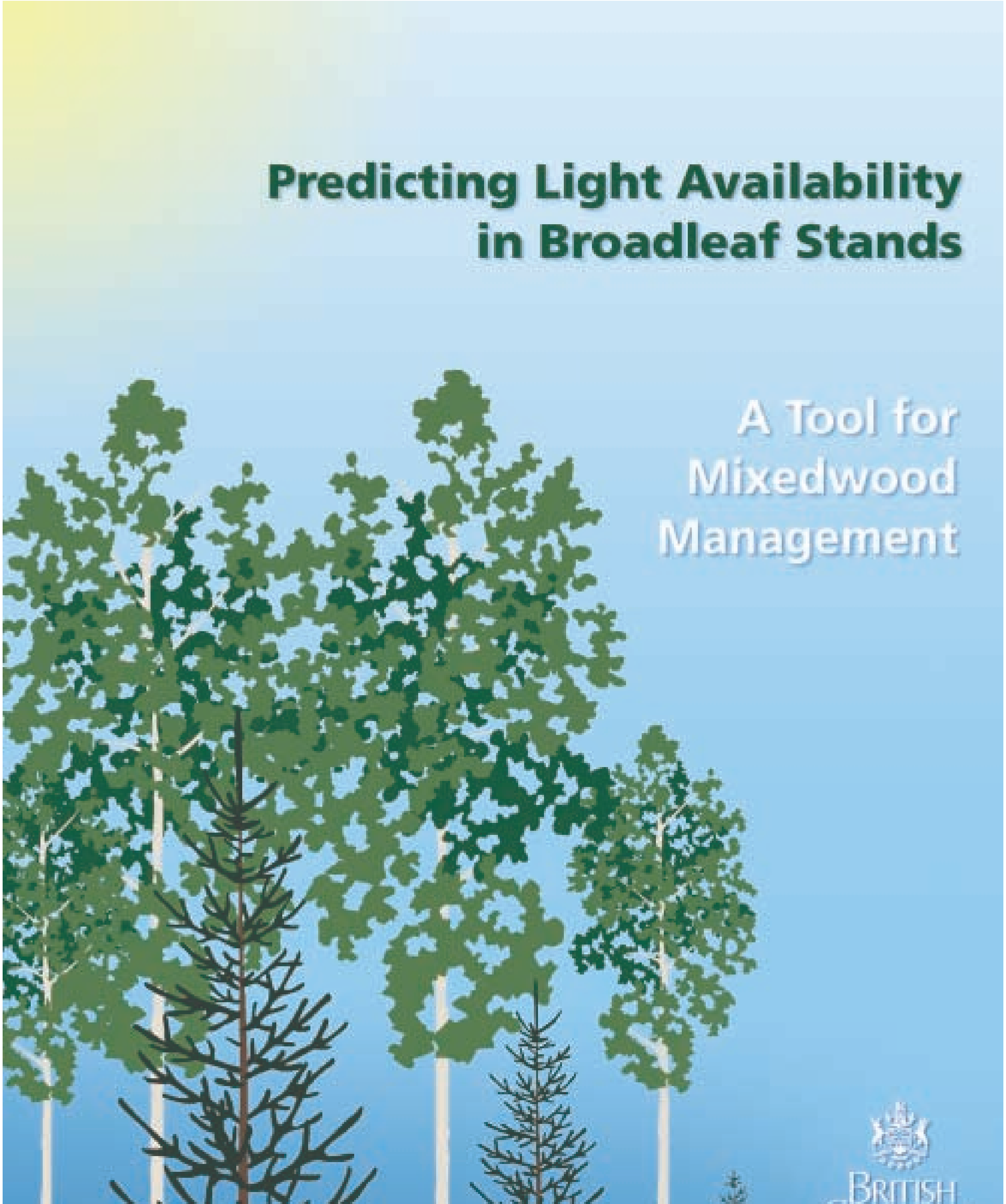
Predicting Light Availability in Broadleaf Stands

A Tool for Mixedwood Management



BRITISH COLUMBIA

Ministry of Forests

Contents

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Light – a limiting resource

In young mixed stands, light is usually the most limiting resource for conifers that are overtopped by more rapidly growing juvenile broadleaves. Depending on light requirements for the particular conifer species, this can result in reduced survival, vigour, and growth. However, broadleaves also provide many benefits at the ecosystem, site, and individual tree levels, and current management objectives often aim to retain a component of broadleaves while still meeting goals for conifer performance.

To manage individual mixedwood stands, we need practical ways of answering the following questions:

1. Are broadleaves reducing light availability to the point where conifer growth objectives cannot be met?
2. If so, how many broadleaf stems, and which ones, should be removed?

Benefits of broadleaf retention

- Long-term site productivity is maintained because broadleaves cycle nutrients through annual leaf production and leaf fall
- Health and diversity of the soil community is maintained
- Wildlife food and shelter
- The spread of root disease is reduced
- Sprouting and suckering of cut broadleaf stems is minimized.

Regression models can be used to predict light availability

We have information about light requirements for various conifer species (Appendix A), but measuring light in forest stands is not a practical operational procedure because it requires specialized equipment and technical expertise. Instead, light availability can be determined indirectly using **regression models** that predict percent light from easily measured broadleaf variables (e.g., basal area). Regression models have been developed to predict light availability both under and within broadleaf canopies. Both can be important, depending on how tall the conifers are relative to the broadleaves (Figure 1).

'Regression models' use independent variables (e.g., basal area of broadleaves) to predict how a dependent variable (e.g., understorey light) will respond. The measure of how much variation in the dependent variable the model explains is the R^2 value. The R^2 value of 0.525 shown in Figure 8 tells us that, using that model, aspen BA explains 52.5% of the variation in understorey light availability.

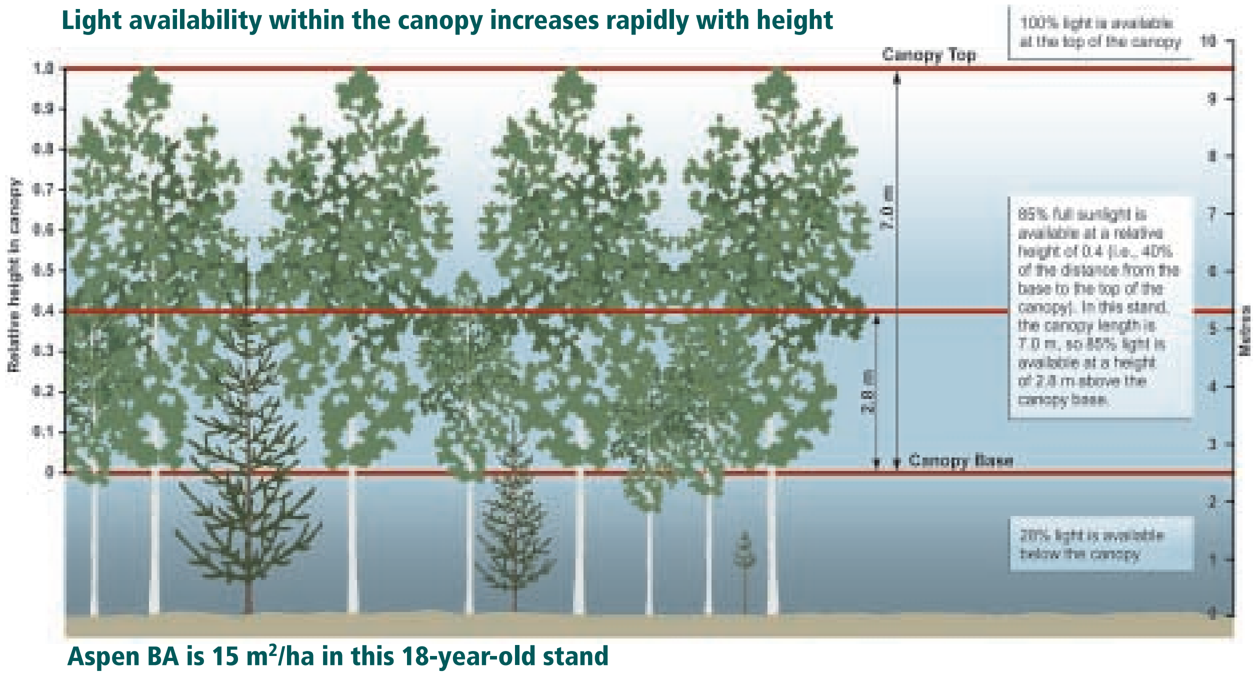


Figure 1. *Light availability increases rapidly with height in the canopy, even in dense stands where understorey light availability is low.*

Researchers have developed models to predict light availability in aspen stands in northern interior BC, paper birch stands in southern interior BC, and to a limited extent in red alder and bigleaf maple stands in coastal BC. The relationships differ between broadleaf species because of factors such as leaf shape, size, orientation, and opaqueness. For example, more light is available in the understorey of an aspen stand with BA of 10 m^2/ha than in birch, red alder, or bigleaf maple stands of similar BA (Figure 2).

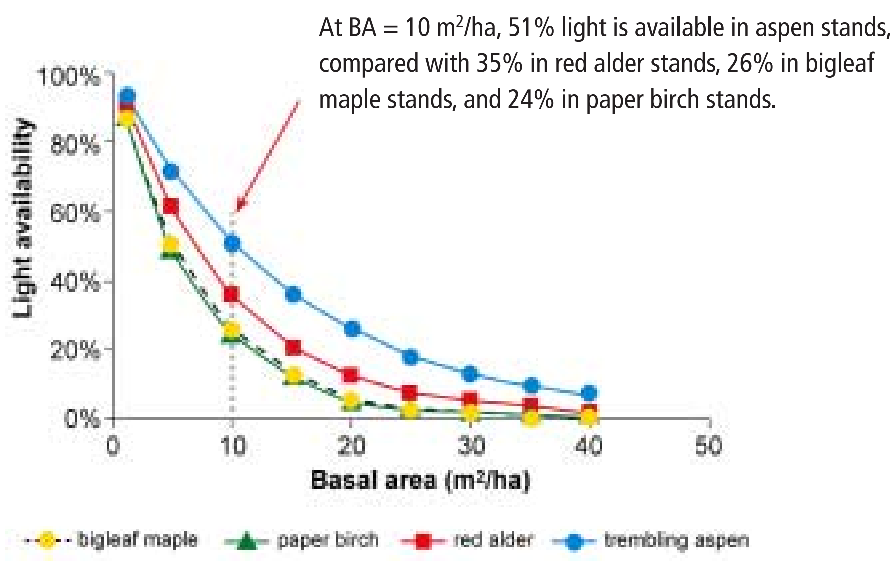


Figure 2. *The relationship between understorey light availability and basal area of trembling aspen (BWBS zone) (Comeau 2001), paper birch (ICH/IDF zone) (Comeau and Heineman 2003), red alder and bigleaf maple (CWH zone) (Comeau, unpublished data).*

Light availability is influenced by broadleaf distribution

General growth habit also varies between broadleaf species and can affect light availability at the microsite level. For example, paper birch produces abundant sprouts from stumps that are cut during harvest. This leads to clumpy distribution and variable light availability on many sites (Figure 3).

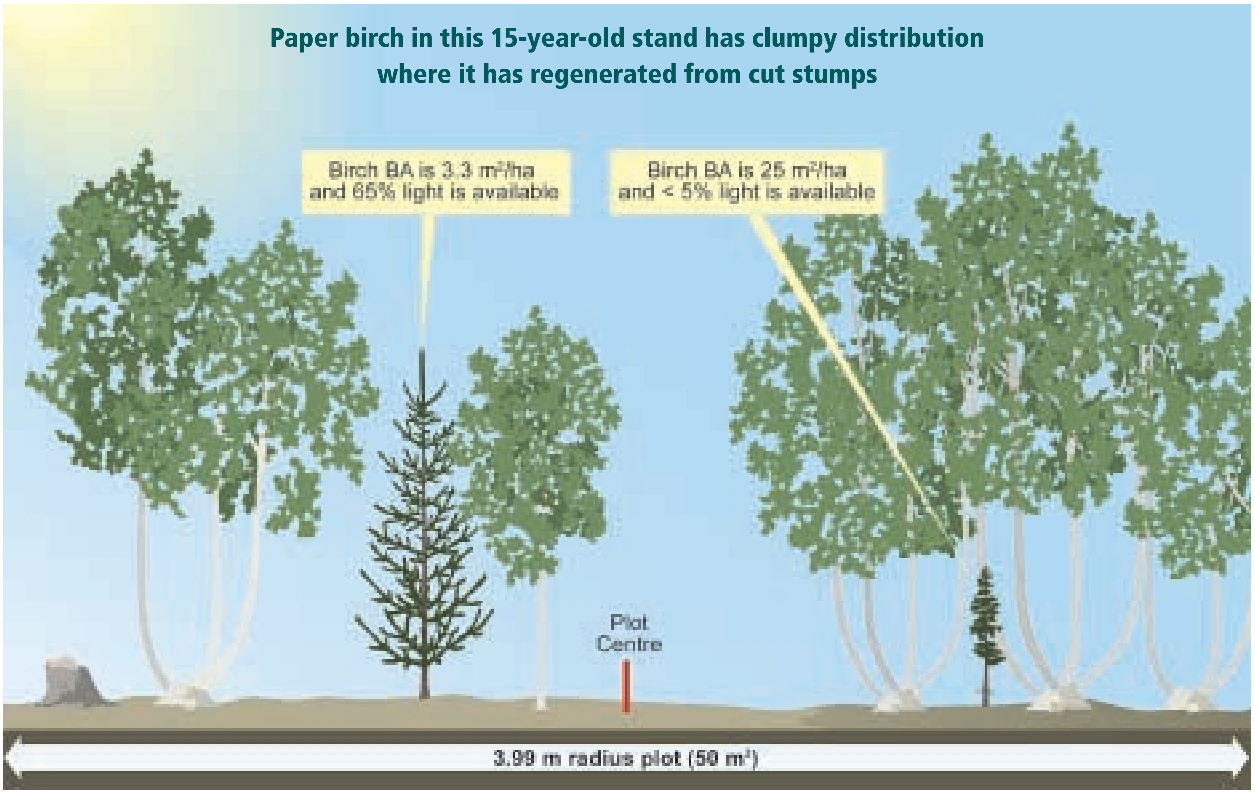


Figure 3. *Typical clumpy distribution of sprout-origin birch.*

In contrast, cut aspen regenerates primarily from suckers that emerge from underground buds on the root system. This results in a more even distribution of stems than in birch stands, but density can still vary a great deal across a cutblock (Figure 4).

Aspen distribution may be regular within small areas, but it varies across a cutblock

Figure 4. *Typical distribution of sucker-origin aspen.*

Light availability can be predicted from broadleaf size and abundance variables

Light availability under and within broadleaf canopies depends on the crown size of individual broadleaf trees and the density and size of stems. In young stands, crown size increases with stem size, which makes it possible to predict light availability from measures of broadleaf abundance that include:

(a) broadleaf basal area (BA);

(b) broadleaf quadratic mean diameter (QMD); and

(c) height of the tallest broadleaf stem.

Broadleaf density alone is not a good predictor of light availability in young stands because it does not contain a measure of individual or collective broadleaf size (Figure 5).

All of these stands have BA of 5.7 m^2/ha and 60% light in the understorey

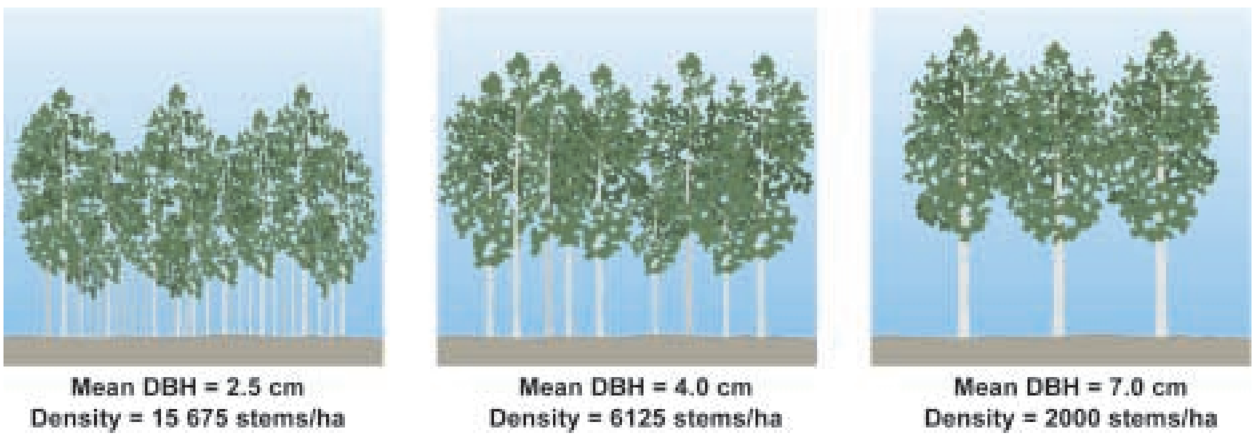


Figure 5. *These three stands have different densities, but they all have BA of 5.7 m^2/ha and 60% light availability in the understorey. In juvenile stands, broadleaf density alone is a poor predictor of understorey light availability.*

Practical Application of the Relationships Between Broadleaf Abundance and Light Availability

Prior to using the models discussed in this report to assist in the development of operational treatment prescriptions for mixedwood management, practitioners should be certain the following criteria are met:

- Stand level objectives for mixedwoods are consistent with management plans.
- The conifer and broadleaf species being managed have passed assessments for future productivity, reliability, and silvicultural feasibility for the ecosystem and site series.
- The regression model is valid for the ecosystem in question. Before these relationships can be applied on a broader operational basis, they must be tested on an ecosystem-by-ecosystem basis. Various studies are underway to accomplish this. The models used in the following example have been tested for the BWBS and SBS zones of north-central BC. Additional models are provided in Appendix B.

In order to illustrate practical application of the relationships between broadleaf abundance and light availability in the development of treatment prescriptions, we will work through an example using data from a stand in the BWBSmw1 near Fort St. John, BC. Aspen in this stand regenerated naturally following harvest 16 years ago. White spruce were planted 15 years ago. A few black cottonwood stems were present in the stand, but were considered to be aspen for purposes of doing the calculations and using the models.

In this example, we will use a model that predicts light availability from aspen BA. Other models that predict light availability from other broadleaf variables, such as quadratic mean diameter and relative density, have also been developed (see Appendix B) but their use is not described in this report. More information about using these models can be obtained from the MOF Forest Practices Branch (contact information is provided on page 14).

We caution readers that stand development is a dynamic process. The following example illustrates the relationship between broadleaf BA and light availability under and within the aspen canopy, which is the primary objective of this report. However, the example does not adequately take into consideration potential increases in aspen BA as the stand matures. Researchers are currently developing models for mixedwood stand development, and when these become available they will help determine if and when additional stand entries are required to maintain adequate light availability to meet conifer growth objectives. In the meantime, Comeau (2003) has used the relationship between light availability, aspen density, and aspen quadratic mean diameter to provide tables that will help practitioners make these decisions. A table showing light availability at different levels of aspen density and quadratic mean diameter is provided in Appendix G (based on Comeau 2003).

Example

In this example, the objectives are:

- Spruce growth and yield will be enhanced as much as possible within the context of a mixedwood stand.
- Spruce will move into a mid-canopy position.
- Spruce and aspen will be harvested together at the end of the rotation.

Research has shown that diameter and height growth of white spruce in boreal regions are approximately 70 and 80% of maximum values, respectively, where light availability is 60% (Wright et al. 1998). P. Comeau (pers. comm. 2003) recommends maintaining approximately 60% full sunlight as a realistic approach to achieving acceptable spruce growth without stimulating the growth of understorey species such as bluejoint (*Calamagrostis canadensis*). We discuss the process of developing a prescription in four steps.

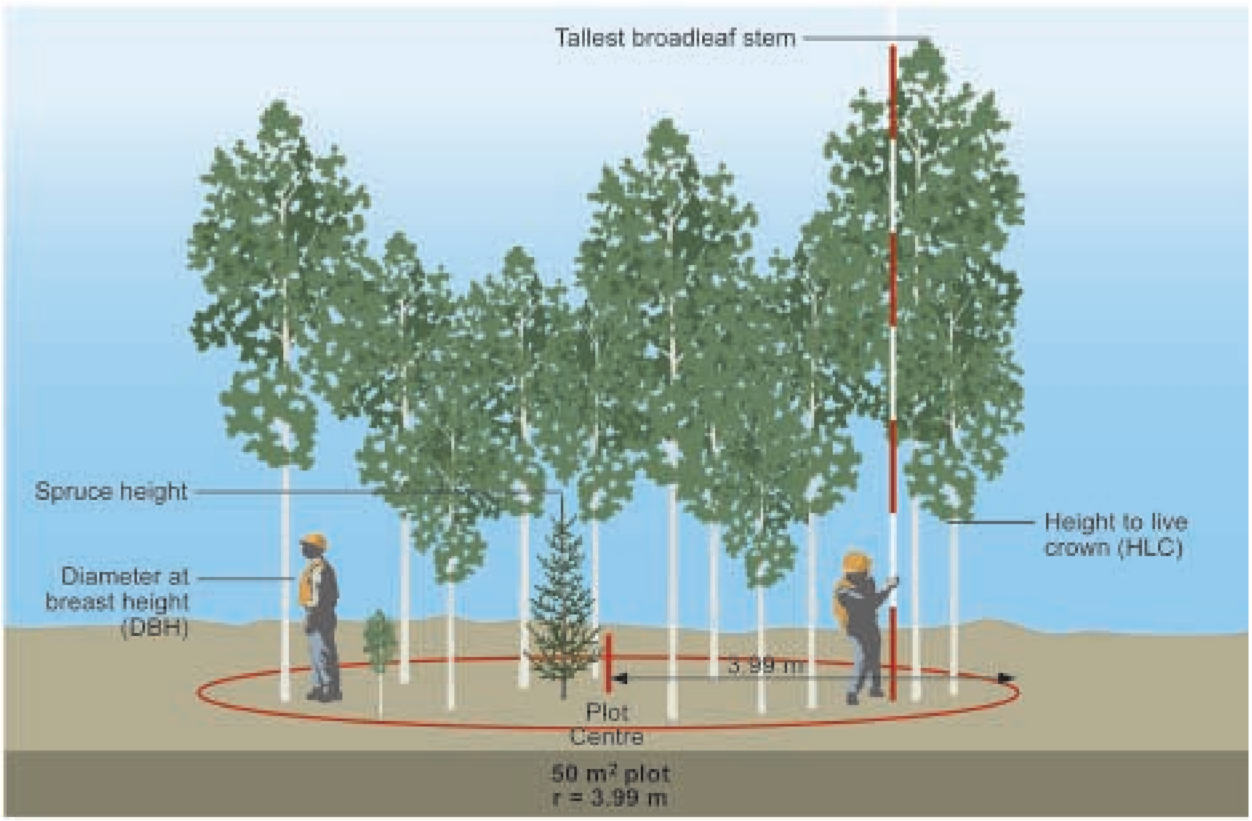
Step 1 – Collect data that characterizes the stand

A – Establish a transect

- Walk through the stand to become familiar with the range in broadleaf density and size.
- Establish a transect that is representative of the variation in density and size. Plots can be established at intervals of 10 m or more, depending on the desired sampling density. The inter-plot distance should be selected to facilitate sampling as full a range of densities as possible.

B – Collect the data

- Data can be collected in 50 m^2 (radius = 3.99 m) plots or, where average height of the aspen canopy is taller than 10 m, in 100 m^2 (radius = 5.64 m).
- Collect data as illustrated in Figure 6. A sample data collection form is provided in Appendix C.



1. Measure the height of the tallest aspen stem
2. Measure DBH for all broadleaf stems that are at least 1.3 m tall (don't measure shorter broadleaf stems)
3. Measure height of all conifers taller than 30 cm
4. Measure HLC for the first 20 broadleaf stems, working clockwise around the plot from due N.

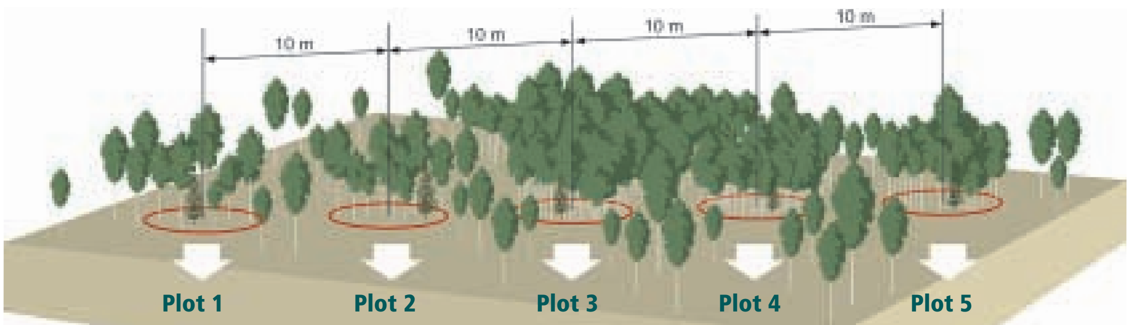
Figure 6. *Collecting data in a 50 m^2 (3.99 m radius) plot.*

Step 2 – Calculating broadleaf stand variables from the data

The following variables can be easily calculated from your data.

- Broadleaf stems per hectare
- Mean broadleaf DBH
- Mean broadleaf HLC
- Mean spruce height
- Mean broadleaf BA per hectare
- Mean broadleaf BA per stem.

All the necessary calculations can be done in Excel. Formulas for doing the calculations can be found in Appendix D and information about how to use Excel for this purpose can be found in Appendix E.



	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5
Aspen density	2575 sph	2800 sph	8000 sph	11 500 sph	4075 sph
Mean aspen DBH	5.3 cm	4.6 cm	4.6 cm	4.0 cm	4.9 cm
Height of tallest aspen	9.8 m	8.4 m	9.7 m	9.1 m	9.8 m
Mean height to live crown (from 20 measurements)	2.3 m	2.5 m	2.0 m	2.2 m	2.1 m
Mean spruce height	3.4 m	3.8 m	3.2 m	3.0 m	4.4 m

Figure 7. *Aspen density and BA for the five plots in our example stand. Note the variation that occurs over a distance of 40 m.*

Step 3 – Use one of the regression models to determine understorey light availability in the present stand

For our example stand, we will use the relationship between broadleaf (aspen) BA and light (Figure 8) to answer the following questions:

How much understorey light is currently available in our sample plots?

Based on our DBH measurements, we know that broadleaf BA in our plots ranges from 7.1 to 20.4 m^2/ha (Figure 8). By reading values from the curve in Figure 8 or using the associated equation [ln(difn) = 0.8583 – 0.78698 × BA] (see Appendix F for an example calculation) we can determine that light availability in our five plots ranges from 22–57%. Our target is to have at least 60% available light in the understorey.

How much broadleaf BA can we retain, and still have 60% light availability?

Based on the relationship shown in Figure 8, we will have 60% light availability in the understorey at aspen BA of 5.7 m^2/ha.

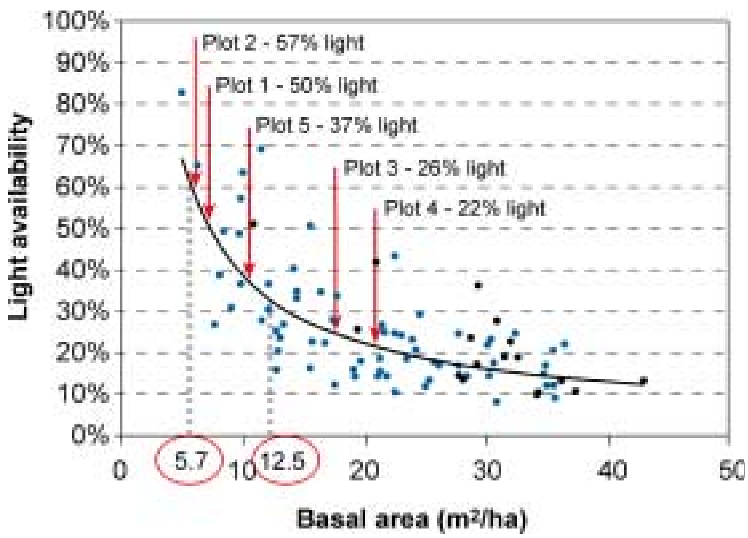


Figure 8. *Scatter plot showing the relationship between understorey light and aspen BA in the BWBS and SBS zones of north-central BC. The line is described by the equation: ln(difn) = 0.8583 – 0.78698 × ln(BA) (n = 86; R^2 = 0.525; RMSE = 0.3608) (Comeau 2003).*

Step 4 – Consider the relative height of spruce within the aspen canopy

We need to consider the height of spruce relative to aspen because light availability increases rapidly from the base to the top of the canopy. If spruce are tall enough, on average, to have more than 30% of their crowns within the aspen canopy, we should consider light availability within the canopy. If spruce are mainly growing below the canopy, we need only consider understorey light availability.

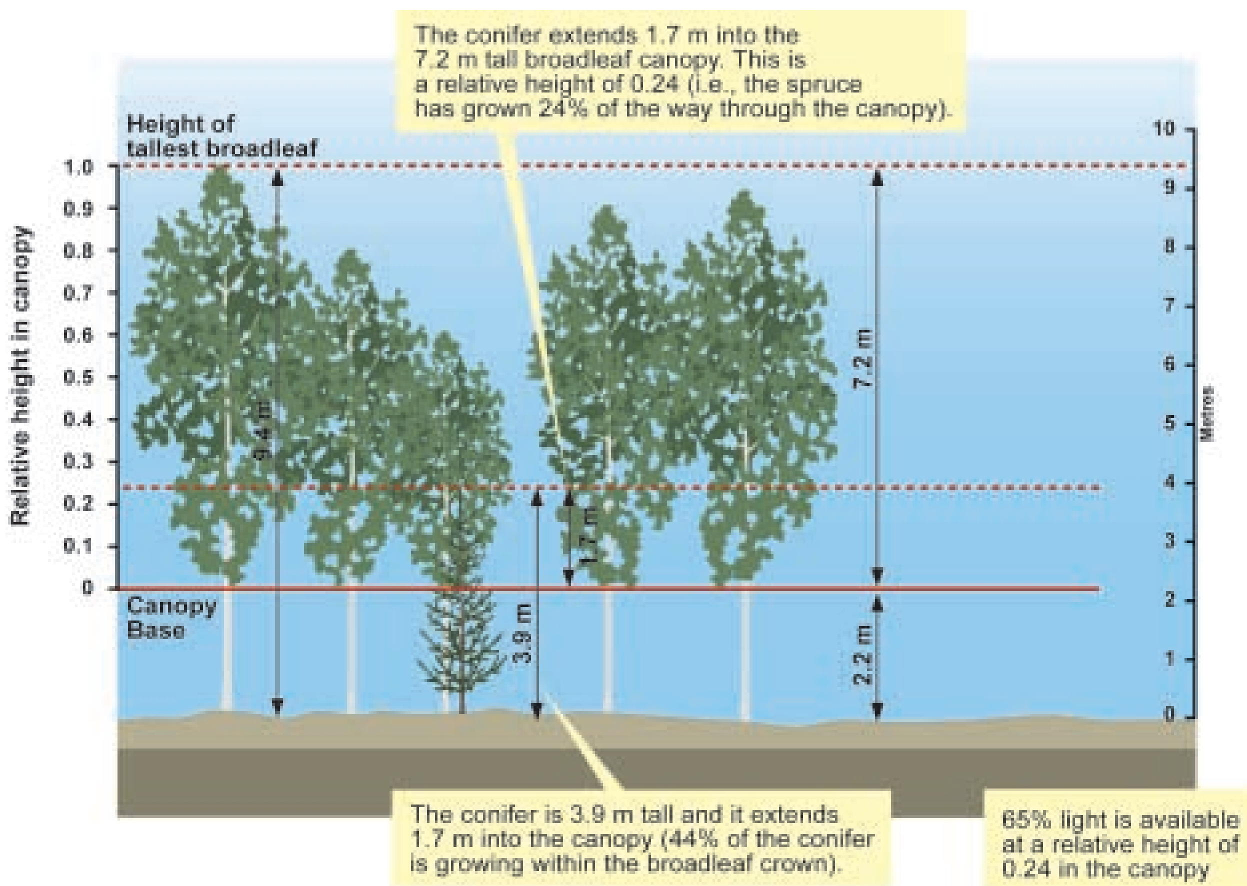
In order to consider relative height of spruce and aspen, we must:

- Determine the average canopy height (i.e., the average distance from the canopy base to the top of the tallest broadleaf).
- For our example stand, the average 'tallest broadleaf' height is 9.4 m and the average HLC is 2.2 m, so height of the canopy is 7.2 m. Our spruce trees average 3.9 m tall, which means they extend 1.7 m into the canopy. This is a relative height of 0.24 within the aspen canopy.
- Based on the relationship shown by the graph in Figure 9, we can see that 65% light is available at a relative height of 0.24.

- We can see from the graph in Figure 9 that 60% light is available at a relative height of approximately 0.20. In our 7.2 m tall canopy, relative height of 0.20 is 1.4 m above the canopy base (0.20 × 7.2 m = 1.4 m), and 3.6 m above the ground (2.2 m to base of the live crown + 1.4 m = 3.6 m).
- Spruce are 3.9 m tall, which means they are receiving adequate (60%) light only within the top 0.3 m of their crown. This suggests that we can look mainly at understorey light to determine whether we need to reduce aspen abundance.

Rule of thumb:

If the top of the conifer is at least halfway into the broadleaf canopy and at least 30% of its live crown is in the broadleaf canopy, the conifer is likely accessing sufficient light to sustain reasonable growth.



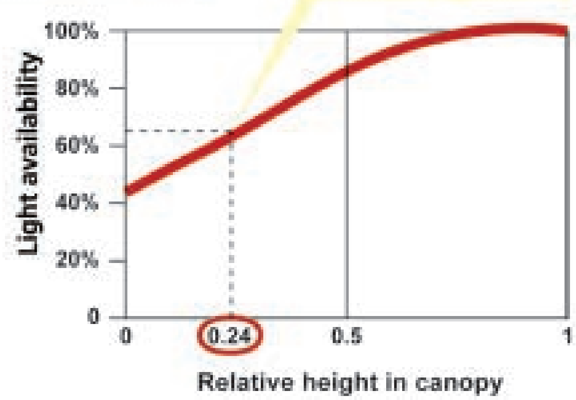


Figure 9. *The height of conifers relative to the broadleaf canopy is important because light availability increases rapidly within the canopy. The graph on the right shows the general relationship between light availability and relative height in the aspen canopy. It is described by the equation:* $difn = 0.4502 + 0.7481 \times relht + 0.5070 \times (relht)^2 - 0.7058 \times (relht)^3$ *(Comeau 2001).*

Step 5 – Develop a strategy for managing the stand based on understorey light availability

We can see from Figure 8 that all of our five sample plots have less than 60% light availability in the understorey. This means that spruce are not receiving enough light to achieve maximum diameter growth. On this basis, we can make the decision to reduce aspen abundance.

We want to reduce aspen BA to 5.7 m^2/ha, but how many stems should we remove and how do we decide which ones to cut?

One approach to developing a treatment prescription is to determine an appropriate aspen density on the basis of **mean aspen BA/stem**.

- In our example stand, mean aspen BA/stem ranges from 0.0018–0.0028 m^2/stem. We can calculate an appropriate density for aspen retention by dividing our desired BA/ha (5.7 m^2/ha) by mean aspen BA/stem. For our example stand, this approach suggests retaining 2036–3167 aspen stems/ha.
- In practical terms, we could prescribe the retention of 2000 aspen stems/ha (10 aspen stems in a 50 m^2 plot), with brushers instructed to leave a range of stem sizes. This approach is illustrated in Figure 10.
- In order to maintain at least 60% understorey light availability, Comeau (2003) recommends that quadratic mean diameter in a stand with 2000 aspen stems/ha should not exceed 6.0 cm (see Appendix G).

A second approach to reducing aspen BA to 5.7 m^2/ha so that 60% light is available is to focus on removing the largest aspen stems.

- This approach is practical because we would like to maximize spruce growth within the confines of a mixed stand and allow spruce to eventually move into dominant and co-dominant canopy positions.
- If we remove all aspen with DBH ≥ 8 cm, we can change the sample plot characteristics to those shown below. Following removal of stems ≥ 8 cm DBH, plots 1, 2, and 5 will meet target light levels and plots 3 and 4 will require additional aspen removal.

Characteristics of our example stand after removal of all stems with DBH ≥ 8 cm

	Plot 1	Plot 2	Plot 3	Plot 4	Plot 5
Aspen density* (stems/ha)	2075	2625	7500	10,600	3350
Mean aspen DBH (cm)	4.3	4.3	4.4	3.9	3.6
Aspen BA per hectare (m^2)	3.8	4.9	13.5	14.8	5.5
Aspen BA per stem (m^2)	0.0018	0.0019	0.0018	0.0014	0.0016
Understorey light (%)	83	68	30	28	62
Aspen density per hectare where BA is 5.7 m^2/ha	3167	3000	3167	4071	3562

* Aspen density where BA is 5.7 m^2/ha is determined by dividing 5.7 m^2/ha by mean aspen BA/aspen stem.

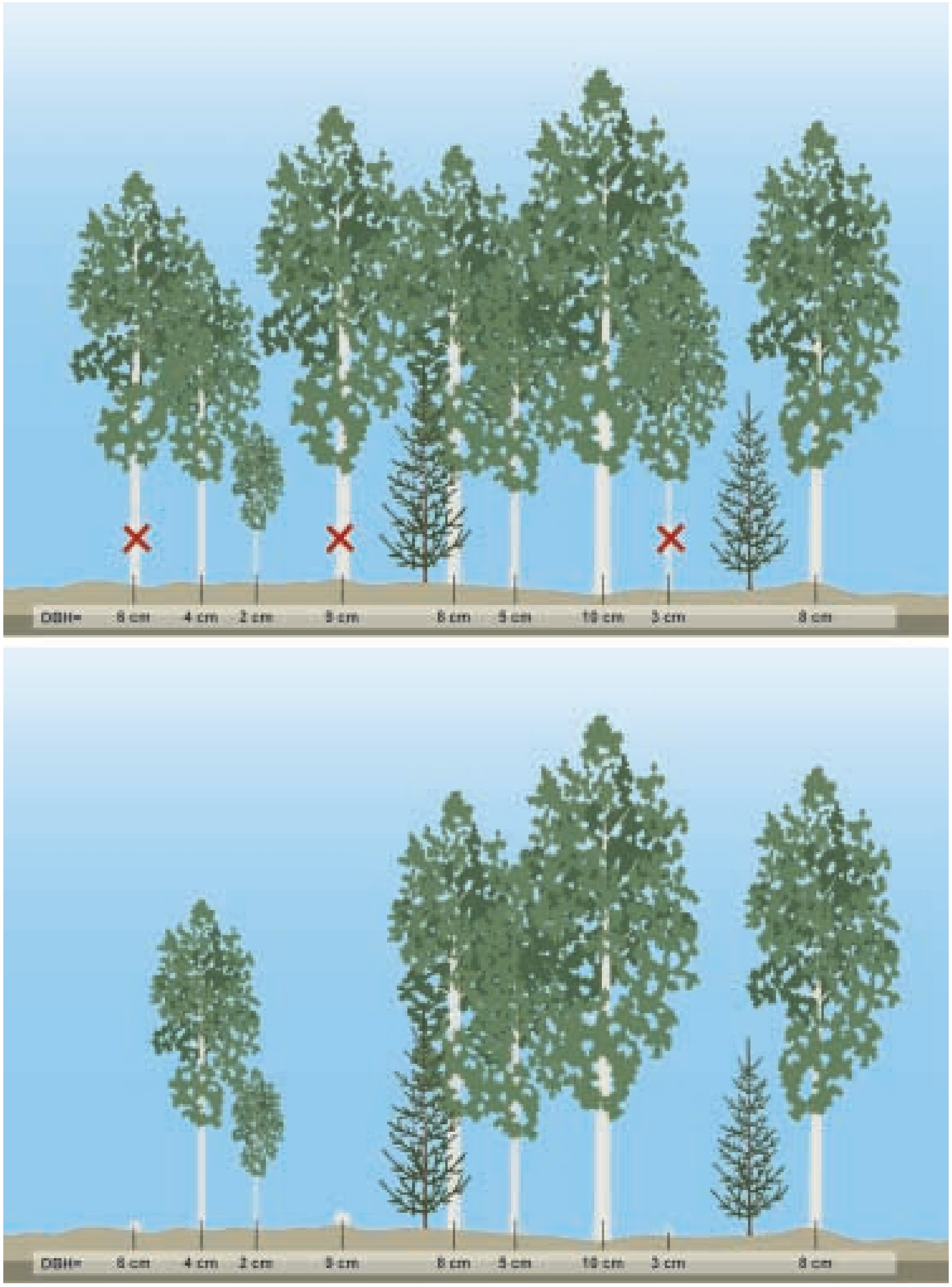


Figure 10. *One approach to reducing aspen density to the prescribed level is to instruct brushers to remove aspen with a range of diameters. In this example, the worker cut stems that were 3 cm, 6 cm, and 9 cm.*

- Brushers can be instructed to ensure that density of remaining aspen stems is no higher than 3000 stems/ha (17.5 aspen stems in a 50 m^2 plot). A maximum density of 3000 aspen stems/ha is appropriate because it will result in all areas of the stand (based on the above table) having aspen BA of 5.7 m^2/ha or lower.
- Removing the largest aspen stems will also reduce overall height of the aspen canopy and will move spruce into a mid-canopy position. This approach is illustrated in Figure 11.
- In order to maintain at least 60% understorey light availability, Comeau (2003) recommends that quadratic mean diameter in a stand with 3000 aspen stems/ha should not exceed 4.0 cm (see Appendix G).

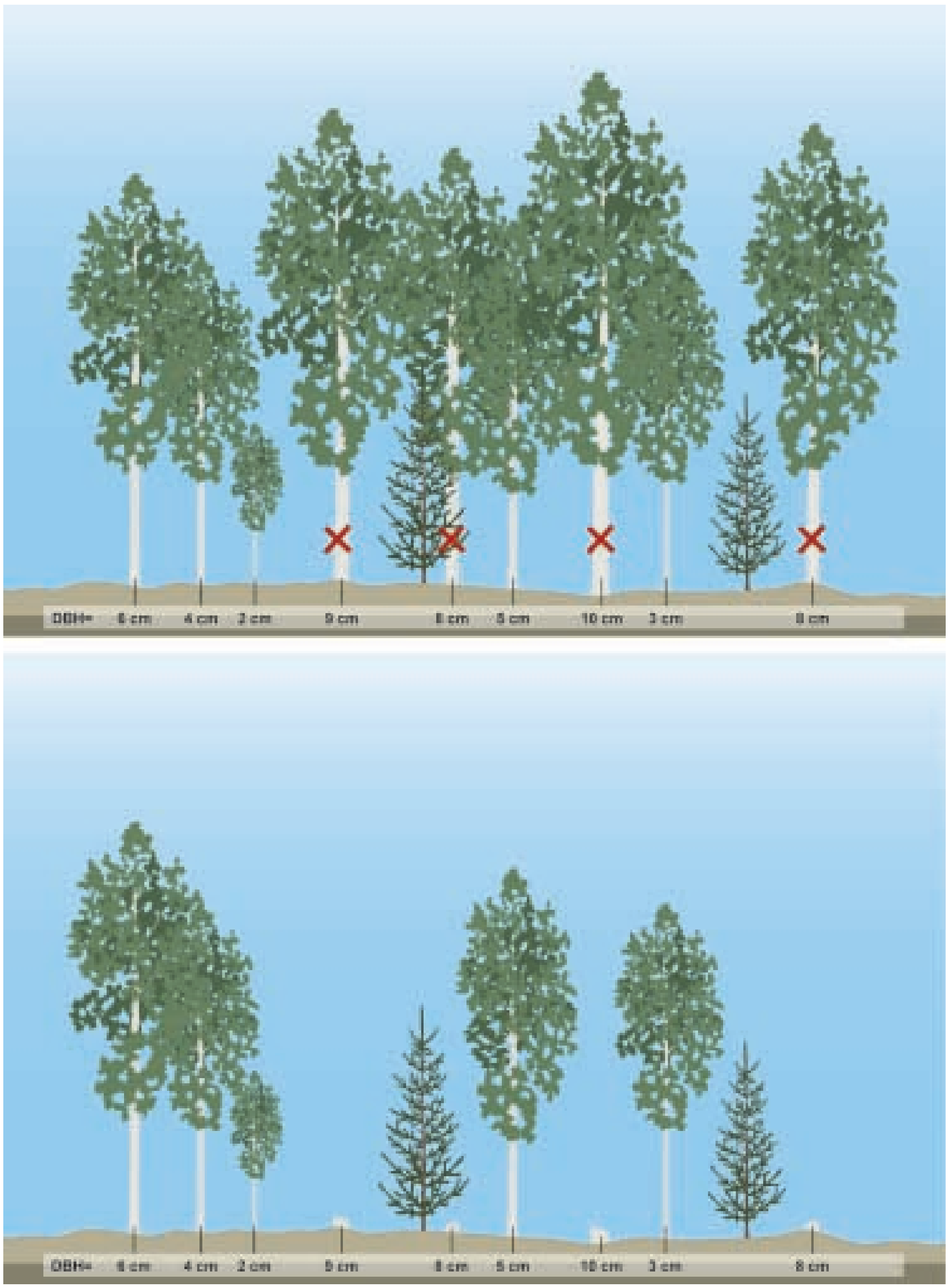


Figure 11. *In this approach, brushers are instructed to reduce aspen density to the required level by first of all removing stems with DBH ≥ 8 cm and then, where it is necessary, further reducing density to 3000 stems/ha by removing a range of diameters.*

Other Considerations

Should treatments be applied on a broadcast basis or a microsite-specific basis? If we are brushing by microsite, how big should the treatment radius be?

Research suggests that size of the neighbourhood in which broadleaves and conifers compete for light increases as stands age. It also increases in size as the height differential between broadleaf and conifers increases. Recommended brushing radius ranges from a minimum of approximately 2 m in the Cariboo-Chilcotin (Newsome et al. 2003) to much larger sizes in boreal regions. Where conifer stocking is at least 1200 stems/ha, and stems are well-spaced, manipulating broadleaf density in a 2 m radius around crop conifers is essentially a broadcast treatment. This is demonstrated below in Figure 12.

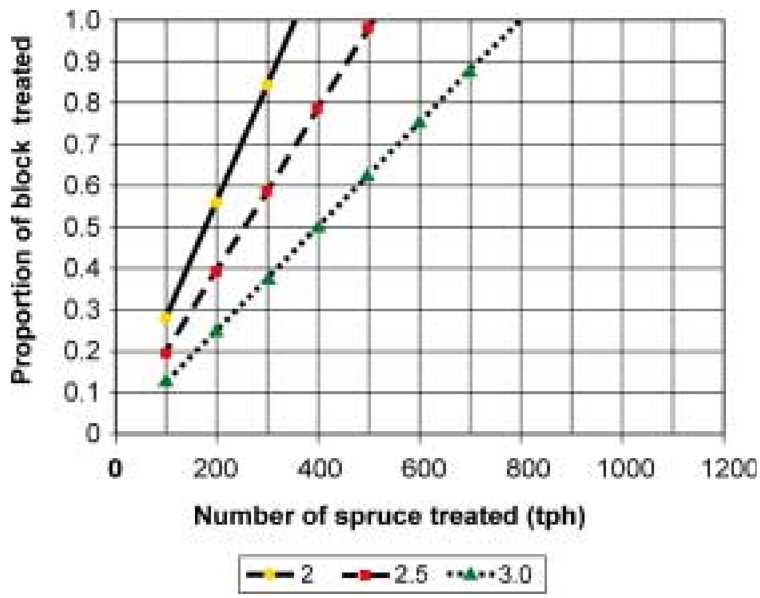


Figure 12. *The amount of area that is brushed increases with the number of conifer stems per hectare and the treatment radius. The three lines represent brushing radii of 2 m, 2.5 m, and 3 m (P. Comeau, pers. comm. 2003).*

How are rates of sprouting and suckering related to levels of aspen removal or retention?

There is evidence that rates of sucker production following manual cutting in aspen stands can be reduced by retaining some aspen stems. A study in the Cariboo-Chilcotin showed that the retention of 4000 aspen stems/ha reduced sucker production by approximately 60% compared with areas where all aspen had been cut (T. Newsome, unpublished data).

How can ongoing increases in BA during stand development be taken into account when developing treatment prescriptions from these regression models?

After reducing aspen to a known density, tables based on the relationship between density, quadratic mean diameter, and light availability can be used to plan future treatments (see Appendix G). In addition, modeling tools (e.g., TASS) will soon be calibrated for aspen and birch, which will allow practitioners to predict increases in broadleaf BA over time. Modeling tools are also being developed to predict changes in light availability at the same time as growth and yield predictions are made. When completed, these tools will assist practitioners to determine if and when future stand entries will be required.

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Acknowledgements

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APPENDIX A –
Conifer light requirements

Light requirements of central and northern interior BC conifer species[a]

Species	Percent light required to attain 80% max diameter growth	Percent light required to attain 60% max diameter growth	Percent light required to attain 40% max diameter growth
Lodgepole pine	90	68	62
Hybrid spruce	66	46	28
Western hemlock	66	42	25
Western redcedar	68	45	27
Subalpine fir	71	38	24

[a] Based on models developed by Wright et al. 1998.

APPENDIX B –

Regression models for predicting light availability from broadleaf abundance in different biogeoclimatic units of BC

Equation[a]	n	R^2	RMSE
Trembling aspen – BWBS and SBS zones (Comeau 2003)			
$\ln(difn_1) = 0.8583 - 0.78698 \times \ln(BA_b)$	86	0.525	0.361
$\ln(difn_1) = 0.4858 - 0.86447 \times \ln(RD_b)$	86	0.590	0.336
Trembling aspen – BWBS zone (Comeau 2001)			
$difn = 0.4502 + 0.7481\ RELHT_b + 0.5070\ (RELHT_b)^2 - 0.7058\ (RELHT_b)^3$	48	0.858	0.114
Paper birch – ICH and wetter IDF subzones (Comeau and Heineman 2003)			
$\ln(difn_1) = -0.05371\ BA_c - 0.14037\ BA_b$	55	0.802	0.699
$\ln(difn_1) = -0.02861\ C_c - 0.14276\ BA_b$	55	0.825	0.657
$\ln(difn_1) = -0.01584\ C_c - 0.00008109\ TPH_b - 0.09896\ QMD_b$	55	0.844	0.625
$\ln(difn_1) = -0.00006798\ TPH_b - 0.08323\ HT_b$	55	0.868	0.570
$\ln(difn_1) = -0.01872\ C_c - 0.21813\ RD_b - 0.03209\ HT_b$	55	0.878	0.553
$\ln(1 - difn_y) = -4.0746\ RELHT_b - 2.3732\ difn_1 + 0.03435\ OC_c$	118	0.849	1.150

[a] $difn_1$ is transmittance at 1 m height above the ground; BA_c is conifer basal area ($m^2 ha^{-1}$); BA_b is broadleaf basal area ($m^2\ ha^{-1}$); C_c is conifer cover (%); TPH_b is broadleaf density (trees ha^{-1}); QMD_b is broadleaf quadratic mean diameter (cm); HT_b is height of the tallest broadleaf (m); RD_b is broadleaf relative density (trees ha^{-1}); $DIFN_y$ is transmittance at height = y; $RELHT_b$ is height of the measurement point (y) expressed in relationship to the crown of the broadleaves; C_c is total conifer % cover; and OC_c is overtopping conifer cover.

APPENDIX C – Example data form

Date:	Site:	Transect bearing:
Plot #:	Distance along transect:	Plot size:
Height of tallest broadleaf		

Individual broadleaf tree measurements

Tree #	Species	DBH	HLC	Tree #	Species	DBH
1				32		
2				33		
3				34		
4				35		
5				36		
6				37		
7				38		
8				39		
9				40		
10				41		
11				42		
12				43		
13				44		
14				45		
15				46		
16				47		
17				48		
18				49		
19				50		
20				51		
21				52		
22				53		
23				54		
24				55		
25				56		
26				57		
27				58		
28				59		
29				60		
30				61		
31				62		

Individual conifer tree measurements

Tree #	Species	Height	Tree #	Species	Height
1			11		
2			12		
3			13		
4			14		
5			15		
6			16		
7			17		
8			18		
9			19		
10			20		

Comments:

APPENDIX D – Calculations

Calculations for individual variables are described below. They can easily be done with Excel, as shown in the sample spreadsheet in Appendix E.

Broadleaf density per hectare (stems/ha)

1. Determine the number of broadleaf stems in the plot from your data form.
2. Determine the appropriate multiplier.
   - For 3.99 m radius plots (50 m^2) use a multiplier of 200.
   - For 5.64 m radius plots (100 m^2) use a multiplier of 100.
3. Multiply the number of broadleaf stems in the plot by the multiplier (i.e., if there are 14 broadleaves in a 50 m^2 plot, the density per hectare (based on that plot) is 2800 stems/ha).

Aspen basal area per hectare (m^2/ha)

1. Calculate the BA for each stem.

   i.e., $BA_{stem\ 1} = [(DBH_{stem\ 1}/2)^2] \times \pi$

   ($\pi = 3.1415927$)
2. Calculate total aspen BA in the plot by summing the BA for all stems.

   $(BA_{plot} = BA_{stem\ 1} + BA_{stem\ 2} + BA_{stem\ 3} + BA_{stem\ 4} \ldots\ldots.. + BA_{stem\ n})$
3. Calculate aspen BA/ha by multiplying total aspen BA in the plot by the appropriate multiplier (see the previous calculation).

Mean aspen BA per stem

1. Divide total aspen BA in the plot by the number of aspen stems.

APPENDIX E –

How to use Excel functions to calculate stand variables (using a 3.99 m radius plot)

	A	B	C	D	E	F
1	Data for 'Plot 2' of our example					
2						
3	Broadleaf data		*Entered from*			
4	Tallest aspen: 9.5 m		*field sheets*		=(PI()*(C7/2)^2	=E7/10,000
5						
6	**Tree #**	**Species**	**DBH (cm)**	**HLC (m)**	**BA (cm²/stem)**	**BA (m²/stem)**
7	1	At	4.5	2.5	15.90431281	0.00159
8	2	At	8.5	3.2	56.74501731	0.00567
9	3	At	8.6	3.3	58.08804816	0.00581
10	4	At	2.7	1.9	5.725552611	0.00057
11	5	At	4.3	2.3	14.52201204	0.00145
12	6	At	8.7	3.6	59.44678699	0.00594
13	7	At	1.9	2.0	2.83528737	0.00028
14	8	Act	1.4	1.9	1.5393804	0.00015
15	9	At	2.5	2.0	4.908738521	0.00049
16	10	At	6.6	2.3	34.211944	0.00342
17	11	At	5.4	2.6	22.90221044	0.00229
18	12	At	5.1	2.5	20.42820623	0.00204
19	13	At	3.1	2.4	7.5476635	0.00075
20	14	At	0.5	1.1	0.196349541	0.00002
21	***Total in plot***					***0.03050***
22						
23	***Total per hectare***					***6.10003***
24						
25	***Mean values per stem***		***4.6***	***2.4***		***0.00218***
26		=(sum(C7:C20))/14		=(sum(D7:D20))/14		=(sum(F7:F20))/14
27						
28						=F21*200
29						
30	**Conifer data**					
31	Tree #	Species	Height			=sum(F7:F20)
32	1	Sw	3.9			
33	2	Sw	3.7			
34	3	Sw	2.9			
35	4	Sw	4.5			
36	5	Sw	4.0			
37	***Mean height***		***3.8***			
38						
39						
40						

APPENDIX F –
Using the regression equations

How to determine light availability using the regression equation: $\ln(\text{difn}) = 0.8583 - [0.78698 \times \ln(\text{BA})]$

EXAMPLE: You have determined that the aspen basal area (BA) is 8.2 m^2/ha. How much light is available in the understorey?

$\ln(\text{difn}) = 0.8583 - [0.78698 \times \ln(\text{BA})]$

Step 1: Take the natural log (ln) of 8.2

Using a pocket calculator press ln, then enter "8.2". The answer will be "2.10413".

(Note: you can also do this calculation with Excel, using the "LN" function.)

$\ln(\text{difn}) = 0.8583 - [0.78698 \times 2.10413]$

Step 2: Do the calculation

$\ln(\text{difn}) = -0.79761$

Step 3: Determine difn

(Note: difn stands for "diffuse non-interceptance" and is the amount of diffused light NOT intercepted by the canopy. It is the same as "light availability," but is expressed as a fraction instead of a percentage.)

ln and e^x are inverse functions, so another way to write the equation is:

$\text{difn} = e^{-0.79761}$

Using a pocket calculator, press 2ndF, then ln, then enter "-0.79761". The answer will be "0.450404".

(Note: you can also do this calculation with Excel, using the "EXP" function.)

$\ln(\text{difn}) = -0.450404$

Step 4: Convert to percent light by multiplying difn by 100

Percent light = 0.450404×100
= 45%

APPENDIX G –
Light transmittance at various combinations of aspen quadratic mean diameter (qmd)[a] and aspen density (stems/ha) (Comeau 2003)

Survival of white spruce is expected to be reduced substantially when light availability is below 0.15 (15% light availability) (Logan 1969, Kobe and Coates 1997) and growth of white spruce is expected to be approaching maximum values when transmittance exceeds 0.60 (60% light availability) (Wright et al. 1998). Transmittance values in the range between 0.15 and 0.60 are shown in bold. Treatments to reduce aspen to prevent light availability from dropping below the desired level can be planned according to changes in density and quadratic mean diameter. (See following page.)

Aspen qmd (cm)	Aspen density (stems/ha)																					
	600	1000	1500	2000	3000	4000	5000	6000	7000	8000	9000	10000	11000	12000	13000	14000	15000	16000	17000	18000	19000	20000
2.5									0.893	0.804	0.733	0.675	0.626	**0.584**	**0.549**	**0.518**	**0.490**	**0.466**	**0.444**	**0.425**	**0.407**	**0.391**
3							0.873	0.757	0.670	0.603	**0.550**	**0.506**	**0.470**	**0.439**	**0.412**	**0.388**	**0.368**	**0.350**	**0.333**	**0.319**	**0.305**	**0.293**
3.5						0.817	0.685	**0.594**	**0.526**	**0.473**	**0.432**	**0.397**	**0.368**	**0.344**	**0.323**	**0.305**	**0.289**	**0.274**	**0.262**	**0.250**	**0.240**	**0.230**
4					0.830	0.662	**0.555**	**0.481**	**0.426**	**0.384**	**0.350**	**0.322**	**0.299**	**0.279**	**0.262**	**0.247**	**0.234**	**0.222**	**0.212**	**0.203**	**0.194**	**0.187**
4.5				0.949	0.690	**0.550**	**0.461**	**0.400**	**0.354**	**0.319**	**0.291**	**0.267**	**0.248**	**0.232**	**0.218**	**0.205**	**0.194**	**0.185**	**0.176**	**0.168**	**0.161**	**0.155**
5				0.804	**0.584**	**0.466**	**0.391**	**0.339**	**0.300**	**0.270**	**0.246**	**0.227**	**0.210**	**0.196**	**0.184**	**0.174**	**0.165**	**0.157**	0.149	0.143	0.137	0.131
5.5			0.868	0.692	**0.503**	**0.401**	**0.336**	**0.291**	**0.258**	**0.232**	**0.212**	**0.195**	**0.181**	**0.169**	**0.159**	**0.150**	0.142	0.135	0.128	0.123	0.118	0.113
6			0.757	0.603	**0.439**	**0.350**	**0.293**	**0.254**	**0.225**	**0.203**	**0.185**	**0.170**	**0.158**	0.147	0.138	0.130	0.124	0.117	0.112	0.107	0.103	0.099
6.5		0.918	0.667	**0.532**	**0.387**	**0.308**	**0.259**	**0.224**	**0.198**	**0.179**	**0.163**	**0.150**	0.139	0.130	0.122	0.115	0.109	0.104	0.099	0.094	0.090	0.087
7		0.817	**0.594**	**0.473**	**0.344**	**0.274**	**0.230**	**0.199**	**0.177**	**0.159**	0.145	0.133	0.124	0.116	0.109	0.102	0.097	0.092	0.088	0.084	0.081	0.077
7.5		0.733	**0.533**	**0.425**	**0.309**	**0.246**	**0.206**	**0.179**	**0.158**	0.143	0.130	0.120	0.111	0.104	0.097	0.092	0.087	0.083	0.079	0.075	0.072	0.069
8		0.662	**0.481**	**0.384**	**0.279**	**0.222**	**0.187**	**0.162**	0.143	0.129	0.117	0.108	0.100	0.094	0.088	0.083	0.079	0.075	0.071	0.068	0.065	0.063
8.5		0.602	**0.437**	**0.349**	**0.253**	**0.202**	**0.170**	0.147	0.130	0.117	0.107	0.098	0.091	0.085	0.080	0.075	0.071	0.068	0.065	0.062	0.059	0.057
9	0.822	**0.550**	**0.400**	**0.319**	**0.232**	**0.185**	**0.155**	0.134	0.119	0.107	0.098	0.090	0.083	0.078	0.073	0.069	0.065	0.062	0.059	0.057	0.054	0.052
9.5	0.755	**0.505**	**0.367**	**0.293**	**0.213**	**0.170**	0.142	0.123	0.109	0.098	0.090	0.082	0.077	0.071	0.067	0.063	0.060	0.057	0.054	0.052	0.050	0.048
10	0.697	**0.466**	**0.339**	**0.270**	**0.196**	**0.157**	0.131	0.114	0.101	0.091	0.083	0.076	0.071	0.066	0.062	0.058	0.055	0.053	0.050	0.048	0.046	0.044
10.5	0.645	**0.432**	**0.314**	**0.250**	**0.182**	0.145	0.122	0.105	0.093	0.084	0.077	0.070	0.065	0.061	0.057	0.054	0.051	0.049	0.046	0.044	0.043	0.041
11	**0.599**	**0.401**	**0.291**	**0.232**	**0.169**	0.135	0.113	0.098	0.087	0.078	0.071	0.065	0.061	0.057	0.053	0.050	0.048	0.045	0.043	0.041	0.040	0.038
11.5	**0.559**	**0.374**	**0.272**	**0.217**	**0.158**	0.126	0.105	0.091	0.081	0.073	0.066	0.061	0.057	0.053	0.050	0.047	0.044	0.042	0.040	0.038	0.037	0.035
12	**0.523**	**0.350**	**0.254**	**0.203**	0.147	0.117	0.099	0.085	0.076	0.068	0.062	0.057	0.053	0.049	0.046	0.044	0.042	0.039	0.038	0.036	0.034	0.033
12.5	**0.490**	**0.328**	**0.238**	**0.190**	0.138	0.110	0.092	0.080	0.071	0.064	0.058	0.054	0.050	0.046	0.044	0.041	0.039	0.037	0.035	0.034	0.032	0.031
13	**0.461**	**0.308**	**0.224**	**0.179**	0.130	0.104	0.087	0.075	0.067	0.060	0.055	0.050	0.047	0.044	0.041	0.039	0.037	0.035	0.033	0.032	0.030	0.029
13.5	**0.434**	**0.291**	**0.211**	**0.168**	0.122	0.098	0.082	0.071	0.063	0.057	0.052	0.047	0.044	0.041	0.039	0.036	0.034	0.033	0.031	0.030	0.029	0.027
14	**0.410**	**0.274**	**0.199**	**0.159**	0.116	0.092	0.077	0.067	0.059	0.053	0.049	0.045	0.042	0.039	0.036	0.034	0.033	0.031	0.030	0.028	0.027	0.026
14.5	**0.388**	**0.260**	**0.189**	**0.150**	0.109	0.087	0.073	0.063	0.056	0.051	0.046	0.042	0.039	0.037	0.034	0.033	0.031	0.029	0.028	0.027	0.026	0.025
15	**0.368**	**0.246**	**0.179**	0.143	0.104	0.083	0.069	0.060	0.053	0.048	0.044	0.040	0.037	0.035	0.033	0.031	0.029	0.028	0.026	0.025	0.024	0.023

[a] Quadratic mean diameter is calculated as: $QMD = \{[(DBH_{stem\ 1})^2 + (DBH_{stem\ 2})^2 + (DBH_{stem\ 3})^2 + \ldots\ldots\ldots\ldots + (DBH_{stem\ n})^2\ ]/n\}^{1/2}$.

[b] Light availability are based on the equation: $\ln(difn) = 0.8583 - 0.7869 \times \ln(BA)$.