with aspen (H. Cullen, B.C. Ministry of Forests, pers. comm., 1993). This is partly because of the diffuse, open-grown, asymmetric crown form of aspen. Competition indices and variables based on aspen crown characteristics have been less accurate than those derived from less-ambiguous parameters such as density and the BDR competition index.

In spite of the drawbacks mentioned by Burton (1993), researchers and those involved in vegetation management continue to search for the appropriate indices to use in stand evaluation and tending decisions. One cannot expect to develop a universally applicable index. Indices must be developed for each combination of species in each ecoregion. When used for assessment, a particular competition index may only be appropriate in portions of the block because of variations in slope, aspect, and competition situations. Although

important, competition indices are only one approach to quantifying the relationship between conifer growth and broadleaves in regenerating boreal conifer-broadleaved mixed stands in the Prairie Provinces.

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### References

- Alberta Forest Service. 1990. Free-to-grow standards. Reforestation Branch. Edmonton, Alta.
- Alberta Ministry of Environmental Protection. 1994. Natural regions and subregions of Alberta. Land Inf. Serv. Div., Alta. Environ. Protection. Edmonton, Alta.
- Alemdag, I. 1978. Evaluation of some competition indices for the prediction of diameter increment in planted white spruce. Can. Dep. Environ. Can. For. Serv., For. Manage. Inst. Ottawa, Ont. Inf. Rep. FMR-X-108. 39 p.
- Braathe, P. 1989. Development of regeneration with different mixtures of conifers and broadleaves. II. Proc. IUFRO Conf. on Treatment of Young Forest Stands. June 19-23, 1989, Dresden, GDR. IUFRO Working Party S 1.05-03.
- Brace, L. and I. Bella. 1988. Understanding the understory: dilemma and opportunity. In Management and utilization of northern mixedwoods. Proc. symp. April 11-14, 1988, Edmonton, Alta. J.K. Samoil (editor). Can. For. Serv. North. For. Cent., Edmonton, Alta. Inf. Rep. NOR-X-269. pp. 69-86
- Brand, D. 1986. A competition index for predicting the vigour of planted Douglas-fir in southwestern British Columbia. Can. J. For. Res. 16:23-29.
- Burton, P.J. 1993. Some limitations inherent to static indices of plant competition. Can. J. For. Res. 23:2141-2153.

- Carter, R.E. and K. Klinka. 1992. Variation in shade tolerance of Douglas fir, western hemlock, and western redcedar in coastal British Columbia. *For. Ecol. Manage.* 55:87-105.
- Caza, C.L. and J.P. Kimmins. 1989. Problems with the development and application of competition indices in complex, multispecies communities. In *Vegetation management: an integrated approach*. Proc. 4th Annual Vegetation Management Workshop, Nov. 14-16, 1989, Vancouver, B.C. E. Hamilton (compiler). B.C. Min. For. and For. Can. Victoria, B.C. FRDA Rep. No. 109, pp. 30-32.
- Comeau, P.G., T.F. Braumandl, and C.Y. Xie. 1993. Effects of overtopping vegetation on light availability and growth of Engelmann spruce (*Picea engelmannii*) seedlings. *Can. J. For. Res.* 23:2044-2048.
- Daniels, R. 1976. Simple competition indices and their correlation with annual loblolly pine tree growth. *For. Sci.* 22:454-457.
- Delong, S.C. 1991. The light interception index: a potential tool for assisting in vegetation management decisions. *Can. J. For. Res.* 21:1037-1042.
- Klinka, K., Q. Wang, G.J. Kayahara, R.E. Carter, and B.A. Blackwell. 1992. Light-growth response relationships in Pacific silver fir (*Abies amabilis*) and subalpine fir (*Abies lasiocarpa*). *Can. J. Bot.* 70:1919-1930.
- Lorimer, C. 1983. Tests of age-independent competition indices for individual trees in natural hardwood stands. *For. Ecol. Manage.* 6:343-360.
- MacDonald, B., D.M. Morris, and P.L. Marshall. 1990. Assessing components of competition indices for young boreal plantations. *Can. J. For. Res.* 20:1060-1068.
- MacDonald, G.B. and G.F. Weetman. 1993. Functional growth analysis of conifer seedling responses to competing vegetation. *For. Chron.* 69:64-70.
- MacIsaac, D.A. 1995a. Competition and juvenile growth in mixed regeneration in Manitoba. *Can. For. Serv. North. For. Cent. Edmonton, Alta. Canada-Manitoba Partnership Agreement in For. Rep.*
- . 1995b. Validation of basal diameter ratio competition index for lodgepole pine-aspen. Establishment and progress report. Foothills Model Forest. Hinton, Alta.
- Martin, G.L. and A.R. Ek. 1984. A comparison of competition measures and growth models for predicting plantation red pine diameter and height growth. *For. Sci.* 30(3):731-743.
- Mugasha, A. 1989. Evaluation of simple competition indices for the prediction of volume increment of young jack pine and trembling aspen trees. *For. Ecol. Manage.* 26:227-235.
- Navratil, S. and D.A. MacIsaac. 1993. Competition index for juvenile mixed stands of lodgepole pine and aspen in west-central Alberta. *For. Can. North. For. Cent. Edmonton, Alta. For. Manage. Note 57.*
- . [1996]. Juvenile growth of white spruce and deciduous on mixedwood sites in Alberta. *Can. For. Serv. North. For. Cent. Edmonton, Alta. Canada-Alberta Partnership Agreement in For. Rep. In press.*
- Neter, J., W. Wasserman, and M.H. Kutner. 1989. *Applied linear regression models*. 2nd ed. Irwin. Boston, Mass.
- Pacala S.W. and J. Weiner. 1991. Effects of competitive asymmetry on a local density model of plant interference. *J. Theor. Biol.* 149:165-179.
- Rowe, J.S. 1972. Forest regions of Canada. *Can. For. Serv. Dep. Environ. Ottawa, Ont. Publ. No. 1300.*
- SAS Institute Inc. 1990. *SAS/STAT user's guide*. Version 6. 4th ed. SAS Institute Inc., Cary, N.C. 2 vols.
- Simard, S. 1990. A retrospective study of competition between paper birch and planted Douglas-fir. *For. Can. and B.C. Min. For. Victoria, BC. FRDA Rep. No. 147.*
- Sims, R.A., H.M. Kershaw, and G.M. Wickware. 1990. The autecology of major tree species in the north-central region of Ontario. *Ont. Min. Nat. Resour. Thunder Bay, Ont. Publ. No. 5310, COFRDA Rep. No. 3302. NWOFTDU Tech. Rep. No. 48.*
- Towill, W.D. and D.A. Archibald. 1991. A competition index methodology for Northwestern Ontario. *Ont. Min. Nat. Res., NW Ont. For. Tech. Devel. Unit, Rep. No. TN-10.*
- Wagner, R. and S. Radosevich. 1987. Interspecific competition indices for vegetation management decisions in young Douglas-fir stands on the Siuslaw National Forest. *Dep. For. Sci. Oreg. State Univ. Corvallis, Oreg. Rep. No. 1. 108 p.*
- . 1991a. Interspecific competition and other factors influencing the performance of Douglas-fir saplings in the Oregon Coast Range. *Can. J. For. Res.* 21:829-835.
- . 1991b. Neighbourhood predictors of interspecific competition in young Douglas-fir plantations. *Can. J. For. Res.* 21:821-828.
- Zar, J.H. 1984. *Biostatistical analysis*. Prentice-Hall. Englewood Cliffs, N.J.

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# Silviculture of Temperate and Boreal Broadleaf-conifer Mixtures

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1996

BROADLEAF  
MIXEDWOOD  
MANAGEMENT



Province of British Columbia  
Ministry of Forests Research Program

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