Effects of aspen competition on growth of lodgepole pine.

Report on EMLP2 Study
(FRIAA Project OF-02-16)

Phil Comeau
Univ. of Alberta, Dept. of Renewable Resources, 751 General Services Bldg., Edmonton, AB T6G 2H1;
telephone: 780-492-1879; email: phil.comeau@ales.ualberta.ca

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Executive Summary
This study was designed to examine effects of aspen on lodgepole pine in western Alberta. During 2006 and 2007 a total of 18 installations were established in 6 FMA's with 6 installations located in each of the three age classes (10-20, 20-30, and 30-40 years old). For comparison between the lower and upper foothills ecological subregions, 9 installations (3 in each age class) were located in each ecological subregion.

Results show that competitive effects of aspen and pine on pine growth can be estimated using basal area or other simple competition measurements such as Lorimers index. Neighbouring aspen, pine and spruce basal area influence diameter growth of lodgepole pine in both the lower foothills and upper foothills subregions. The influence of pine is stronger than that of aspen and the influence of spruce is even stronger than that of pine. While the influence of aspen and pine neighbour basal area on pine growth is stronger in the lower foothills, the influence of spruce on pine growth is much stronger in the upper foothills than in the lower foothills. Data from this study suggest that deciduous basal area above 5 m^2/ha (lower foothills) and 9 m^2/ha (upper foothills) may be potential thresholds relating to diameter growth effects (and represent about a 30% reduction in pine diameter growth).

While aspen and pine basal area influence subject pine height increment in the lower foothills, their influence on height growth is not significant in the upper foothills.

Examination of the partitioning of total density (measured as stand density index) suggest that aspen and pine are about equal in their contribution to total density, so that thinning of either species provides nearly equal space for remaining trees. This would suggest that removing provides space for growth of pine and, conversely, adding aspen contributes to total stocking (SDI).

While control of aspen when it exceeds threshold basal area or density may be beneficial to lodgepole pine growth and to conifer yield, maintenance of a component of aspen is desirable for maintenance of biodiversity and site productivity. While accepting moderate to high densities of aspen may impact on growth of lodgepole pine, this may provide some protection against risk of complete stand loss to mountain pine beetle in high risk areas.

Introduction

Aspen is considered to be a potentially serious competitor in regenerating lodgepole pine stands and is common in such stands in western Alberta and in the B.C. Interior. Aspen has more rapid height growth than lodgepole pine on some sites, and when present in sufficient density it can cast sufficient shade to impact on the growth of subordinate shade intolerant lodgepole pine. Wright et al. (1998) show that growth of lodgepole pine increases as light levels increase. However, on many sites lodgepole pine height growth keeps pace with aspen and results in the two species sharing the overstory canopy. Studies indicate that aspen removal can increase growth of lodgepole pine (Newsome et al. 2004, 2006a, 2006b) and that growth of lodgepole pine generally declines with increasing aspen density (Newsome et al. 2003, Newsome et al. 2008, Harper et al. 2009, Heineman et al. 2009). Recent studies also indicate that the effect of aspen on light and on lodgepole pine growth rates varies with climatic and site conditions (Comeau et al. 2006, Newsome et al. 2008, Harper et al. 2009, Heineman et al. 2009).

When present at low densities, aspen may contribute to the productivity of pine forests through its influences on nutrient cycling and other factors. Results from a study in Quebec show that aspen can increase litter decomposition in black spruce dominated ecosystems through influences on both litter quality and the decomposer community (Laganiere et al. 2010). As a result, an understanding of the influence of aspen abundance on pine growth is needed to serve as a basis for the management of this species within lodgepole pine stands. In addition, development of growth and yield models for mixtures of aspen and lodgepole pine requires data on the development of mixed stands of these two species.

Stadt et al. (2002) tested the correlation between pine growth and several widely used competition indexes. Using data from permanent sample plots in maturing stands they found that basal area of aspen and Hegyis index were the most effective indexes(of those tested) for describing variation in lodgepole pine diameter growth, with basal diameter ratio working poorly. In contrast, Navratil and MacIsaac (1993) and Newsome et al. (2003) found that of the competition indexes that they tested, basal diameter ratio (the ratio of the diameter of the tallest aspen to the diameter of the subject pine) was the best index in the young stands that they examined. Newsome et al. (2003) also found that aspen density, basal area, Lorimers index and Hegyis index were strongly correlated with pine size and growth rates. Navratil and MacIsaac (1993) report that Lorimers index, Braathes index, and Hegyis (Daniels) index follow closely behind BDR in terms of their ability to describe variation in height and diameter growth of lodgepole pine. A criticism of the basal diameter ratio is that inclusion of diameter of the subject tree as a numerator will automatically inflate the strength of correlations to tree size. A further criticism is that it ignores the effects of aspen density, and may not adequately characterize competition for light. Harper et al. (2009) report that a variation of Hegyis index, which used diameter and distance of the three nearest aspen, was most effective of the indexes that they tested. Newsome et al. (2008) and Heineman et al. (2009) report that the density of aspen taller than the subject lodgepole pine is an effective index for describing competitive effects of aspen. However, as Harper et al. (2009) point out, height measurements and relative height determination can be difficult and inaccurate in stands that are more than a few meters tall. Results presented by Newsome et al. (2008) indicate that Lorimers and Hegyis indexes are better at explaining variation in pine height and diameter than density of taller aspen and that Lorimers index is slightly better than Hegis index.

Indexes that link well with light levels would be expected to relate closely to growth. Results presented by Comeau (2001, 2003) and Lieffers et al. (2002) indicate that light levels under aspen are best predicted using basal area of aspen, or similar measures that incorporate both tree basal area and number. It may also be desirable to utilize an index that correlates well with the primary resource for which competition is expected to be occurring, since this enhances its usefulness and interpretation.

While results presented by Navratil and MacIsaac (1993), Stadt et al. (2002), Newsome et al. (2008), Harper et al (2009), and Heineman et al (2009) provide useful information on relationships between pine growth and aspen competition, there is a need for additional data that encompasses a range of stand ages, and that allows examination of effects of aspen competition on height and diameter growth in Western Alberta. Such data are required as a basis for development of competition models that can be used in growth and yield models such as MGM.

Objectives

The objective of this study is to develop models for estimating effects of amount of aspen on growth of lodgepole pine. Specific questions to be addressed include:

- How serious are the effects of aspen and what are threshold densities?
- Are effects similar in the Upper foothills and lower foothills?
- What variables (and competition indexes) are useful for modeling competitive effects?

Methods

During 2006 and 2007 a total of 18 installations were established in 6 FMA's (Table 1, Figure 1). A total of 6 installations were located in each of the three selected age classes (10-20, 20-30, and 30-40 years old). For comparison between the lower and upper foothills ecological subregions, 9 installations (3 in each age class) were located in each ecological subregion.
Member companies provided recommendations for potential candidate sites, which were assessed in a reconnaissance survey. Criteria for selection of study sites for sampling included: minimum block size of 4 ha, suitable age, no evidence of health problems other than competition, circum-mesic soil moisture regime, pine densities above 400 stems/ha, aspen present in the block with a range of densities evident in various portions of the block, site adjacent or close to a drivable road, and distribution of sites across companies, subregions and age classes.

Within each installation 6 sample plots (9.77 m radius) were established across a gradient ranging from lowest to highest aspen density. Locations of plots were subjectively determined in order to capture a range of aspen densities within the installation. In each plot all trees taller than 1.3 m in height were measured (DBH, height, height growth over the past 5 years, height to crown base, crown radius) and their location mapped. Within each sample plot the 12 acceptable lodgepole pine trees located closest to the plot center were designated as "SUBJECT" (focal) pine.

Acceptable subject trees were live lodgepole pine, greater than 1.3m in height, NOT showing signs of disease or physical defects.

Three installations in each age class were selected for destructive sampling to collect stem sections (disks) needed to determine diameter growth of the pine and aspen. In each of these 9 selected installations, three plots were selected for destructive sampling. In the selected plots the 12 pine subject trees and a sample of 12 aspen located closest to plot center were cut and disks from collected from DBH and measured to determine diameter increment pine in 3 plots. Disks were sanded in the laboratory after air drying under magnification on a Velmex UniSlide.

Non-linear multiple regression is used in this report to explore relationships between lodgepole pine growth and measures of completition. Appropriate models were selected based on results shown in similar published studies and model fit to the data. Analysis was completed using Proc NLIN in SAS 9.2 (SAS Institute, Cary NC).

Table 1. EMLP2 installations overview information.

Age Class	Installation	FMA	Location	Date Measured	Natural Subregion	Ecological Description	Destructive Plots
10-20	2-008-0462	HWP	Emerson Rd km 80	15-Jan-06	LF	E 4 C	2, 4, 6
10-20	2-009-0048	HWP	Swansons South Rd km 72.5	1-Jan-06	UF	E 5 C	2, 4, 6
10-20	2-008-0443	HWP	Emerson Rd km 83	15-May-06	LF	E 5 C	
10-20	68130046	WCG	Calahoo Rd km 31	5-Jun-06 / 18-Jan-06	UF	C 5 C	2, 3, 6
10-20	S19904	CFG	4123 km RHS		UF	F 5 D	
10-20	ER 129-418	MWW	Eagle Tower Rd km 7.6	30-Jan-07	LF	C 4 C	
20-30	2-007-0596	HWP	Emerson Rd km 86	23-Jan-06	LF	D 6 B	
20-30	120	SDA	Sundance Rd km 60.1	15-Feb-06	UF	E 5 C	2, 4, 6
20-30	121	SDA	Sundance Rd km 60.3	10-Feb-06	UF	E 5 C	2, 4, 6
20-30	2-009-0060	HWP	Emerson Rd km 73	25-May-06	UF	C 3 C	
20-30	65070015	WCG	3.0 km W on Weyco Main from Bald Mtn Rd Junction	10-Jan-07	LF	C 5 C	
20-30	3-003-025A	HWP	3-3-102 Rd, 1.0 km past Erith bridge, RHS	Jan-07	LF	C 4 C	2, 4, 6
30-40	55	SDA	Sundance Rd km 61	5-Feb-06	UF	D 5 B	2, 4, 6
30-40	65070016	WCG	3.0 km W on Weyco Main from Bald Mtn Rd Junction	15-Jan-07	LF	C 4 C	
30-40	3-003-0011	HWP	Sundance Rd km 21.5, RHS 0.2 km	15-Nov-06	UF	C 4 C	
30-40	OG3-8-604	MWW	Goose km 57 (approx) 1 km SW of bridge	Feb, Mar-07	LF	F 6 D	2, 4, 6
30-40	1970	SLS	Hwy 68, S of Jumpingpound Demo Forest	Feb-07	LF	E 5 C	2, 4, 6
30-40	4-006-0682	HWP	Prest Creek Rd km	17-Jan-07	UF	D 6 B	

FMA: HWP=WestFraser - Hinton Wood Products; WCG=Weyerhaeuser Canada Grande Prairie; CFG=Canfor Grande Prairie; MWW=Millar Western Whitecourt; SDA=Sundance Forest Products; SLS=???
Natural Subregion: LF=Lower Foothills; UF=Upper Foothills; **Ecological Description**: ecosite, soil moisture regime and soil nutrient regime.

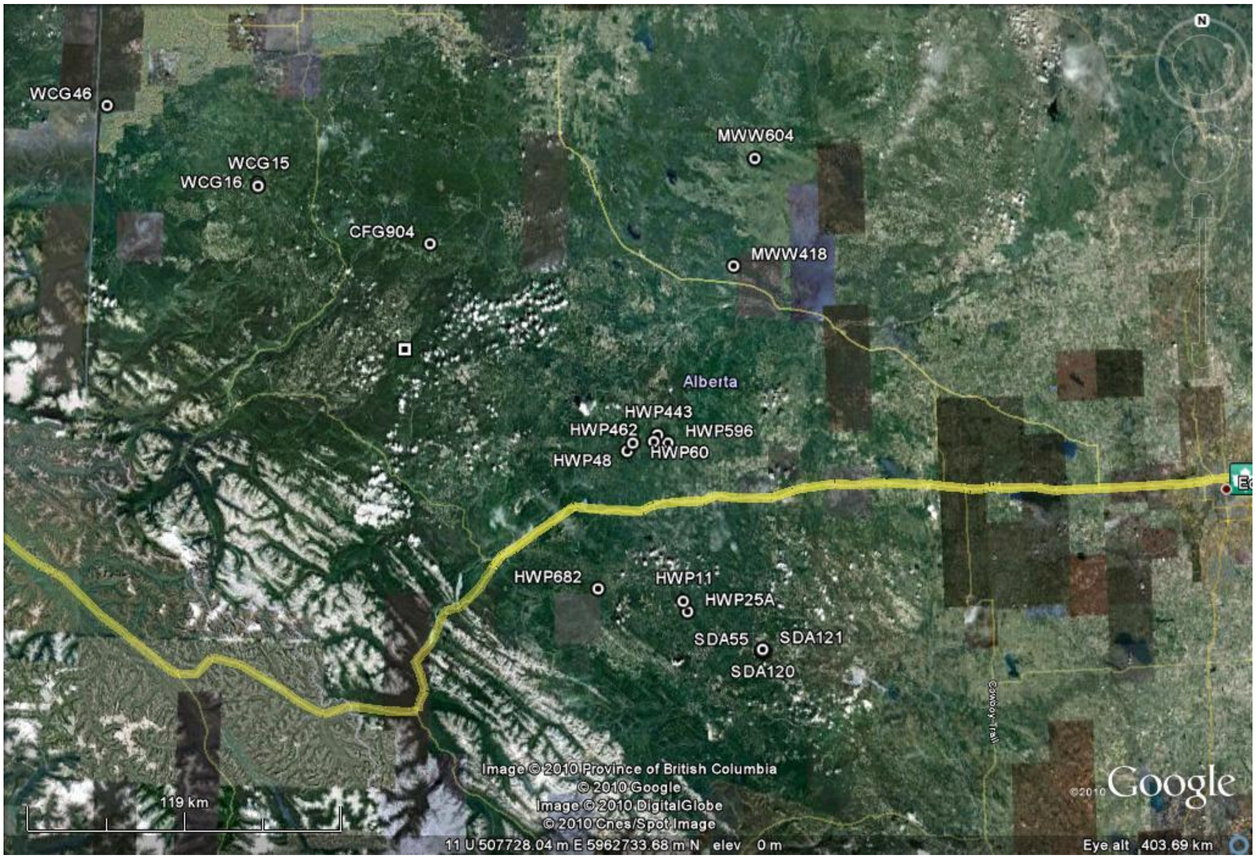


Figure 1. Map showing locations of study installations.

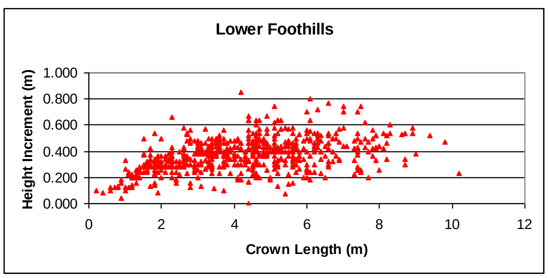
Results

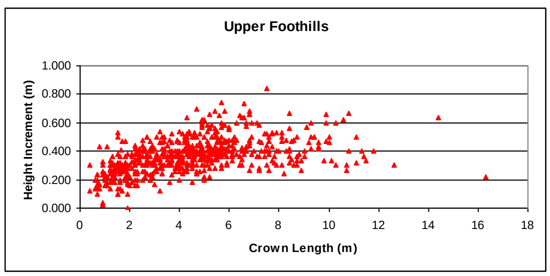
Analysis of plot level results based on use of the 9.77 m radius plots indicates that stems/ha is the best competition index for explaining variation in height growth in both subregions, while SDI (Reineke 1933) and basal area/ha work best for estimating pine diameter growth (Table 2). Figures 2 and 3 show scatter plots for height increment and diameter increment plotted against selected independent variables. Adding height ratio did not improve explanatory power of the non-linear regression models for diameter increment, but did improve explanatory power of BAHA and SDI for height increment. Given the similarity in R^2 values obtained from these models, results suggest that any of these competition indexes could be used to effectively model competitive effects, with the exception of the poor performance of TPH as a predictor of pine diameter increment. Crown length was found to be a useful variable for explaining variation in growth and is used in the models together with the competition measures.

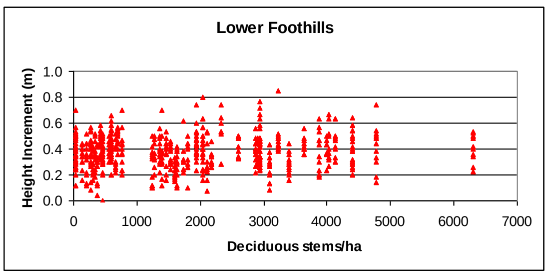
Table 2. Comparison of R^2 values for various competition Indexes (9.77 m radius plot level). TPH=stems/ha; BAHA=basal area/ha; HR*BAHA=height ratio (pine height/competitor top height) x BAHA; SDI=Stand Density Index; HR*SDI=height ratio x SDI.
MODEL I=a * CLb*e (d*CIaw+f*CIpl+g*CIs); CLb=crown length of pine, CIaw=aspen CI, CIpl=lodgepole pine CI, CIs=spruce CI

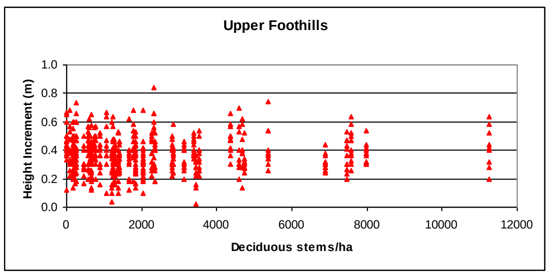
Dependent variable	**CI**	**LF**	**UF**
Height increment	TPH	0.360	0.372
	BAHA	0.309	0.330
	HR*BAHA	0.325	0.360
	SDI	0.323	0.326
	HR*SDI	0.335	0.326
	SAMPLE SIZE	626	626
Diameter increment	TPH	0.333	0.164
	BAHA	0.752	0.471
	HR*BAHA	0.675	0.455
	SDI	0.759	0.430
	HR*SDI	0.678	0.430
	SAMPLE SIZE	138	175

Highlighted cells indicate the best competition indexes for explaining variation in pine growth.









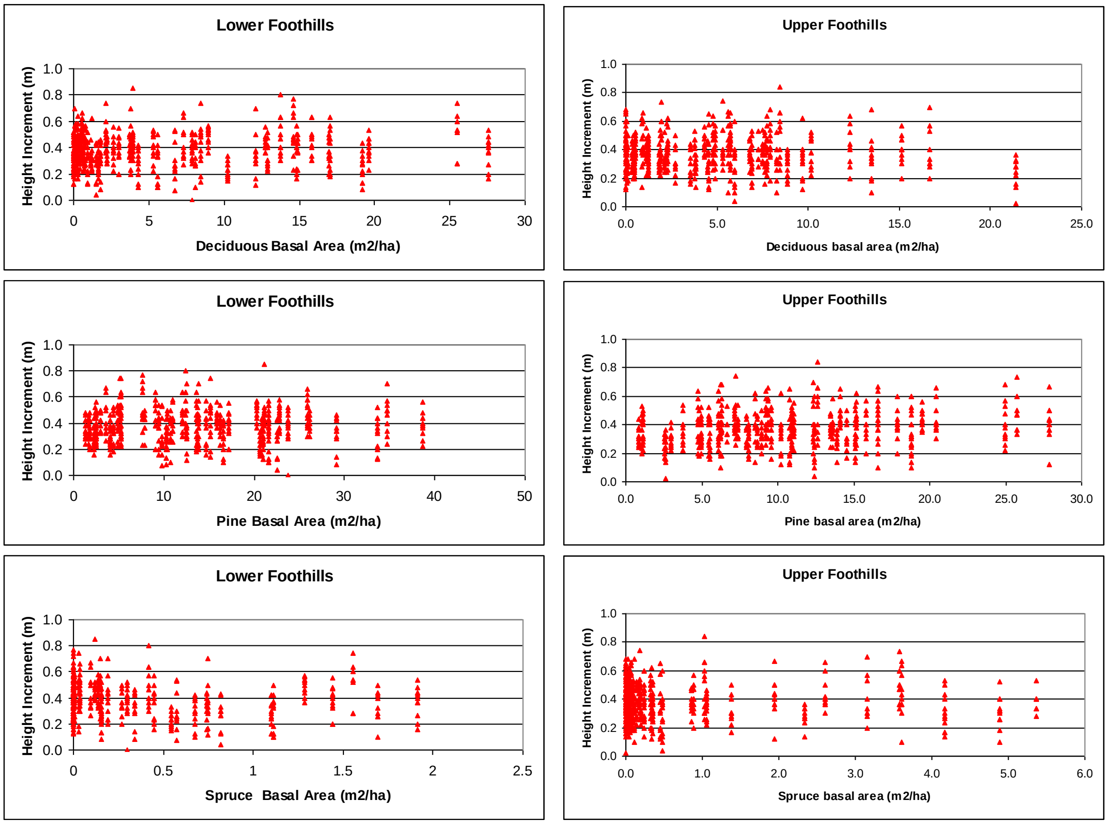


Figure 2. Scatter plots showing general relationships between lodgepole pine height increment and selected independent variables.

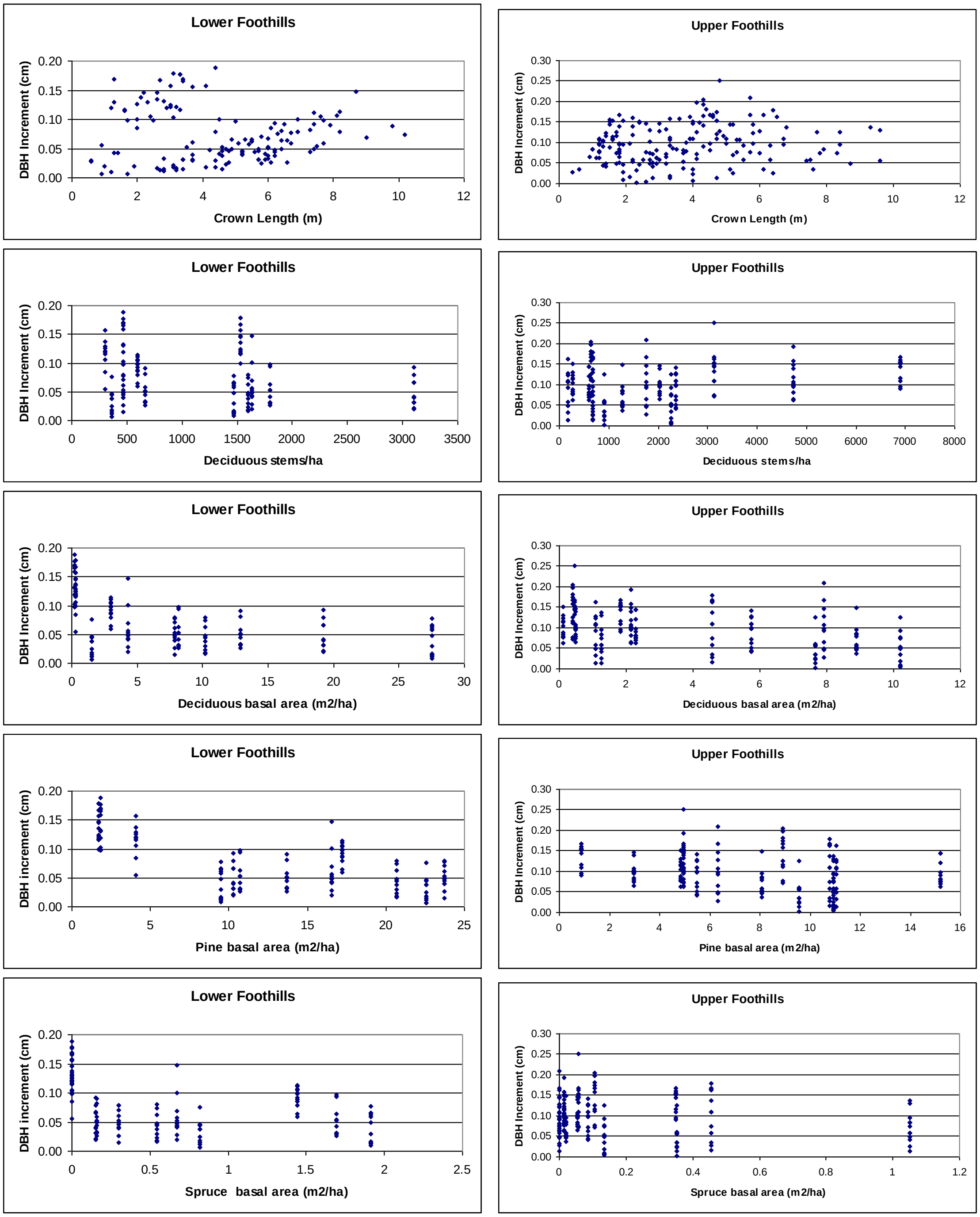


Figure 3. Scatter plots showing general relationships between lodgepole pine diameter increment and selected independent variables.

Table 3. Models for lodgepole pine height increment for Lower Foothills (LF) and Upper Foothills (UF) based on competition assessments for 3.99 m radius sample plots centered on each subject lodgepole pine. Model: $I=a * CL^{b}*\exp(d*TPHaw+f*TPHpl+g*TPHs)$; CL=crown length of pine, TPHaw=aspen tph, TPHpl=lodgepole pine tph, TPHs=spruce TPH.

		Height increment	
Parameter	**Indep variable**	**LF**	**UF**
a		0.2113	0.2315
b	CL	0.2747	0.3241
d	TPHaw	-0.00006	0.00000078
f	TPHpl	0.000024	0.00000014
g	TPHs	0.000014	0.000019
n		138	180
R^2adj		0.2035	0.3881

Highlighted cells indicate where parameter values are non-significant (p>0.10).

Table 3 presents results from an examination of relationships between lodgepole height increment and crown length, aspen density, pine density and spruce density within a 3.99 m radius of the subject pine. In the lower foothills, aspen density is having a small but significant negative effect on pine height growth. In contrast, aspen density is not significantly related to pine height increment in the upper foothills. Pine and spruce densities are not significantly influencing aspen height increment in either subregion. As shown in Figure 3, while aspen densities range up to 7000 sph in the upper foothills and 3200 sph in the lower foothills, the range in aspen basal area is much lower in the upper foothills.

Results shown in table 4 and figure 4, based on 3.99 m radius plots centered on each subject pine indicate that aspen is having a significant negative influence on pine diameter increment in both the UF and LF, but aspen is more competitive (value of parameter d is bigger) in the LF than in the UF. The effect of aspen basal area on height is not significantly different from 0 in the upper foothills, while the effect is larger and significant in the lower foothills. Competing pine are also significantly reducing diameter growth and the effect is stronger in the LF than in the UF. Spruce basal area is negatively correlated with pine diameter growth in both subregions but is not significant in the height increment model.

Table 4. Models for lodgepole pine diameter and height increment for Lower Foothills (LF) and Upper Foothills (UF) based on assessment within a 3.99 m radius of each subject pine. Model: I=a * CL^b*exp(d*BAaw+f*BApl+g*BAs); CL=crown length of pine, BAaw=aspen CI, BApl=lodgepole pine CI, BAs=spruce CI

		Diameter increment		**Height increment**	
Parameter	**Indep variable**	**LF**	**UF**	**LF**	**UF**
a		0.5392	0.5247	0.2333	0.2424
b	CL	0.2955	0.3362	0.3270	0.3259
d	BAaw	-0.05237	-0.04145	-0.0111	-0.00062
f	BApl	-0.05412	-0.04069	-0.00949	-.00260
g	BAs	-0.1094	-0.2699	-0.0259	-0.0180
n		139	183	138	180
$R^2 adj$		0.672	0.400	0.246	0.390

Highlighted cells indicate where parameter values are non-significant (p>0.10).

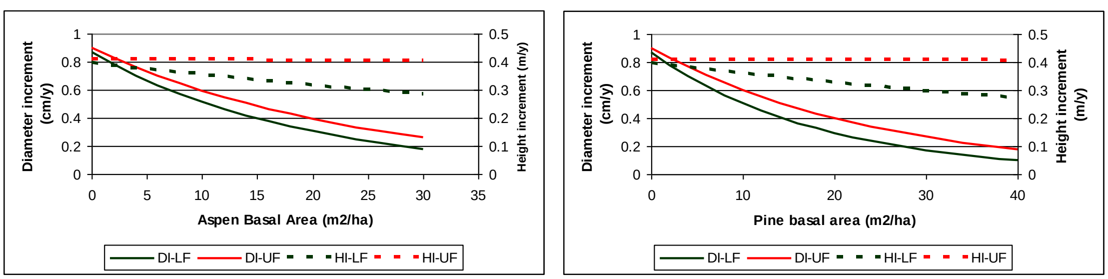


Figure 4. Illustration of aspen and pine effects on diameter and height increment of lodgepole pine. Lines shown are based on models described in table 4. In both cases CL=5.0 m ; pine basal area is assumed to be 0 in the graph showing aspen basal area on the x axis and aspen basal area is assumed to be 0 in the graph showing pine basal area on the x axis.

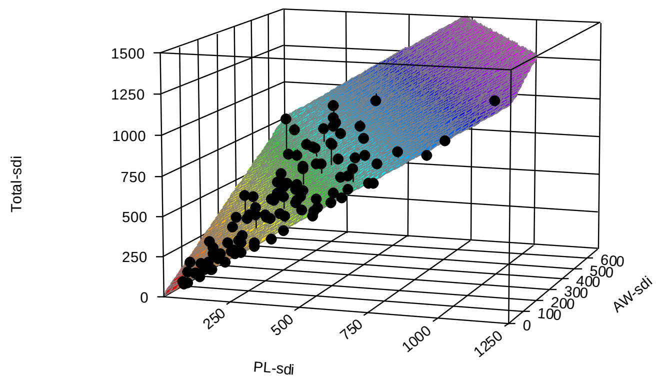


Figure 5. Relationships between total Stand Density Index (Total-sdi) and SDI values for lodgepole pine (PL-sdi) and aspen (AW-sdi) (based on data from 9.77 m radius sample plots for both subregions). The line is described by the equation: SDItotal=12.08+1.03 SDIpl+1.07SDIaw R^2adj=0.973

Figure 5 illustrates the contribution of aspen and pine to stand density index (SDI). SDI is defined as "the number of trees per hectare as if the quadratic mean diameter of the stand were 25 cm" (Long 1985). SDI is calculated using the formula: SDI=N x $(D_q /25)^{1.605}$ (where N= number of trees per hectare and D_q =quadratic mean diameter (cm)). There appears to be a linear relationship between total SDI and that of the two major component species, and the parameter values for the influence of the two species are nearly equal. These results suggest that aspen and pine make nearly equal contributions to the stand and have equivalent influences on achievement of full stocking.

Discussion

Results show that competitive effects of aspen and pine on pine growth can be estimated using basal area or other simple competition measurements such as Lorimers index. These findings are similar to those obtained from several studies comparing the effectiveness of various competition models for estimating aspen competition (Navratil and MacIsaac 1993, Stadt et al. 2002, Filipescu and Comeau 2007, Newsome et al. 2008, Harper et al. 2009, and Heineman et al. 2009). The addition of crown length (or other tree size measures) to the models substantially improves their ability to describe variation growth rates, as reported in several other studies (eg. Filipescu and Comeau 2007).

In the upper foothills, aspen, other pine, and spruce are not having significant effects on height growth of lodgepole pine while in the lower foothills, aspen and pine are having significant effects on pine height increment increment. In both subregions, aspen, other pine and spruce all appear to be having significant effects on pine diameter increment. Aspen competition has stronger effects on pine diameter growth in the lower foothills than the upper foothills. This is consistent with other studies that have shown that climate, site and other factors influence the effects of aspen on light levels and on growth of lodgpepole pine (Comeau et al. 2006, Newsome et al. 2008, Harper et al. 2009, Heineman et al. 2009). This is also similar to results reported by Filipescu and Comeau (2007) for white spruce. The fact that aspen appears to be less competitive in the upper foothills is likely related to its reduced vigour in this subregion and the fact that pine vigour is not reduced to the same degree.

Results for the lower foothills also suggest that intraspecific competition from other pine has a stronger effect on diameter growth than aspen competition, and that spruce is having an even stronger negative effect than pine. In the upper foothills, competition from pine is slightly weaker than that from aspen and pine, while effects of spruce are stronger than that of the other species, and than observed for the lower foothills. Spruce effects on diameter growth may be reflecting spruce effects on soil temperature, since spruce are generally shorter than pine in these stands, however other factors (such as litter decomposition and nutrient availability) may also be involved. These results suggest that, while control of aspen may be beneficial, control of conifer density and basal area in these plots should also be considered. It is, of course, necessary to consider tradeoffs between individual tree growth and stand growth in developing prescriptions for overall density management.

Data from this study suggest that deciduous basal area above 5 m^2/ha (lower foothills) and 9 m^2/ha (upper foothills) may be potential thresholds relating to diameter growth effects. Figure 3 indicates diameter growth may be consistently reduced when aspen basal area exceeds these levels or when aspen densities exceed 1700 trees/ha (lower foothills). Figure 4 illustrates that these basal area thresholds would coincide with a reduction in diameter growth to approximately 70% of that of trees without aspen. Thresholds for pine height increment are approximately 15 and 20 m2/ha of aspen basal area for the lower and upper foothills, respectively (Figure 2), and these levels would reduce height increment to 80 to 85% of that of trees without competition.

Analysis of stand density index at the plot level indicates that aspen and lodgepole pine contribute nearly equally to stocking of these stands. This result suggests that adding aspen to a stand contributes primarily to total stocking of the stands. This would also indicate that removal of aspen from these stands will likely benefit the pine through reduction of total stand density.

Maintenance of an aspen component in these stands is likely to be beneficial due to its contribution to species and structural diversity and to nutrient cycling. Maintenance of aspen at levels below thresholds that result in undesirable levels of growth reduction may be desirable, but should be tempered against the risk of insect (eg. mountain pine beetle) and root disease problems which may cause substantial mortality of lodgepole pine. While accepting moderate to high densities of aspen may impact on growth of lodgepole pine, this may provide some protection against risk of complete stand loss to mountain pine beetle in high risk areas.

Further analysis of these data is underway with plans to publish results in a peer reviewed journal during 2011 or 2012.

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