Handbook for Commercial Thinning in Alberta
(Version 1)

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43
41

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

1.0 INTRODUCTION AND ASSUMPTIONS

The purpose of this handbook is to support commercial thinning (CT) planning and operations in Alberta. There is an increased interest in commercial thinning in the province. This is due to a desire to minimize timber supply gaps and because a substantial amount of harvested area is becoming old enough where CT is an option. A CT harvests volume earlier in the rotation, volume which would otherwise have been lost to mortality. CT may also shorten the rotation age to reach merchantability and operability, relative to un-thinned stands. This is especially true of stands that had very high densities during the reforestation stage if they were carefully managed with either pre-commercial thinning (PCT) or herbicide. Proponents of CT on public land will need to review and address the requirements in Alberta's Partial Cutting Guidelines. These guidelines were developed by Greenway *et al.* (2006) and are now under revision.

This handbook is a "living document" which will change as Alberta gains more experience with CT. This experience will be supplemented by a network of research plots which are expected to eventually inform this document.

There is a longer history of CT research and practice in British Columbia than Alberta, and there are several useful resources that were developed in British Columbia that are relevant to Alberta. However, the practice in British Columbia is somewhat specific to the province, so practitioners would be wise to also consider how CT is done in the rest of Canada (notably the Maritime provinces) and around the world. For example, British Columbia generally recommends relatively wide harvesting trails which may be too wide for many Alberta locations and objectives, as these wide trails may result in unacceptable stocking losses, and an extended waiting period for basal area recovery after CT. Alberta practitioners may find that a more traditional or even a hybrid approach may be appropriate for the stands they manage. Keeping this context in mind, proponents of CT in Alberta are encouraged to review the recently developed publications from British Columbia:

- The Operational Manual for CT in British Columbia (Pavel *et al.* 2021).[1]
- British Columbia's Interim Guidance for CT (British Columbia Ministry of Forests 2021).[2]

The decision whether to begin a CT program is based on various factors. For the Alberta context, some of the most notable factors include:

- Company objectives.
- Known and existing gaps in future timber supply.

[1] https://library.fpinnovations.ca/media/FOP/TR2021N93.pdf
[2] https://www2.gov.bc.ca/assets/gov/farming-natural-resources-and-industry/forestry/stand-tending/interim_guidance_for_commercial_thinning.pdf

- Vulnerability of future timber supply (i.e. risk of fire or mountain pine beetle).
- Availability of appropriate stands.
- Availability of appropriate equipment and skilled operators.
- Price of lumber and premiums for larger tree sizes.
- AAC chargeability.
- Stumpage relief.

This document does not directly address late-stage salvage thinning or thinning on private land, though many of the principles will apply. If the CT project is on afforested private land some of the recommendations would likely be different, since the provincial regulations do not apply (i.e. potential rotation age may be shorter and the first CT may be earlier).

The following assumptions for CT in AB are established as basic practice:

- Remove >40 m^3 ha^{-1} of merchantable sawlogs.
- Ensure sufficient foliage remains to support a high likelihood of growth response.
- Minimize risk of blowdown and other types of mortality after CT.

For consistency, the following height definitions were assumed:

- Dominant/co-dominant trees: trees that are within 75% of the height of the main canopy.
- Intermediate/suppressed trees: trees that are >5m tall and < 75% of the height of the main canopy.
- Low woody vegetation: trees and shrubs that are <5m tall.

2.0 UNDERSTANDING FUNDAMENTAL CONCEPTS AND TOOLS

2.1 Fundamental Concepts

The practitioner should read and understand Figure 1 before attempting to plan CT. It generically describes the classic options for managing forest crops, and includes several options with CT. It is necessary to understand the components of this graph because it illustrates the underlying principle behind the various mathematical expressions that are used to determine when and how much to CT. There are many valid and related mathematical expressions to develop crop plans for when and how much to CT. Valid approaches are based on the -3/2 Power Law of Natural Thinning described by Kira *et al.* (1953). European foresters were likely using this law for ~ 100 years before it was explicitly defined.

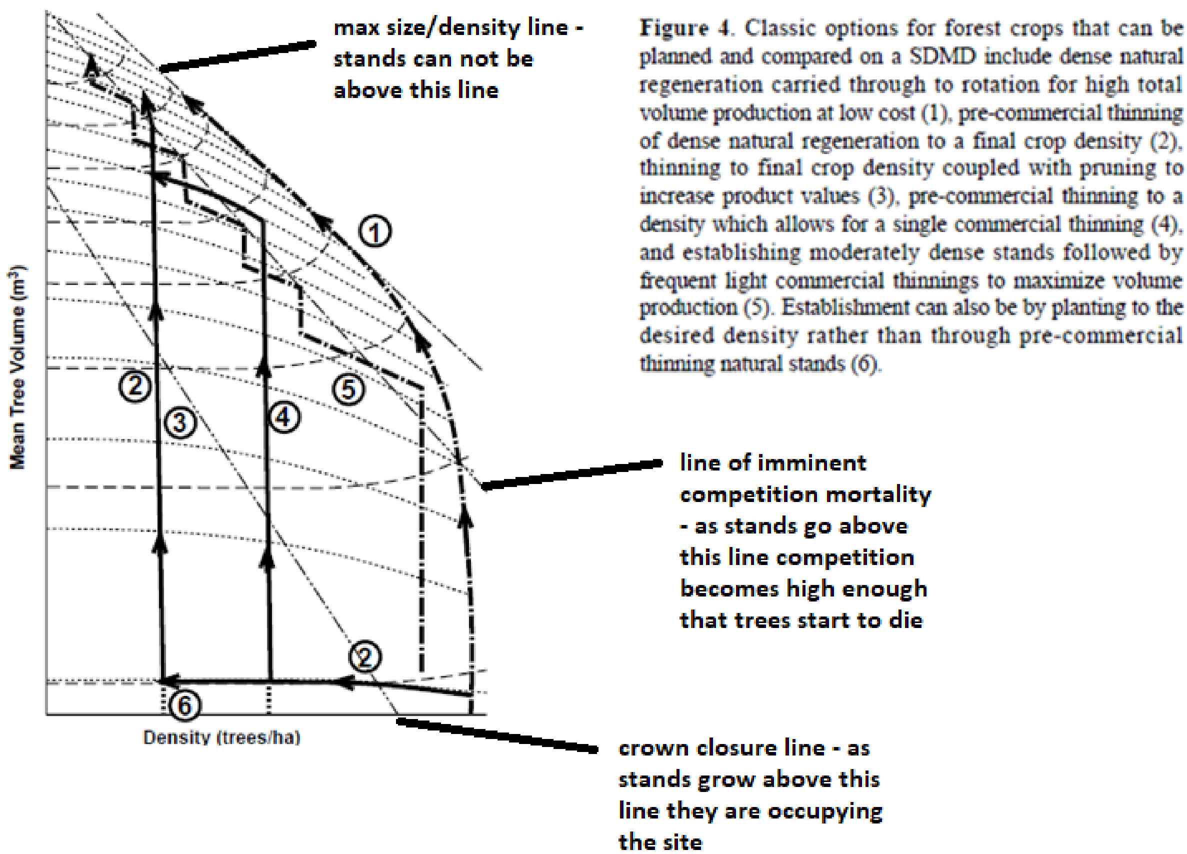


__Figure 1__ An adapted excerpt from Farnden's 1996 classic options for managing forest crops. Definitions of the lines for max size/density, imminent mortality and crown closure have been added in bold.

Crop planning is an invaluable tool to rank stands for CT and to optimize when and how much to CT. To provide decision support for CT, mathematical expressions of the -3/2 Power Law of Natural Thinning are used to develop crop plans. Below we summarize spacing factor and density management diagrams which are two of the easiest and most intuitive ways to carry out crop planning. These are direct (spacing factor %) or indirect (density management diagrams) applications of the -3/2 law. There are many other equally valid (but harder to visualize) approaches that are used, such as Reinecke's Stand Density Index (Day 1994).

2.2 Spacing Factor Tool

Spacing factor can be used to develop CT crop plans. The plans are developed by using spacing factor % (SF%) in conjunction with yield tables or growth models, such as Alberta's Growth and Yield Projection System (GYPSY) or the Mixedwood Growth Model (MGM).

SF% is the average distance between dominant/co-dominant trees as a percentage of their average height. Wilson (1946) defined the mathematical relationship that underlies the use of SF%, which led to Kira *et al.'s* (1953) definition of natural thinning.

SF% has been the most common approach taken by operations staff in Alberta because it is intuitive, easy to visualize, and easy to measure in the field. Although it is not always called "spacing factor" this approach is used around the world by forestry planning and operations staff where there is a long history of very precise stand-specific CT, such as for thinning *Pinus radiata* in New Zealand.

To optimize growth and minimize risk the ideal SF% ranges are dependent on the shade tolerance of the species. Approximate SF% recommendations for Alberta are summarized in Table 1. The ideal SF% will vary slightly depending on whether dominant/co-dominant heights or site index (top height) tree heights are used for the calculations.

Table 1 *Approximate minimum and maximum spacing factor % for CT in Alberta when dominant/co-dominant tree heights and inter-tree spacing are measured.*

Genus	Shade Tolerance	Minimum Spacing Factor %	Maximum Spacing Factor %
Fir	Very tolerant to tolerant	15	19
Spruce	Mid tolerant	16	20
Pine	Intolerant	18	23
Poplars & poplar hybrids	Very intolerant	23	30

Notes:

1. These recommendations have been operationalized to remove sufficient volume and increase the likelihood that CT will be cost effective in Alberta.
2. Check the spacing factor maximum against your desired BA reduction to ensure you CT the desired amount. This table was adapted from Day (1992).

An illustration of the use of SF% is in Figure 2 where mid tolerant white spruce was used as an example. If a moderately aggressive CT is desired, white spruce should be managed between roughly 16% and 20% SF%, removing about 33% of the basal area per ha. As the trees get taller the white spruce SF% will decrease. Once measurement data is available and the stands are old enough for ground truthing (usually around 30 years of age), use growth models or yield tables to "grow the stand" into the future. When the SW stand is tall enough that the spacing factor is 16% the CT should take place. In this example the SW were calculated to be tall enough for CT when

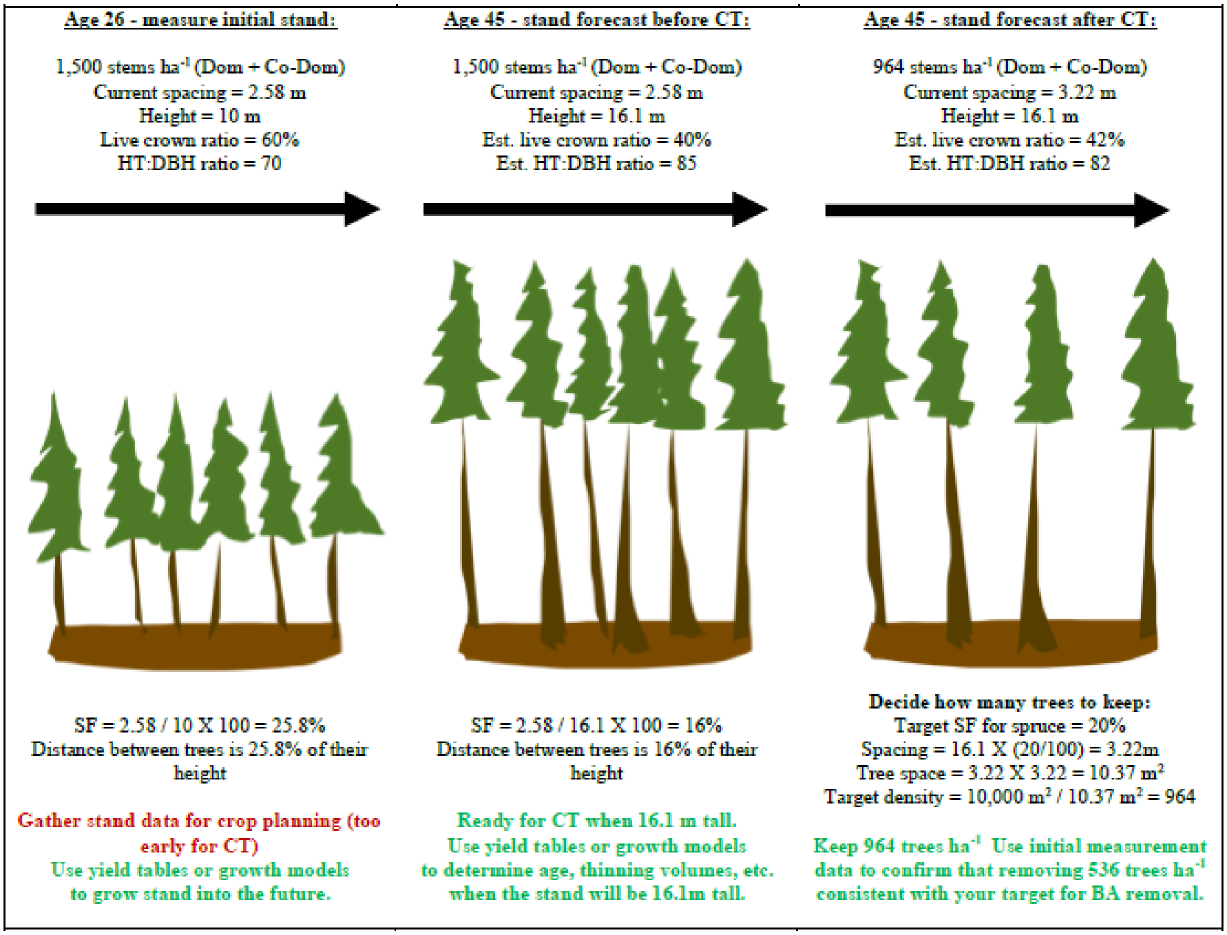


Figure 2 *A simplified example of how spacing factor (%) can be used for crop planning and decision making on when and how much to commercial thin. For this example, using white spruce, the chosen target spacing factor minimum was 16% and the maximum was 20%. The density should be reduced enough so that the remaining trees are at about 20% SF. During crop planning, double check and adjust the maximum SF% to ensure that you are removing your target BA (i.e. 33%). After CT the stand will grow until the SF% reaches no less than 16%. At that time a 2nd CT or a clearcut could take place.*

they reached 16.1m. As a confirmation the live crown was checked to confirm that it was not <40%, and the ht:dbh was confirmed to be <90. By these measures the stand should respond well in growth to the CT and is unlikely to have blowdown problems. During CT the density should be reduced enough so that the remaining trees are at about 20% SF. During crop planning, double check and adjust the maximum SF% to ensure that you are removing your target BA (i.e. 33%). After CT the stand will be allowed to grow again until the SF% is again at 16%. At that time a 2nd CT or a clearcut can take place.

2.3 Density Management Diagrams Tool

Density Management Diagrams (DMDs) can also be used to develop CT crop plans. The plans are developed by using DMDs in conjunction with yield tables or growth models, such as Alberta's Growth and Yield Projection System (GYPSY) or the Mixedwood Growth Model (MGM).

Rather than using the mathematical relationships directly as with SF%, DMDs allow the practitioner to use stand measurements to more generically forecast CTs and clearcuts. Like SF% DMDs are fairly simple to use, but they may be less flexible and less precise than using other approaches, such as SF%. Farnden (1996) suggested that DMDs should be used as complementary to other models, rather than as a replacement. Figure 3 provides an example of the use of Farnden's (1996) DMDs, applied to a lodgepole pine CT that was carried out in Alberta. This stand reached the "line of imminent competition mortality" (our target for time of CT) when the spacing factor was 17.6%, the ht:dbh ratio was 90, and the live crown was 41%. Stand density management diagrams for white spruce and lodgepole pine specific to Alberta were developed for FGrOW by Gyula Gulyas and are available for download along with online excel visualization tool.[3]

[3] https://fgrow.ca/project/enhanced-forest-management

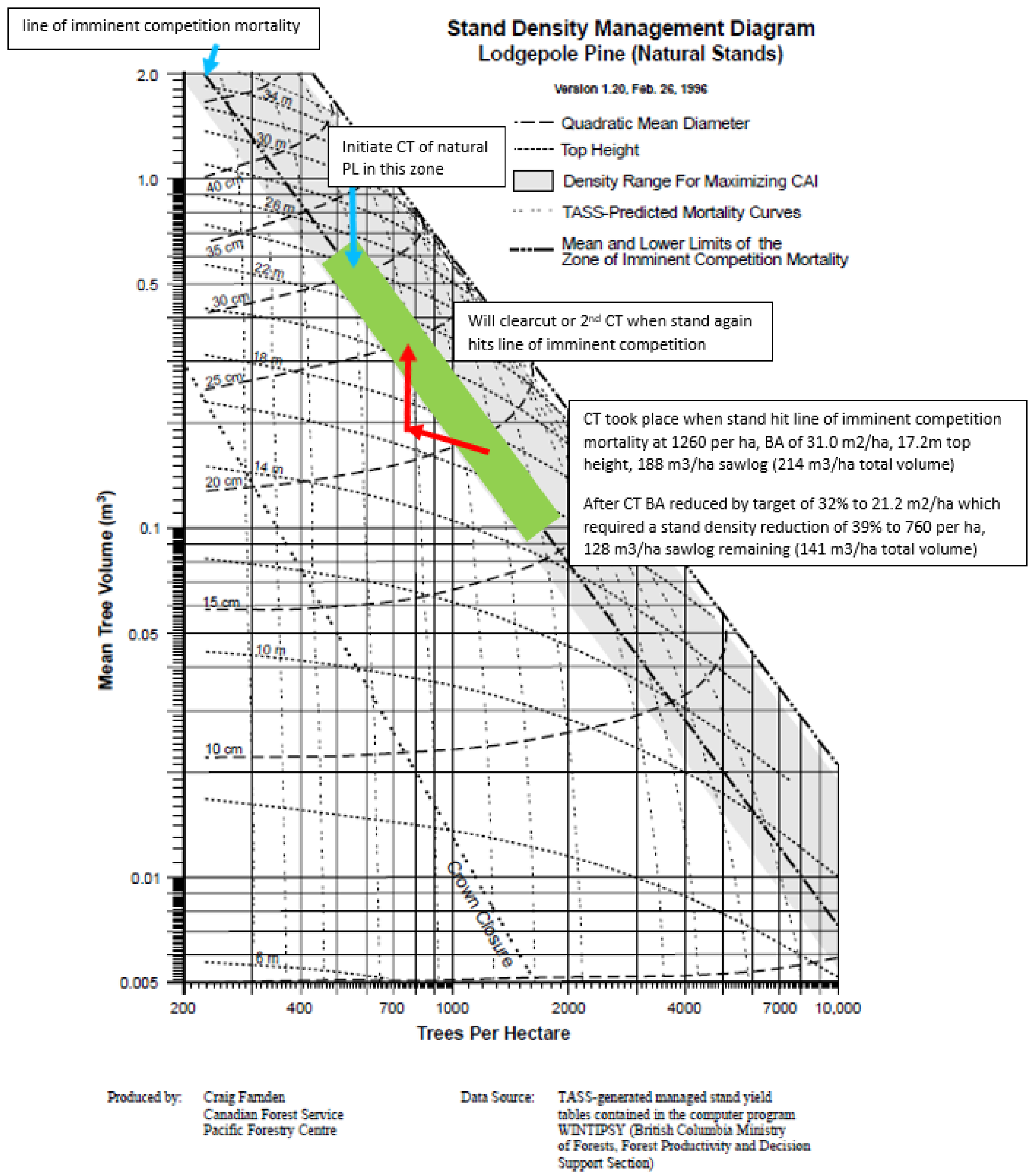


Figure 3 *An example of the use of density management diagrams using a Farnden (1996) diagram. These are approximate because as is often the case this stand did not fit perfectly on the diagram. Data from a recent Alberta CT has been added to illustrate reasonable conditions and expectations for CT of lodgepole pine plantations in Alberta.*

3.0 REFORESTATION AND SUBSEQUENT LOCATION OF SITES FOR COMMERCIAL THINNING

3.1 Relationship between reforestation and commercial thinning

To prioritize areas for CT it is helpful to understand which reforestation treatments lead to options for CT. The relationship between reforestation and CT is sometimes overlooked, perhaps because it involves long term investment and patience. Strategic reforestation is the most important factor in determining whether a company will have stands with a reasonable option to CT in the future. If the desire is to set up stands with options for CT (or options for short rotation clearcuts), reforestation efforts and subsequent stand improvement should focus on crown management of good sites, striking a balance between maximizing stocking of crop species while also minimizing competition, throughout the rotation. Strategic planting spacing and appropriate vegetation management are examples of important choices affecting future CT potential. Stands that have had PCT (commonly for pure pine stands) or herbicide application (commonly for mixed white spruce stands) will generally have far higher potential for CT. This is because these treatments result in stands that are more likely to have, a) less variability in tree size, b) merchantable sized trees by the time thinning must take place, and c) crop trees that still have a suitable ratio of green crown to respond to the thinning.

Past reforestation standards will often be a factor determining the amount of area available for CT. Because the 1991 regeneration survey standards were more challenging to meet than earlier standards, stands that were reforested to meet the 1991 requirements often have higher potential than those harvested earlier.

3.2 Note regarding pre-commercial thinning densities

High density stands that are 8-12 years old are at a stage where even extreme BA reduction is unlikely to result in blowdown. This allows the silviculturist a window of opportunity to manage the crown optimally and set the stand up to optimize volume and value, potentially also preserving a future option for CT.

As high density stands get older (taller) they are far more prone to blowdown and snow breakage, so the proportion of BA that can be removed over time decreases. As a hypothetical example, a high density 12-year-old PL stand may generally be thinned down to 2000 stems per ha at minimal risk. However, at 20 years of age that same stand may require that 4000 stems per ha be left during pre-commercial thinning, to minimize risk. By age 30, that same high-density stand may have to be pre-commercially thinned using the same approach as CT, with <40% of the BA removed to minimize risk.

3.3 Density

Due to differences in shade tolerance the ideal density for CT will vary by species. The ideal density for the first CT of dominant/co-dominant trees in a white spruce stand will be about 1500 trees per ha. Depending on the other stand characteristics mentioned below and the timber supply situation, white spruce stands that average about 1000 – 1800 trees ha^{-1} of dominant/co-dominant trees may be reasonable to CT. The ideal density for first CT of dominant/co-dominant trees in a lodgepole pine stand will be about 1300 trees ha^{-1}. Depending on the other stand characteristics mentioned below and the timber supply situation, lodgepole pine stands that average about 1000 – 1600 may be appropriate to CT. In mixed stands of lodgepole pine and white spruce the ideal pre-CT density (and pre-CT SF%) will depend on which species is the main target to be left as crop trees.

If the proportion of intermediate/suppressed trees is high the cost of CT will be increased. A high proportion of intermediate/suppressed may also reduce the potential of the crop trees for release, due to more competition from below and reduced foliage. Ideally there would be fewer intermediate/suppressed present than dominant/co-dominant trees.

For CT in the late fall/winter, small broadleaf vegetation such as willow and alder are typically not a significant visual impediment. However, if there are high densities of understory spruce or fir the vision of the harvester operator may be obscured, and CT costs will be increased. In this situation it is generally better to avoid doing CT, or to remove most of the understory conifer before CT (widely space understory with chainsaw or brushsaw as is common practice in Scandinavia).

3.4 Variability in density and other stand characteristics

The variation in density is another key metric to evaluate. Even if the average density is appropriate, stands that are clumpy will generally not be appropriate to CT. This is because clumpy stands will tend to have more variable tree sizes resulting in higher harvesting costs, lower growth response, and higher blowdown potential. The more evenly-spaced a stand is the higher the potential for CT. This is generally true for all stand characteristics. The less variability the higher the potential.

3.5 Site index

Stands with a site index of >18m are generally a higher priority for CT than sites with a <18m site index. In general, the higher the site index, the higher the priority, due to the return-on-investment period. However, there may be cases where it makes sense from a cost/benefit perspective for a company to also CT medium sites from 16m-18m site index (depending on timber supply situation, lumber prices or other relevant factors).

3.6 Species

Commercial thinning will generally make the most sense in conifer stands. It is recommended that clumps within stands that are hardwood dominated should not be treated, because the cost of CT will be very high if a significant amount of lower value hardwood is generated. However, it should be noted that the largest net increase in conifer volume is likely to take place when hardwoods are removed to favor conifers. If there is a reasonable market for cut-to-length hardwood, from a growth response perspective it may be advantageous to CT stands that are primarily conifer, but that have a low volume of hardwoods throughout.

3.7 Basal area and sawlog volume

A typical CT in Alberta conditions might be approximately 33% BA removal (example: reduce from 33 $m^2\ ha^{-1}$ to 22 $m^2\ ha^{-1}$). In other jurisdictions it is common to remove anywhere from 20% to 40% of the BA. A light CT of 20% removal often results in the need for multiple CTs over time to maintain growth response. This is very expensive because a small volume is removed per CT treatment. However, the investment in expensive multiple light CTs will generate the highest merchantable volume over the rotation. A heavier CT of 40% of the BA results in lower harvesting costs but may result in reduced volume production and in some situations may be at increased risk of blowdown. Heavily thinned stands will take longer to recover the basal area before the next harvest, whether that be a 2nd CT or a clearcut.

Thinning "from below" results in what is commonly known as the "chainsaw effect", with the remaining crop trees being approximately 10% larger in DBH after CT than the stand average prior to CT (depending on company selection criteria). Therefore, the sawlog volume prior to CT should generally be >140 $m^3\ ha^{-1}$. This is to ensure there is an economically viable amount (> 40 $m^3\ ha^{-1}$) of sawlog available for removal, without over-thinning and causing a high risk of blowdown.

3.8 Live Crown Ratio

If SF% and/or DMDs are used appropriately there generally will not be a problem with the ability of the stand to respond to thinning. However, as a double check the live crown ratio should be calculated. Live crown ratio has often been used to determine when to carry out thinning and which trees should be retained as crop trees (Smith *et al.* 1997). A 40% live crown is the most common threshold recommended in the literature. In a Minnesota study D'amato *et al.* (2011) found that for white spruce, keeping the live crown at a minimum of 40% ensured high tree and stand growth rates and was an indicator of the tree's ability to respond positively to thinning. Schnell *et al.* 2012 also recommended a threshold of not lower than 40% live crown when managing white spruce in Ontario. A live crown of >40% was recommended by the British Columbia Ministry of Forests for various species (1999). Currently we recommend 40%. It is possible that for pine species a slightly lower live crown threshold may yield acceptable responses. This will be investigated through the research plot network that is under development.

3.9 HT:DBH ratio

As mentioned above, if SF% and DMDs are used appropriately there also will generally not be a problem with blowdown. However, as a double check the ht:dbh ratio should be calculated. The ht:dbh ratio is a good indicator of the stability of a stand. The average ht:dbh ratio should be less than 90 to keep the risk of blowdown low. The ht:dbh ratio also can be another indicator of the likelihood that there will be a growth response to CT.

3.10 Summary Decision Tool

Figure 4 is a decision support tool that summarizes our key recommendations for how to identify areas for potential CT.

4.0 FIELD DATA COLLECTION AND GROUND TRUTHING

The British Columbia Operations Manual by Pavel *et al.* (2021) suggested a useful process for identifying areas for CT. Another similar option is suggested in Table 2 below, based on our experiences in Alberta. The process described below is only as an example. Every practitioner will invariably develop their own innovative process to find areas for CT utilizing the tools available to them. Aerial imagery, Enhanced Forest Inventory (EFI) from LIDAR and/or a timber cruise will often be used to help locate areas for CT. Ground truthing is a key component that should be integrated throughout the process.

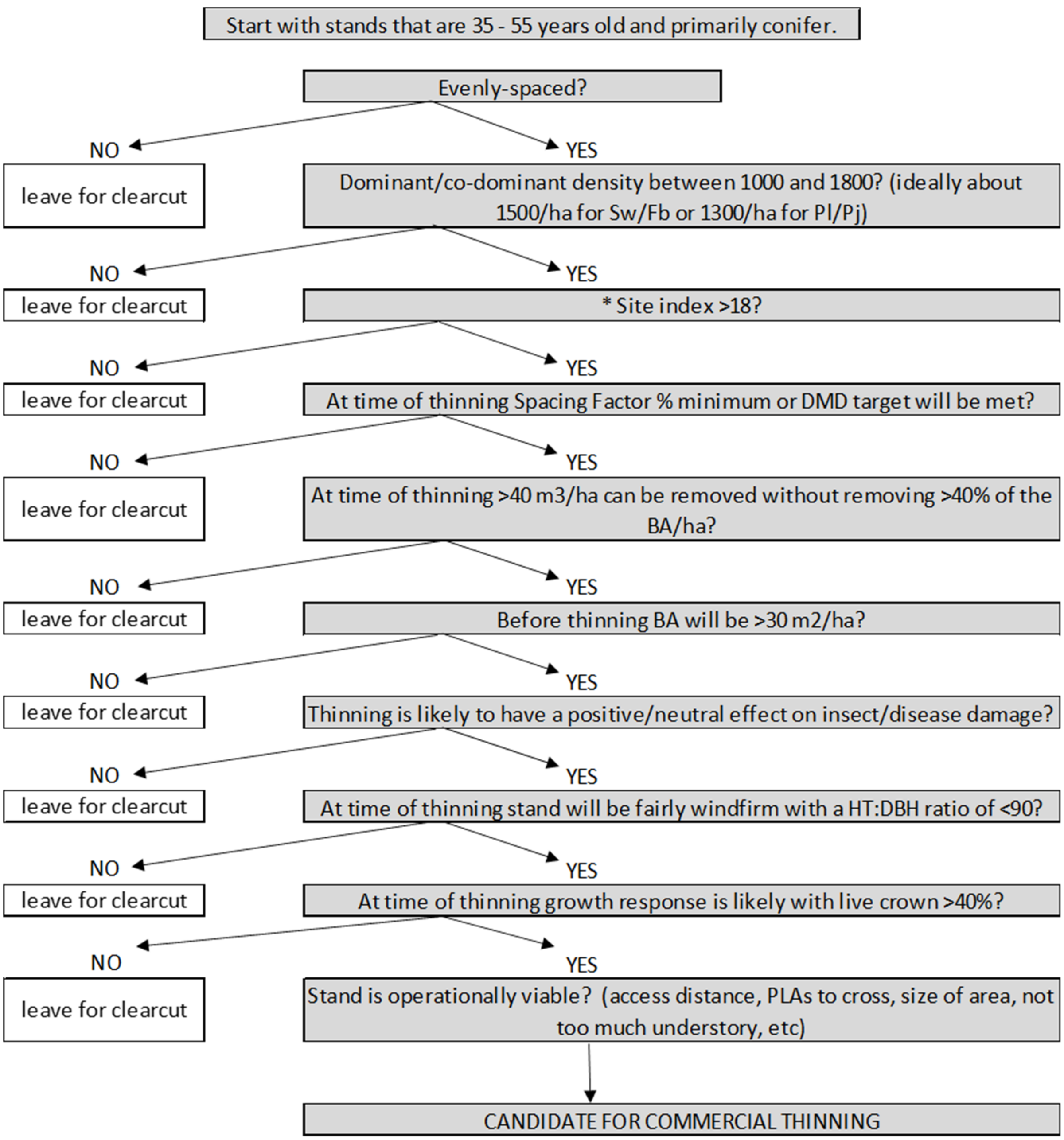
Figure 5 illustrates a map that was prepared for ground truthing after the initial data collection and analyses. For the Figure 5 example we had the luxury of using timber cruise data, LIDAR data, and aerial imagery. The LIDAR data was operationalized after the original queries, to identify logical groupings of polygons to ground truth for CT operations. After ground truthing, this map was adjusted to use the appropriate data for subsequent crop planning and preparation of a layout map.

5.0 COMMERCIAL THINNING AGE

The CT age for a stand will be determined based on the use of yield tables or growth models in conjunction with SF % or DMDs. Generically the approximate ideal ages for CT by site productivity, density, and species are suggested in Table 3. These optimum CT ages were determined using ideal spacing factors and Alberta's Growth and Yield Projection System (GYPSY). The ideal age for CT at a given density varies by species due to differences in shade tolerance and early height growth. In Table 3 mid-tolerant white spruce and tolerant fir were pooled as they are often found in association. At these recommended ages, the spacing factor, live crown, and ht:dbh are generally aligned and ideal for CT implementation. It may be acceptable to adjust CT ages +/- 5 years, giving some flexibility and coherence to operations. Stands should be monitored to ensure that at the time of CT they still meet acceptable thresholds for live crown and ht:dbh, to maximize the possibility of growth response and minimize the risk of blowdown.

Table 2 *Suggested process for field data collection and ground truthing to identify stands for commercial thinning.*

1. Query reforestation records. Although some stands that have not had vegetation management are reasonable to CT, you should closely examine areas that have had vegetation management, as they often have the highest potential. Include the vegetation management treatment on your ground truth and layout maps to increase field efficiency. Stands that have had a PCT treatment also have high potential for CT.
2. Example: query LIDAR and/or timber cruise files to find areas with concentrations of: a. Leading species = PL, PJ, SW, or FB b. Appropriate density of potential crop trees. For example, if you are evaluating stands that are 30 years old now, for CT 5-20 years in the future you might query for densities of between 1000 and 2500 that are >8m tall. You should initially keep the density range wide because of variability between LIDAR EFI hexagons or timber cruise plots and because LIDAR may overestimate the density of shorter trees, especially if there was a PCT treatment. c. Density of all trees >5m is <3500 trees ha^{-1}. d. Site index is >18m.
3. Look at the queried areas on an image. Identify and tag larger areas that meet the above specifications and appear to have homogenic tree canopy. Consider operational factors such as access and size of CT area. Build your maps for ground truthing.
4. Confirm that your query is indeed identifying ideal CT areas. If you have timber cruise data or a high level of confidence in the LIDAR data you may calculate parameters such as ht:dbh ratio, SF% and LCR%. If you are looking for areas that are immediately ready for CT, you will also be able to include queries to ensure the average minimum BA is currently >30 m^2 ha^{-1} and the average sawlog volumes are >140 m^3 ha^{-1}.
5. Ground truth representative areas of potential, noting CT vs. no CT areas. If you do not have timber cruise data, consider adding a few plots to the proposed CT areas. British Columbia has developed a field supplement guide which includes a plot protocol for evaluating suitability for CT (British Columbia Ministry of Forests 2021).
6. Build a preliminary layout map based on the ground truthing, removing cut blocks and portions of cut blocks where you do not recommend CT. Spatially tag LIDAR polygons and/or timber cruise plots that fall within the areas where you recommend CT.



* In some economic and/or wood supply situations you may consider CT if site index is 16-18.

Figure 4 *A decision support tool for identifying Alberta stands with high potential for commercial thinning.*

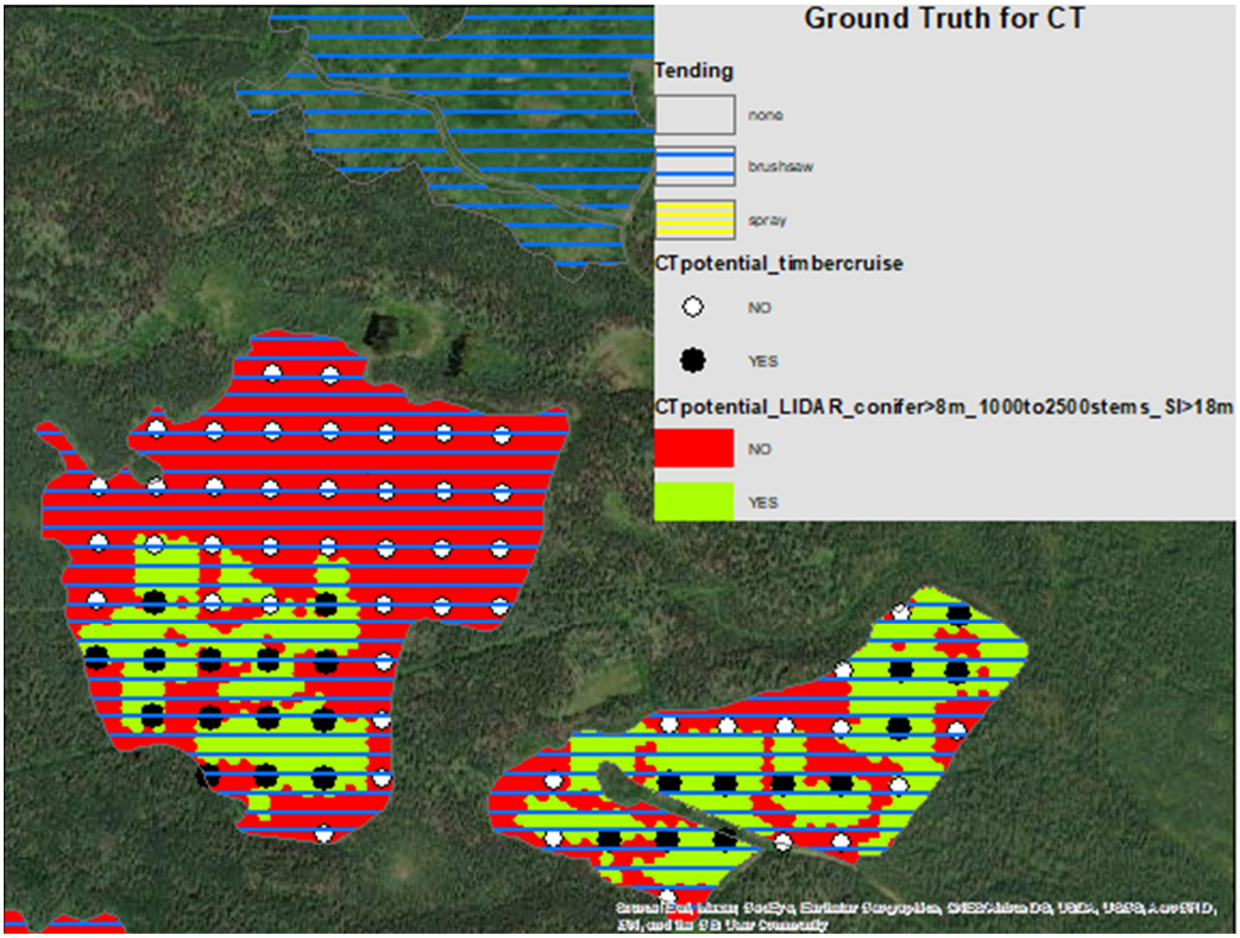


Figure 5 *Example of a ground truthing map to be used for finding areas with high potential for CT 5-20 years in the future (at time of evaluation these were 30-year-old cutblocks). In this case both timber cruise data and LIDAR data were available.*

***Table 3** Spacing factor and associated ages for first CT of white spruce, fir, and pine species in Alberta. On poorer sites the economics will be less favorable for CT.*

Species	Density of Dom/Codom	Site Index					Spacing Factor (based on dom/codom ht)	Dom/Codom Height pre CT (m)	Dom/CoDom Spacing pre CT (m)
		16	18	20	22	24			
mid tolerant white spruce and tolerant fir	1200	clearcut		54	46	41	16%	18.0	2.89
	1400		57	49	42	37		16.7	2.67
	1600		53	45	39	35		15.6	2.50
	1800	57	49	42	37	33		14.7	2.36
intolerant lodgepole or jack pine	1000	clearcut		50	43	37	18%	17.6	3.16
	1200		53	44	38	33		16.0	2.89
	1400	56	47	40	35	28		14.8	2.67
	1600	51	43	37	33	27		13.9	2.50

Notes:

(1) Live crown and ht:dbh ratios should be monitored, which may result in slightly earlier or later CT than the ages recommended below. This is to allow for operational planning flexibility, as well as to optimize growth and minimize blowdown.

(2) At the extreme (i.e. pine with a site index of 24m and a density of 1600 stems) there may be concerns (such as too high a proportion of juvenile wood). This would require the CT to be delayed longer than the theoretical optimum age of 27 years.

6.0 RISK FACTORS TO CONSIDER

Some of the major risk factors that should be considered include blowdown, snow breakage, insect and disease damage, damage from harvesting, and increasing likelihood of droughts. In this section we will attempt to establish some principles, rather than being overly prescriptive. It is important not to consider the risk factors in isolation, but rather to be mindful of cumulative effects.

For the various risk factors, one should attempt to thoughtfully balance the potential negative and potential positive impacts of the proposed CT. The following example is given as an illustration of how to consider risk factors. In a lodgepole pine stand with CT potential, consider the degree to which trees that are more susceptible to damage from the wind/snow can be removed. By carefully thinning from below the most windfirm trees will remain. Also, if the harvesting operator can see most of the trees where the bole is encircled with western gall rust (WGR) it may be possible to reduce the proportion of trees that will suffer blowdown/snow breakage in the future. These efforts are likely to have a net positive effect on stand hygiene and total merchantable volume. However, if the operator reduces the density but does not reduce the proportion of WGR and otherwise snow/wind-susceptible trees, the net effect may be negative. This is because wind/snow breakage may increase due to the reduced density and increased susceptibility of the remaining trees.

Key elements to reduce the damage from harvesting
1. Experienced operators. 2. A strong quality control system with quick feedback to operators. 3. Use of bumper trees that can be harvested later, or other measures to protect crop trees. 4. Appropriately sized harvester and forwarder with good visibility. 5. Careful location of forwarding trails (i.e. avoid side slopes).

Key elements to decrease risk of blowdown
1. Removing no more than 40% of the basal area. 2. Not carrying out CT if the ht:dbh ratio is >90. 3. Generally thin from below and prioritize removal of at-risk trees (i.e. more slender trees, WGR trees). A possible exception to thinning from below may be shade intolerant PL overtopping mid tolerant SW. In this case some of the trees that are more at-risk and less likely to have a growth response may be the taller PL. Therefore, it may make sense to do a combination of CT from below and above, favoring the most windfirm trees with the best live crowns, irrespective of their position in the canopy. 4. Manage densities and stocking during the reforestation phase with appropriate planting densities and PCT or other vegetation management treatments. 5. If the stand location makes the blowdown risk very high, consider dropping from CT program or consider leaving an un-thinned protective buffer on the NW (prevailing wind) side.

Key elements to decrease insect and disease risk
1. Conducting informal or formal surveys prior to thinning to determine the amount of western gall rust, armillaria, white pine weevil, or other pathogens of concern. 2. Make an informed judgement as to whether the stand hygiene and overall stand survival and growth is likely to be improved or worsened by thinning. 3. Good visibility from the cab of the harvester (at least 5m up the bole of the trees, the more the better). 4. For additional information on forest health considerations related to CT review BC's Interim Guidance for CT (British Columbia Ministry of Forests 2021).

Key elements to reduce impacts of droughts associated with climate change
1. Ensuring the ideal species mix is reforested. 2. Thoughtfully considering the literature, some of which indicates that careful management of densities with thinning may reduce drought risk. It appears that only one thinning intervention is unlikely to decrease drought risk, because the thinning would need to be so aggressive that it would predispose the stand to blowdown.

7.0 APPROVAL AND LAYOUT

7.1 CT Approval

It is necessary to review and address the latest requirements for CT approval found in Alberta's Partial Cutting Planning and Monitoring Guidelines (Greenway *et al.* 2006), which is currently being revised. The guidelines describe the submission requirements, including the requirements for crop planning and monitoring. The monitoring requirements in the current guidelines include a responsibility to report on harvesting and subsequent damage to the stands, as well as requirements for the installation of PSPs. Crop plans are required in order to forecast and evaluate the impacts of CT vs. no CT and evaluate the risks over the entire life of the stand. A detailed description of crop planning is outside the scope of this handbook. However, the necessary foundational tools to develop crop plans are included, such as the use of SF % and/or DMDs.

If the crop plan is approved, the timber that is harvested during CT may not be AAC chargeable and may be subject to reduced stumpage fees.

7.2 Layout

In many ways layout of CT is similar to traditional clearcut layout. However, there are notable differences, some of which are outlined below:

- Minimize unnecessary harvesting of conifer for activities such as road building and decking space. Much of the growth response benefit of CT can be lost if trees were unnecessarily harvested for roads and decks.
- Forwarders can work efficiently up to about 600m which allows roads to be minimized. Far less road and decking space will be needed than in clearcut harvesting.
- Oil and gas may be satisfied with smaller pipeline crossings because the weight and ground pressure of CT equipment is lower.
- CT harvesting is much slower (approximately 1 ha per day) and more expensive per m^3, so the layout should be careful to exclude small areas where the operator should not work. Examples of areas to remove within a cutblock include deciduous patches, areas where the

density is too high or low for CT, and areas where the site index is too low. If the operator wastes time in these areas the cost per ha will increase and the benefit will be decreased.
- Use of on-board GPS (i.e. tablet with Avenza^{TM}) can reduce the quantity of layout that must be flagged.
- Layout personnel should note even minor slopes, so that the trails can be oriented to minimize side slopes.
- Consider laying out the forwarding trails, at least during the startup training phase.
- Consider marking the trees to be removed during the startup training phase.

8.0 SUPERVISION

Suggestions for implementation of CT can be found in the British Columbia operational manual (Pavel *et al.* 2021)[4] and the British Columbia Ministry of Forests interim guidance (2021). The following sections highlight some factors that we have found to be of particular importance.

8.1 Operators

A lack of experienced harvester operators may well be the biggest constraint currently facing CT in Alberta. Operator experience and natural ability are critical to the success of CT. It is not unusual for operators of other logging equipment (i.e. feller buncher) to be unable to transfer that experience to productive operation of CT equipment. It generally takes 2 years to develop an operator, even if they have a high level of natural ability.

8.2 Equipment

Although other configurations may be considered, a single grip harvester and a forwarder are generally used for CT. Where it is operationally feasible trails should go directly up and down slopes. Minimize harvesting on side slopes, as the slopes will result in increased damage to the crop trees or require wider trails. There are various trail systems that can be used for the harvester and forwarder. Depending on a variety of factors, “ghost trails” are sometimes beneficial to increase productivity, reduce damage, and maintain the best crop trees. Only the harvester travels on the ghost trails. Ghost trails are particularly useful if the forwarder is wider than the harvester and/or if the harvester is much more maneuverable than the forwarder. Another benefit of ghost trails is that the harvester can meander a little, thereby leaving more of the best crop trees. Also, the wood is consolidated to minimize the forwarding time. The use of ghost trails requires a high level of harvester operator ability. Figure 7 is an illustration of three common options, assuming a 10m boom on the harvester.

[4] https://library.fpinnovations.ca/media/FOP/TR2021N93.pdf

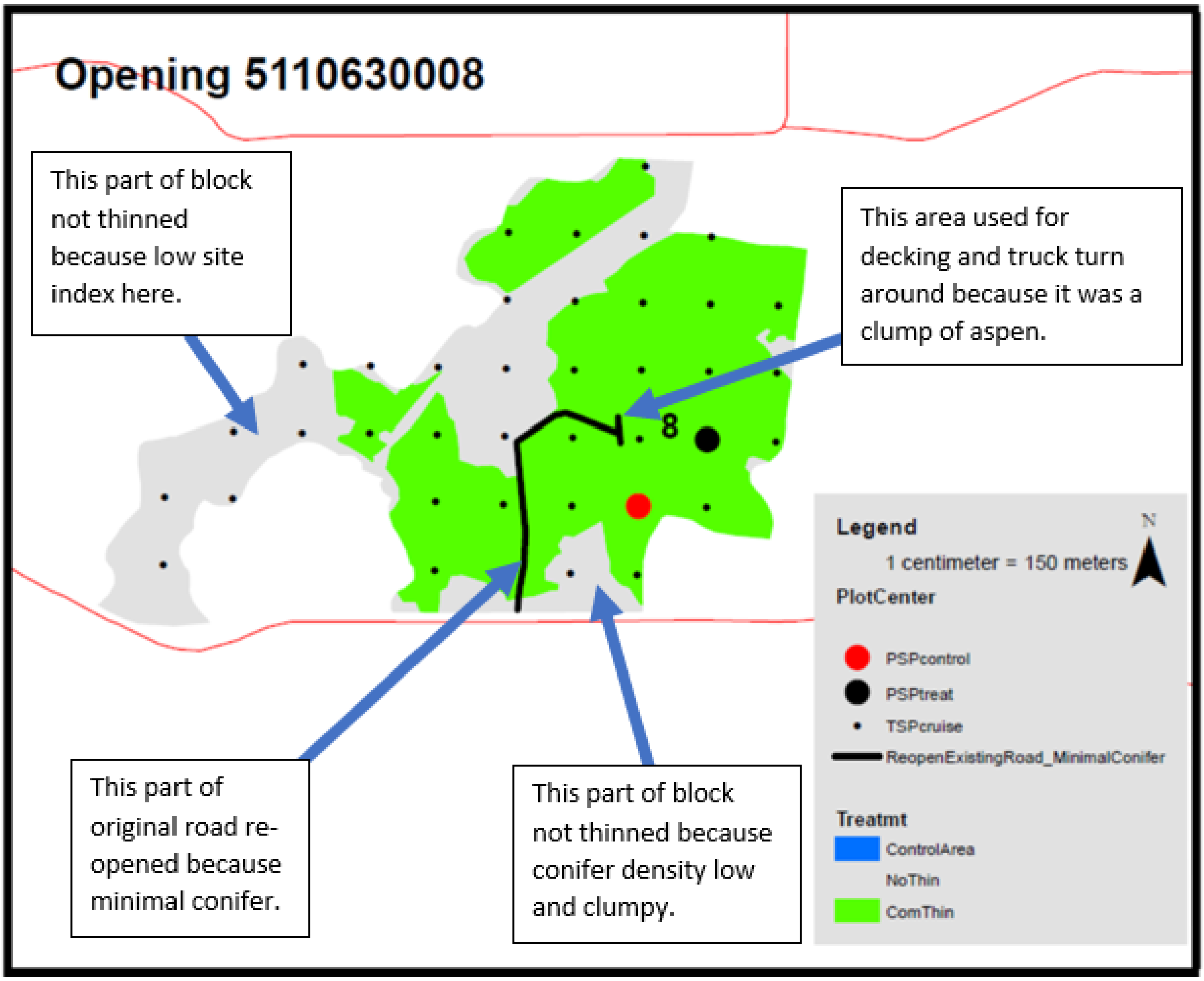


Figure 6 *Example of some of the things to consider when laying out a block for commercial thinning.*

Factors related to selecting CT equipment selection
1. Once the crop planning has defined the maximum trail width, the equipment can be selected. The equipment should be about 1m narrower than the trail width. For example, if the desired target trail width is 4m, a 3m wide harvester/forwarder is likely to be ideal. This allows the equipment to move quickly and efficiently without causing significant damage to the remaining crop trees, assuming the operator is experienced. A balance should be struck between size and capability because: a. the harvester must also be large enough to handle the trees b. if the harvester is too small it will have problems in deep snow
2. The felling head should be large enough to able to handle the target tree size, but the head should also be small enough to be maneuverable. Large felling heads make it more difficult to avoid damage to the crop trees.
3. Longer harvester booms are more efficient, as they require fewer trails. A 12m boom will generally be much more productive than an 8m boom (assuming you have highly skilled operators).
4. Operator visibility from the cab of the harvester is important in determining which trees to thin, especially in situations where there are big differences in tree quality. For example, when thinning lodgepole pine you want to maximize visibility of trees that are badly infected with WGR as these trees should be taken because they are likely to break off in the future if left as crop trees. The operator should be able to see at least 5m up the bole of the trees.

Trail option examples with 10 m long harvester boom (effective reach of 8.5 m)
1. All trails are main trails where both the harvester and forwarder travel. In this case there would be a main trail roughly every 17 m center to center (2 X 8.5m).
2. A ghost trail is used between each main trail where the main trail is every 25.5 m on center (3 X 8.5m). The forwarder only travels on every second trail. Only the harvester travels on the ghost trails. The harvester reaches out to drop the bucked wood within reach of the trails where the forwarder will travel.
3. Use 2 ghost trails between each main trail where the main trail is every 34 m (4 X 8.5m). The forwarder only travels on every third trail. The harvester will have to swing the wood across as can be seen in Figure 7.

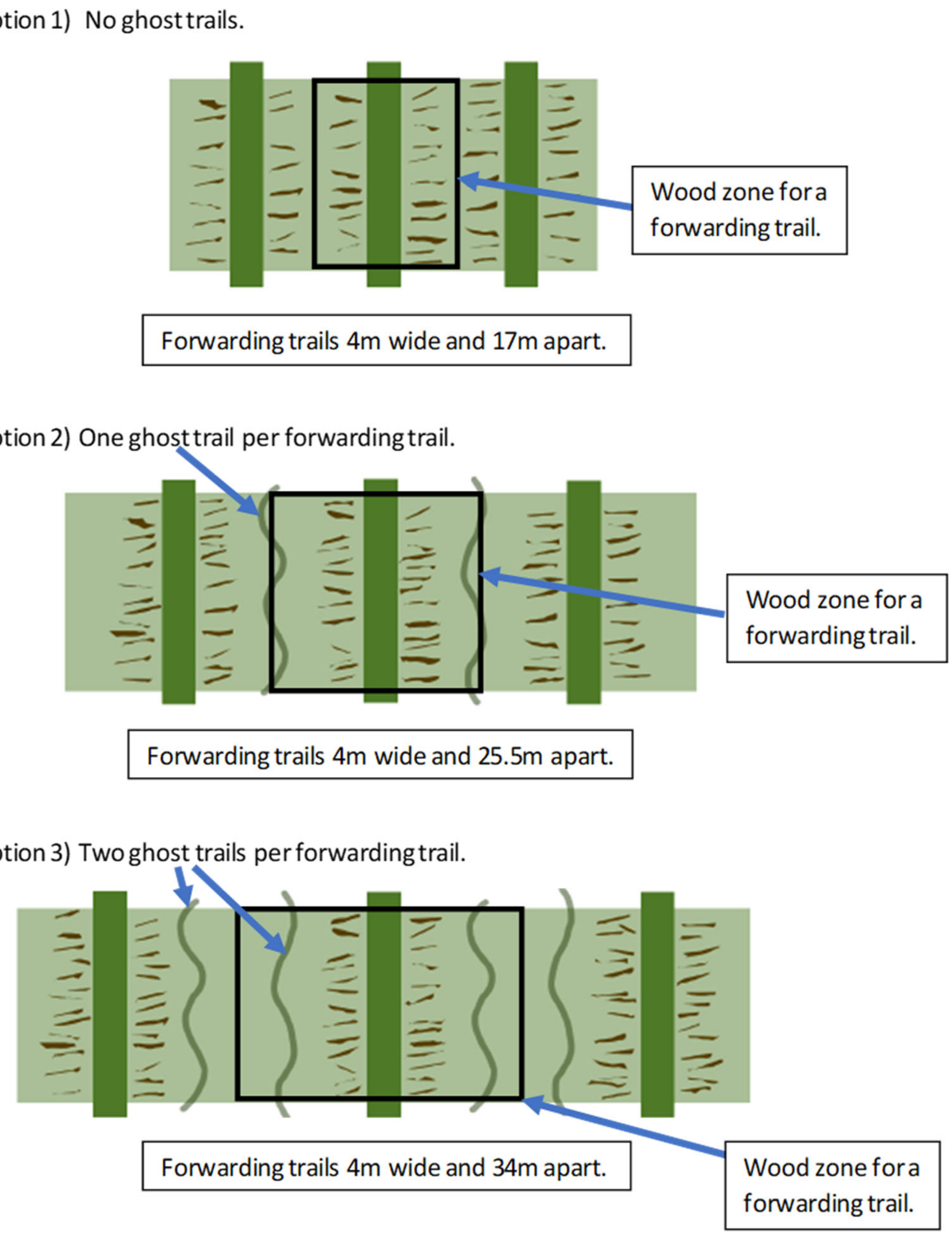


Figure 7 *Commercial thinning trail options for a harvester/forwarder. The harvester was assumed to have a 10m boom with 8.5m effective reach. Only the harvester travels on the "ghost" trails. In some cases, ghost trails may reduce damage, retain better crop trees, and increase productivity.*

8.3 Quality control

The level of supervision required for CT is much higher than for conventional clearcut harvesting. A strong quality control system is a necessity for successful CT. In terms of the level of quality control required it is more comparable to a tree plant than to conventional harvesting. Quality control plots and a high level of on-the-ground communication and supervision is important, especially early in a project.

Key quality control factors for a successful CT
1. CT is not recommended into late winter/spring because damage will increase as the trees begin to be active (i.e. loose bark). Monitor closely.
2. Wounds should be <400 cm^2 per any one location on a tree. No more than 5% of the trees should have bole damage greater than these thresholds.
3. Use rub trees where appropriate to minimize damage. Consider having a certified chainsaw operator on the forwarder to fell and buck trees that are badly damaged.
4. Trail widths should be less than the maximum allowed.
5. Density achieved relative to target density (consider initial stocking and what was available to the operator).
6. Selection rules not followed (such as leaving visible bad gall rust or a forked tree as a crop tree). Selection is difficult to evaluate because it is difficult to know what was available to the operator. This problem may be partially alleviated by communicating and evaluating while watching the operator work. It may also be helpful to compare pre and post treatment PSP measurements to determine how well selection was done.

A useful classification system for tree quality is found in the Operational Manual for CT in British Columbia (Pavel *et al.* 2021).[5]

[5] https://library.fpinnovations.ca/media/FOP/TR2021N93.pdf

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