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Relationships between stand parameters and understorey light in boreal aspen stands

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Abstract

Data from six aspen stands in northeastern British Columbia ranging in age from 12 to 40 years were used to examine relationships between understorey light levels and stand attributes (basal area, stand density, and age). Sample points were selected in each stand to characterize the observed range in tree density and size. Fractional transmittance of light (DIFN) was measured at each sample point using a LAI-2000 Plant Canopy Analyzer and a circular plot 3.99 m or 5.64 m in radius was established for density and basal area determination.

Results indicated that data from the six stands could be pooled into a single model describing the relationship between understorey light and basal area. Light levels below 40% are found when basal area of aspen in these stands exceeds 14 m^2/ha and light levels below 60% are found when basal area of aspen exceeds 8 m^2/ha. The potential implications of these light levels to growth of understorey spruce are discussed.

A diagrammatic representation of light-density–diameter relationships is presented that could provide a useful tool for management decisions in young mixedwood stands in northeastern British Columbia.

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Introduction

Trembling aspen (*Populus tremuloides* Michx.) is a common component of the boreal forests of North America. Due to its more rapid initial growth rates, aspen generally overtops white spruce, subalpine fir, or balsam fir for the first 60 years of stand development or longer. The overtopping aspen canopy influences growing conditions for understorey trees. The aspen overstorey canopy reduces understorey light levels (Lieffers and Stadt 1994; Man and Lieffers 1997; Messier *et al.* 1998; Lieffers *et al.* 1999), influences air and soil temperatures, and may also influence soil moisture and nutrient availability (Man and Lieffers 1999). The aspen overstorey can also serve as a nurse crop, reducing frost and insect damage, reducing competition from understorey vegetation, contributing to accelerated nutrient cycling, and contributing to species and structural diversity in the forest (Man and Lieffers 1999). Managing aspen–spruce mixtures involves balancing these interactions to achieve desired survival and growth levels of the spruce component. These "desired levels" should be defined in terms of target stand conditions, which must be based on management objectives and constraints.

Although maximum photosynthesis of white spruce (*Picea glauca* [Moench] Voss) shoots occurs between 40 and 60% of full sunlight (Man and Lieffers 1997), maximum diameter and stem volume growth of conifer seedlings or saplings generally occurs at full sunlight (Eis 1967; Logan 1969; Brix 1970; Klinka *et al.* 1992; Comeau *et al.* 1993; Lieffers and Stadt 1994; Chen *et al*. 1996; Mailly and Kimmins 1997; Wright *et al.* 1998; Jobidon 2000). Reported minimum light levels for survival of western boreal conifer species (expressed as a percentage of full sunlight) are 8% for white spruce (Lieffers and Stadt 1994), 4% for lodgepole pine (*Pinus contorta* Dougl. *ex* Loud var. *latifolia* Engelm.) (Messier 1996), 1% for subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) (Klinka *et al*. 1992), and 2.5% for balsam fir (*Abies balsamea* [L.] Mill.) (Parent and Messier 1995). Givnish (1988) and Messier *et al.* (1999) suggest that minimum light levels required for survival may increase as tree size increases due to the increase in the amount of respiring tissue that must be supported.

To favour establishment of natural regeneration and growth of subalpine fir and white spruce under coniferous canopies, Klinka *et al.* (1992) recommend 30% of full sunlight as a minimum target. Logan (1969) reports that height growth of white spruce and balsam fir reached a maximum at 45% of full sunlight. However, while total stem weight growth of balsam fir was higher at 45% than at 100% full sunlight, total stem volume growth of white spruce was significantly higher at 100% full sunlight than at 45% of full sunlight. Lieffers and Stadt (1994) also report that height growth of white spruce seedlings at 40% full sunlight beneath aspen canopies was approximately equal to that of seedlings growing in full sunlight. In contrast, Jobidon (2000) found that spruce height and diameter growth over the five years following treatment was greatest with complete removal of all overtopping vegetation.

Diagrams illustrating relationships between density, diameter, and understorey light provide a potentially useful tool for management decisions in young mixedwood stands in northeastern British Columbia.

A variety of studies show consistent relationships between understorey light and basal area of broadleaf-dominated stands (Comeau 1996; Messier 1996; Comeau *et al.* 1998; Buckley *et al.* 1999). MacDonald *et al.* (1990) found that basal area of aspen and other hardwoods served as an effective index for predicting competition effects on the growth of jack pine. An advantage to using basal area over other indexes or measurements is that this value can be obtained from most stand growth models. This provides the opportunity to examine the dynamics of competition over time using predictions of basal area development. However, in complex mixed-species stands, total basal area does not work well for predicting light levels in the understorey (Lieffers and Stadt 1994; Messier 1996).

This report summarizes results from a study conducted in 1998 and 1999 to examine relationships between understorey light levels in young aspen stands and stand attributes such as basal area, stand density, and average diameter. The overall objective of this work was to determine whether a general model could be developed for estimating light levels from readily measured stand attributes. If generally applicable relationships exist, then this information could be used to assist in the development of prescriptions for the management of mixedwood stands, by creating light levels conducive to desired rates of survival and growth of understorey conifers.

Methods

Six sites, ranging in age from 12 to 40 years, were selected for sampling during the summers of 1998 and 1999 (Table 1). All sites are located in the Boreal White and Black Spruce (BWBS) mw1 biogeoclimatic subzone and represented the 01 (white spruce, trembling aspen–step moss) site series (DeLong *et al.* 1990). Sites were located in the Dawson Creek and Fort St. John forest districts of northeastern British Columbia.

At each site, sample points were selected to characterize the observed range in stand density and basal area. Sample plots with a radius of 3.99 m or 5.64 m were used to obtain a tally of all trees. In the 12- and 25-year-old stands all plots were 3.99 m in radius. In older stands, a 3.99-m-radius plot was used when at least 20 trees were counted within the plot. If less than 20 trees were present in the 3.99-m-radius plot, then a 5.64-m-radius plot was used. When 20 or fewer aspen were present within the measurement plot, diameter at breast height (DBH) of each tree was recorded. When more than 20 trees were counted within the measurement plot, a random bearing was selected through plot centre, and the 20 aspen located closest to this line were measured for DBH. Height of the tallest aspen was measured in each plot.

At each plot centre, light was measured 1.5 m above the ground using a LiCor LAI-2000 Plant Canopy Analyzer (LiCor Inc., Lincoln, Nebraska). Measurements were taken at this height to avoid the influence of understorey vegetation. At each point, two readings were taken with 180° view restrictors attached to the sensor. Readings were taken in opposing directions twice during the day. This avoided having the sensor oriented towards the sun. Measurements were made on July 27, 28, and 29, 1998, and August 21 and 24, 1999. Previous studies have shown that diffuse non-interceptance (DIFN) values measured by this sensor give unbiased estimates of average growing season fractional transmittance (% of open-sky light) (Comeau *et al.* 1998; Gendron *et al.* 1998; Machado and Reich 1999).

To characterize vertical changes in light levels in young aspen canopies, a series of seven measurements were made at six locations at the Iron Creek site. At each location, LAI-2000 measurements were taken at seven heights (2, 3, 4, 5, 6, 7, and 8 m above the ground) by attaching a LAI-2000 sensor, equipped with an extension cable, to a 9 m high pole. The sensor head was equipped with a 180° view restrictor, and measurements were taken in each of two directions at each point. Measurements were limited to a height of 8 m because of difficulties encountered with levelling the sensor above this height. Open-sky readings were obtained by taking the sensor into a nearby opening at the beginning and end of the measurement series for each location. Each series of these measurements took approximately 20 minutes.

Results and Discussion

Basal area of the sampled aspen stands ranged from 5.0 to 36.4 m^2/ha, density ranged from 1401 to 29 791 trees per hectare, and DIFN (fractional transmittance) ranged from 0.08 to 0.82 (Table 1). Analysis of the data shows strong relationships between DIFN and basal area

TABLE 1. A summary of stand characteristics (ranges) for each of the 6 stands sampled

Site	Age (years)	No. of sample points	Density (aspen stems per ha)	Aspen basal area (m^2/ha)	Aspen height (m)	DIFN[a]
Bear Mountain	12	12	4 503–27 192	9.8–35.0	6.6–10.2	0.12–0.69
Iron Creek	12	16	2 999–24 393	6.2–35.6	6.8–10.5	0.12–0.65
Kiskatinaw (young)	12	14	6 198–29 791	5.0–30.9	6.0–8.8	0.08–0.82
Siphon Creek	25	6	3 999–14 996	22.6–34.9	11.6–17.5	0.17–0.24
Del Reo	30	14	1 401–9 397	12.1–36.4	12.3–18.2	0.09–0.36
Kiskatinaw (mid)	40	6	1 801–7 798	17.4–34.8	11.1–15.8	0.14–0.28

[a] DIFN = diffuse non-interceptance = fraction of full sunlight.

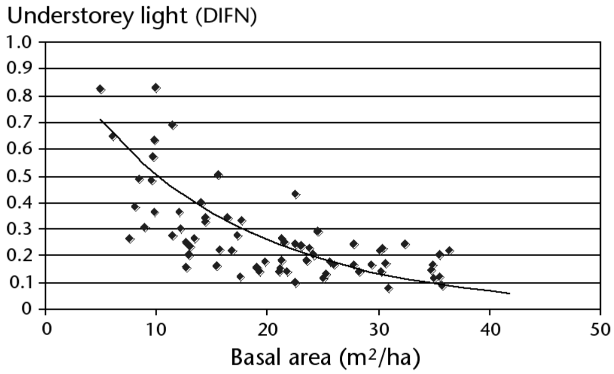

FIGURE 1. Scatter plot showing the relationship between understorey light (DIFN) and basal area (BA). The line is described by the equation: Ln(DIFN) = –0.06727 × BA (n = 68; R^2 = 0.917; RMSE = 0.453).

measured at the individual microsites (Figure 1). Analysis using the extra sums of squares principle (Draper and Smith 1981; Ott 1997) indicates that coefficients for the individual sites are not significantly different (p = 0.636) and that data from all sites can be pooled into a single relationship. Despite the relatively high coefficient of determination (R^2 = 0.917) for the regression shown in Figure 1, variation in light levels at any particular basal area is still substantial.

The line in Figure 1 suggests that a basal area of 8 m^2/ha or greater will result in light levels below 60%, and a basal area of 14 m^2/ha or greater will result in light levels below 40% at individual locations within the stands. At a basal area of 10 m^2/ha, understorey light levels of about 50% are predicted by the regression model. As indicated in Table 1, light conditions within individual stands vary substantially, as a reflection of within-stand variation in density and tree size. Consequently, these relationships should be applied primarily at the individual microsite level within stands.

When used by itself, aspen density was a poor predictor of variation in understorey light levels. However, a strong relationship is obtained when both aspen density and average basal area are used as independent variables (Figures 2 and 3).

In young stands, changes in basal area, average diameter, and stand density over time will result in changes in understorey light levels. Figure 4 illustrates results from simulations of aspen basal area growth completed using the Mixedwood Growth model (MGM98E) (Titus and Huang 1998). Simulations assume an aspen site index of 24 m at age 50 and an average DBH

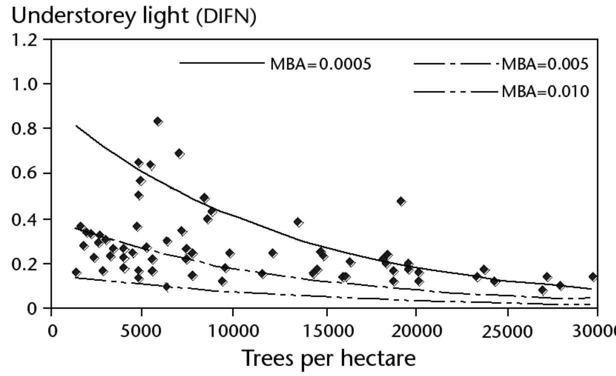

FIGURE 2. Scatter plot showing the relationship between understorey light (DIFN) and aspen density. Lines describe the relationship between DIFN and density (TPH) for different values of mean aspen basal area (MBA). The lines are described by the equation: Ln(DIFN) = –184.469 × MBA – 0.0000801 × TPH (n = 68; R^2 = 0.940; RMSE = 0.386).

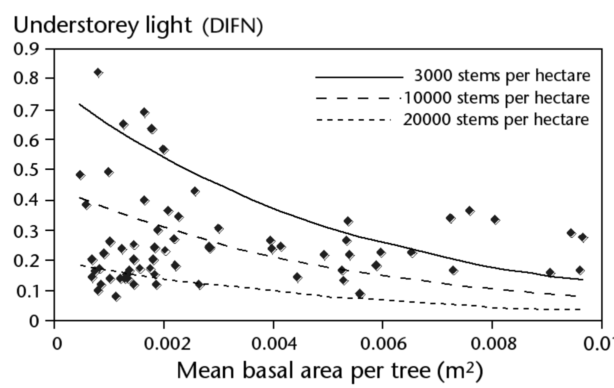

FIGURE 3. Scatter plot showing the relationship between understorey light (DIFN) and mean aspen basal area (MBA). The lines describe the relationship between DIFN and mean basal area for aspen densities. The lines are described by the equation given in Figure 2.

of 6.8 cm at age 12 (based on data from the Iron Creek site). Simulated changes in basal area were used with the equation presented in Figure 1 to estimate understorey light levels. These calculations suggest that light levels will decline from 0.55 at age 12 to 0.22 at age 20 in this stand, which starts with 3000 stems per hectare at age 12 and is predicted to have 2282 stems per hectare at age 30.

Figure 5 illustrates interactions between estimated understorey light levels, stand density, and quadratic mean diameter. These curves are based on the relationship between DIFN and basal area presented in Figure 1

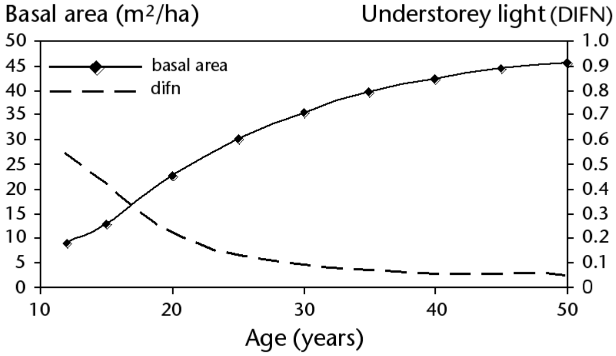

FIGURE 4. Simulated changes in aspen basal area and understorey light levels based on simulations using MGM98 for a stand with 3000 stems per hectare at age 12.

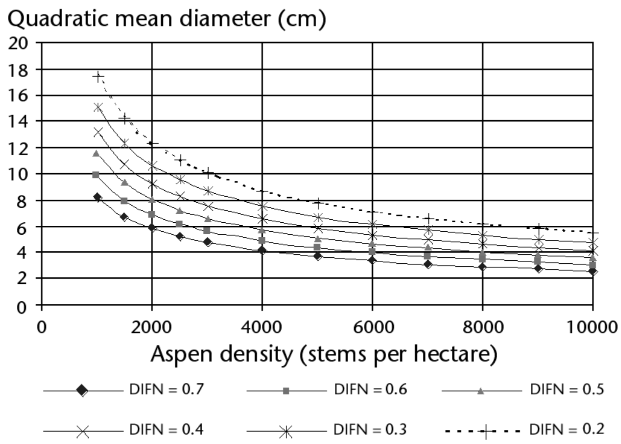

FIGURE 5. The relationships between understorey light, quadratic mean diameter, and stand density for 40-year-old or younger aspen stands. Individual lines correspond to the basal area corresponding to each particular light (DIFN) level.

for the sampled stands 40 years old and younger. While these curves resemble a stocking guide (Gingrich 1967), they do not incorporate expected declines in stand basal area with increased density as is typically observed in fully stocked stands. This figure indicates that maintaining understorey light levels above 0.4 requires maintaining aspen basal area below 14 m^2/ha, and that aspen density would have to be less than 2000 stems per hectare when aspen diameter is 9.3 cm and below 5000 stems per hectare when diameter is 5.9 cm. Likewise, to maintain understorey light levels above 0.6, which requires maintaining aspen basal area below 8 m^2/ha, aspen density would have to be less than 2000 stems per hectare when aspen diameter is 7.0 cm, and below 5000 stems per hectare when diameter is 4.4 cm. Diagrams such as these may be useful in developing prescriptions for manipulating aspen density to create desired understorey light levels. When linked with growth models, this information may be useful in developing stand tending strategies. However, this approach requires further testing before being widely applied. Local data should be obtained to verify these relationships before attempting to apply this approach in other areas.

Following spacing or harvesting, stand leaf area index (LAI) is reduced and the amount of light penetrating the canopy is increased. The fraction of above-canopy light penetrating to the understorey is inversely related to basal area of the residual stand (Johansson 1987; Jenkins and Chambers 1989; Oliver and Dolph 1992; Comeau *et al.* 1998). Following thinning, the crowns of leave trees will expand and, over time, the amount of light reaching the understorey may decrease. The rate at which tree canopies close after thinning will depend on the proportion of the original stand remaining and on the rate at which the remaining trees grow. Since LAI is related to stand basal area, the rate of increase in LAI and associated light reductions should be related to the rate of basal area growth.

Vertical profiles (Figure 6) illustrate a rapid increase in light levels moving from crown base (relative height

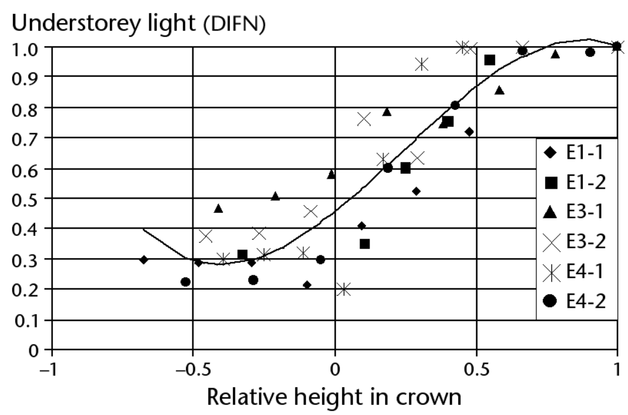

FIGURE 6. Vertical profiles of light (DIFN) for six sampled points at Iron Creek. Relative height in the crown is used to illustrate trends in relation to distance between crown base (0), top of the aspen canopy (1), and the ground (–1). The line shown describes the general relationship between light level and relative height (RELHT) in the crown and is described by the equation: DIFN = 0.4502 + 0.7481 × RELHT + 0.5070 × $(\text{RELHT})^2$ – 0.7058 × $(\text{RELHT})^3$ (n = 48; R^2 = 0.858; RMSE = 0.1143).

in crown = 0) to the top of the canopy (relative height in crown = 1). At a relative height in the crown of 0.5, light levels exceed 0.85 (85% of full sunlight). This vertical gradient in light levels is one factor that may contribute to improved growth of conifers as they grow up through an aspen canopy. This vertical gradient also indicates that the relationship between light and basal area shown in Figure 1 applies only when estimating light below the base of the aspen canopy.

Conclusions

For the stands less than 40 years of age that were sampled, basal area provides a useful general predictor of understorey light levels. However, these results should not be extrapolated to older stands or to very different sites without carefully evaluating the results. Light measurements collected in one 80-year-old stand indicate that these relationships between understorey light and basal area may not hold in older aspen stands. Further study is required to determine whether these relationships change in different regions as a result of changes in climatic conditions. Messier *et al.* (1998) suggest that lower mean annual precipitation may be responsible for the lower LAI and higher levels of light in the understorey of aspen stands in Alberta than in Quebec.

Available literature indicates that height growth of understorey spruce should be maximized when light levels are above 40% or when aspen basal area is below 14 m^2/ha. Growth models presented by Wright *et al.* (1998) indicate that radial growth of white spruce increases almost linearly with increasing light. Using their equation, a continuous decline in radial increment is predicted with increasing aspen basal area. Maximum diameter growth is predicted to occur when virtually no aspen are present (Figure 7). Estimated radial increment is reduced to 70% when aspen basal area is 8 m^2/ha (DIFN = 0.6), to 62% when aspen basal area is 10 m^2/ha (DIFN = 0.5), and to 51% when aspen basal area is 14 m^2/ha (DIFN = 0.4). When applied to the data presented in this paper, the Wright *et al.* (1998) models also suggest that mortality of spruce will remain very low up to a basal area of 20 m^2/ha, and will increase rapidly as basal area increases beyond this point. Results obtained in this study indicate that once spruce height exceeds the bottom of the aspen canopy, further increases in height are rewarded with increases in the amount of light that reaches the top of the tree.

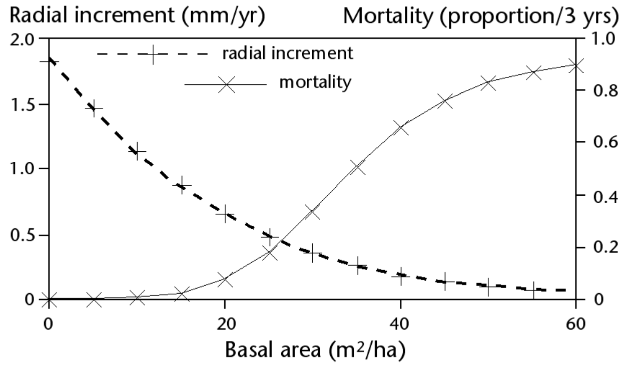

FIGURE 7. Relationships between radial growth or mortality of white spruce and basal area of aspen, based on relationships between spruce performance and light presented by Wright *et al.* (1998).

These estimates must be applied cautiously, since potential benefits of an aspen overstorey are not included in these calculations. As well as serving as a nurse crop, retaining some residual aspen may reduce the vigour with which aspen resprout following cutting and the subsequent growth and survival of aspen suckers (Mowrer 1988).

During the first 30 years of stand development, Mixedwood Growth Model simulations suggest a rapid increase in aspen basal area, with a resulting decline in understorey light levels. Even with relatively low initial aspen densities (3000 stems per hectare at age 12), which may initially give adequate light for growth of understorey spruce, light levels may quickly decline to levels that could cause substantial reductions in spruce growth. At higher initial densities, the decline in understorey light levels is likely to occur more rapidly, resulting in the potential for substantial reductions in growth and survival of understorey spruce due to competition for light and physical damage to spruce resulting from aspen mortality (self-thinning). More refined distance-dependent growth and yield models for individual trees would offer a useful basis for examining temporal dynamics of light in these and other forests.

Diagrams illustrating relationships between density, diameter, and understorey light provide a potentially useful tool for designing prescriptions to create suitable conditions for growth of spruce and other conifers in the understorey of aspen-dominated boreal mixedwood stands. Diagrams such as these could be useful for developing prescriptions for spacing and thinning of the overstorey aspen canopy to create desired light levels for survival and growth of understorey white spruce. Further research is required to improve our understanding of interactions between aspen and white spruce, particularly the influence of site factors on interactions and their intensity, and to test and refine the application of these diagrams to the management of boreal mixedwood stands.

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