Improving Survival for Planted Interior Douglas-fir (Fdi) in The Cariboo Natural Resource Region

CONTRACT#OT20FHQ043 YEAR 2

Final

March 15, 2023

Project [419-46]

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Executive Summary

Establishing Interior Douglas-fir in the Cariboo Natural Resource Region has many challenges. The ecosystems present in the Cariboo experience considerable variability of drought and frost.

Climate change modelling indicates that the Cariboo Natural Resource Region will experience an increase in climate extremes. This can take the form of extended periods of drought and frost as well as extremes in temperature throughout each month of the year (MacKenzie and Mahony 2021). Douglas-fir is extremely difficult to establish, and trends of increased exposure will make this more challenging. However, once Douglas-fir is established it becomes increasingly resistant to these events.

Where Douglas-fir forests currently exist, it must be maintained and further recruited to support forest values such as water, soil, timber, wildlife, and carbon sequestration. The best practices for harvesting in Douglas-fir forests are through silvicultural systems such as uniform shelterwoods, single tree or group selection (Newsome et al. 2016). However, because there have been such extensive catastrophic fires and a recent history of clearcut harvesting in the region, many of the strategies recommended in this paper focus on situations where thermal protection is limited. Forest professionals are planting Douglas-fir into areas that are challenging to establish. This report recommends best management strategies to increase Douglas-fir presence, through improving planted tree survival. It is not enough just to plant Douglas-fir, it must thrive to provide the conditions necessary to maintain our forest values.

Important factors such as the following are discussed in detail:

- Brushing
- Drought
- Fertilization
- Frost hazard assessment
- How seedlings grow
- Identification, coding, and reporting
- Identifying drought prone sites
- Identifying drought prone situations
- Mechanical site preparation (MSP)
- Natural regeneration
- Nursery considerations
- Planting contract implementation
- Planting contract setup
- Planting season
- Post planting review, walkthrough, or survey schedule regime
- Post-harvest assessments
- Pre-harvest signoff of site plans
- Recommended treatment regimes
- Seed selection, germination percentages
- Seedlot selection. Progeny and class
- Species selection
- Stock selection – container type and size
- Thermal protection and shade
- Trials

Multiple situations and silviculture scenarios are recommended as Best Management Practices for managing Douglas-fir.

Photo 1. Example IDFdk4 site. This shows some of the challenges for planting Fdi in the Cariboo Natural Resource Region.

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List of Acronyms

Fdi	Interior Douglas-fir
Pli	Interior lodgepole pine
Sx	Hybrid spruce
Py	Ponderosa pine
CF%	Coarse Fragment Percentage
BEC	Biogeoclimatic Ecosystem Classification system
BGC	Biogeoclimatic unit
CBST	Climate Based Seed Transfer
EMF	Ectomycorrhizal Fungi
GBST	Geographic Based Seed Transfer

MSP	Mechanical Site Preparation
MSS	Minimum Stocking Standard
NSR	Not Satisfactorily Restocked
PHA	Post-harvest assessments
PSB	Plug - Styroblock
PSI	Plug – Styroblock, Individually Wrapped
RESULTS	Reporting Silviculture Updates and Landstatus Tracking System
RGC	Root Growth Capacity test
SPAR	Seed Planning and Registry application.
TSS	Target Stocking Standard

Document Revision History

Version	**Date**	**Description**
1.0	2021-02-27	First submission
2.0	2021-03-30	Final submission
3.0	2022-03-25	Final Submission

1. Introduction

Establishing Interior Douglas-fir in the Cariboo Natural Resource Region has many challenges. The ecosystems present in the Cariboo experience considerable variability of drought and frost.

Climate change modelling indicates that the Cariboo Natural Resource Region will experience an increase in climate extremes. This can take the form of extended periods of drought and frost as well as extremes in temperature throughout each month of the year (MacKenzie and Mahony 2021). Douglas-fir is extremely difficult to establish, and trends of increased exposure will make this more challenging. However, once Douglas-fir is established it becomes increasingly resistant to these events.

Where Douglas-fir forests currently exist, it must be maintained and further recruited to support forest values such as water, soil, timber, wildlife and carbon sequestration. The best practices for harvesting in Douglas-fir forests are through silvicultural systems such as uniform shelterwoods, single tree or group selection (Newsome et al. 2016). However, because there have been such extensive catastrophic fires and a recent history of clearcut harvesting in the region, many of the strategies recommended in this paper focus on situations where thermal protection is limited. As forest professionals are planting Douglas-fir into areas that are challenging to establish, this report recommends best management strategies to increase Douglas-fir presence, through improving planted tree survival. It is not enough just to plant Douglas-fir, it must thrive to provide the conditions necessary to maintain society's desired values from the land-base.

The following maps and charts show the scope and scale of Douglas-fir seedling planting across the Cariboo Natural Resource Region. The majority of Douglas-fir is planted in the IDFdk3 and IDFdk4 biogeoclimatic zones. The SBSdw1 and SBSdw2 biogeoclimatic zones also have considerable planting of Douglas-fir as well.

The following map displays the last 10 years of Interior Douglas-fir (Fdi) plantations on the Chilcotin Plateau. The majority of sites on the plateau where Fdi is planted had less than 30% Fdi. Most of the reforestation on the plateau is for pine dominated forests in the IDFdk4 and IDFdk3. Fdi was prescribed for the portions of these openings that are most suitable for Fdi. The few units that are greater than 30% are for reforestation within the 2017 wildfire.

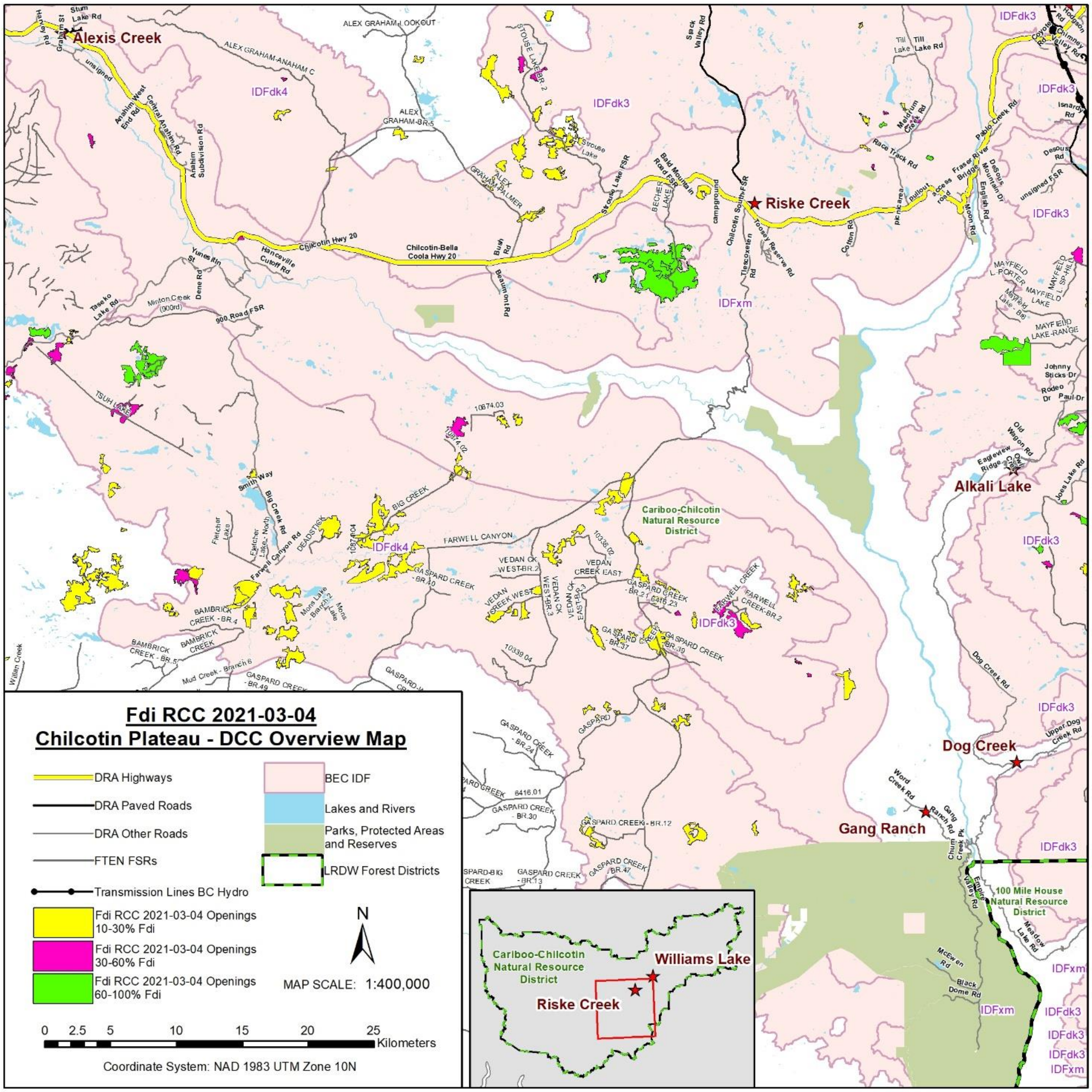

Figure 1. 10 years of planting Fdi near Chilcotin Plateau. DCC.

The following map displays the last 10 years of Fdi plantations east of Williams Lake, near Likely, Horsefly and Quesnel River. Fdi comprises a much higher component of plantations in this area, which is mainly in SBSdw1 and SBSdw2. The reforestation east of town is in Fdi and Pli leading forests, transitioning to spruce, pine, western redcedar, western hemlock and subalpine fir forests. There are many more stands in this vicinity, relative to the Chilcotin Plateau, that were planted with greater than 30% Fdi.

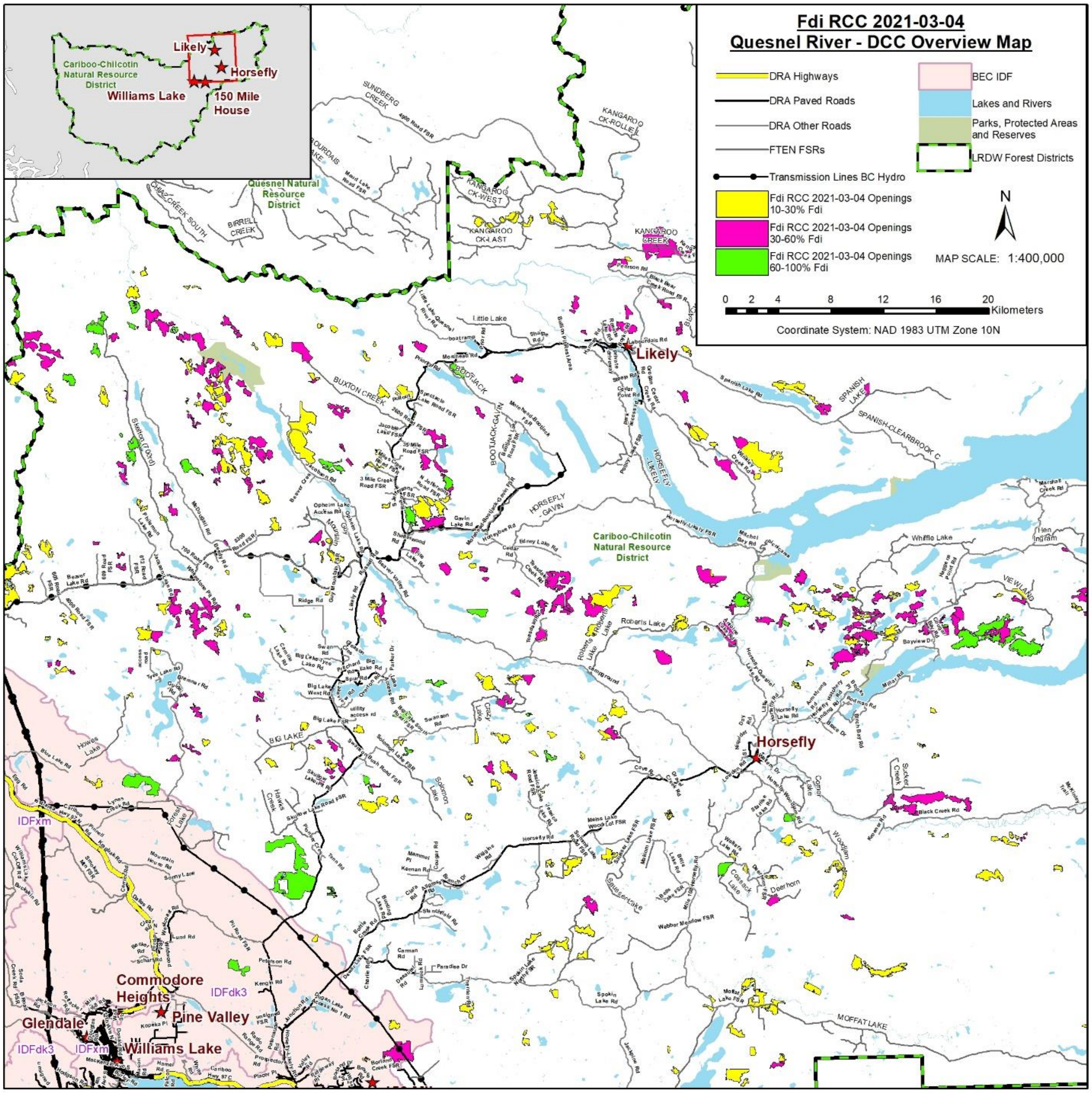

Figure 2. 10 years of planting Fdi near Quesnel River. DCC.

Figure 3 shows a summary of 10 years of Fdi planting in the Cariboo Natural Resource Region. It demonstrates that the majority of Fdi is planted in the IDFdk3, IDFdk4, SBSdw1, and SBSdw2. Significant amounts are also planted into the ICH and SBPS as well.

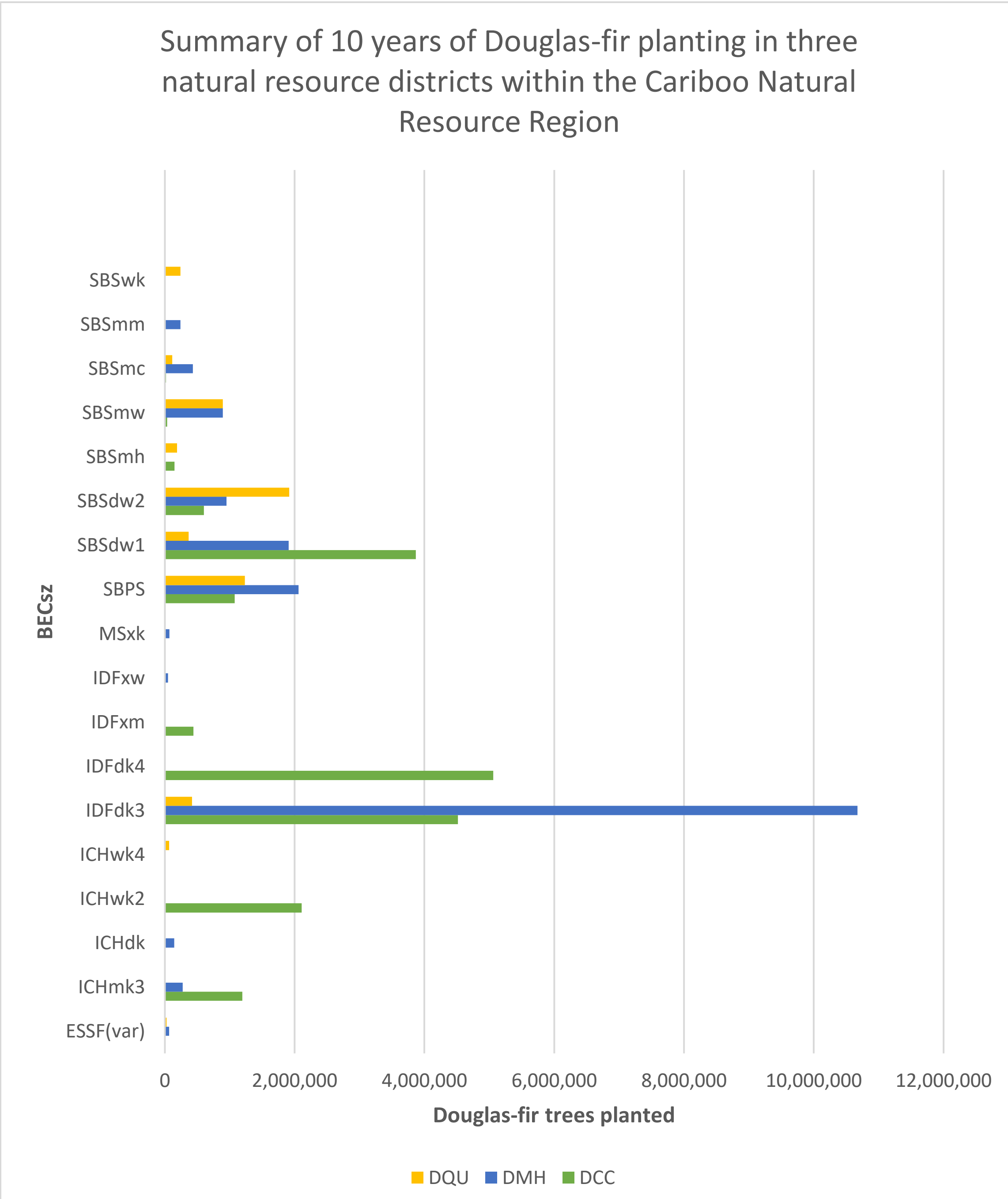

Figure 3. Summary of 10 years of Douglas-fir planting in three natural resource districts within the Cariboo Natural Resource Region

Figure 4 shows a summary of 10 years of Fdi planting in the Cariboo Natural Resource Region relative to the total amount of trees planted in these BEC subzones. It clearly demonstrates that the greatest percentage of Fdi is planted in IDFdk3, IDFdk4, SBSdw1 and SBSdw2, yet the Fdi percentage planted is still relatively minor compared to the total trees planted. There is a reasonable amount of Fdi planted in the SBPS, but the Fdi represents a very small percentage of the total trees.

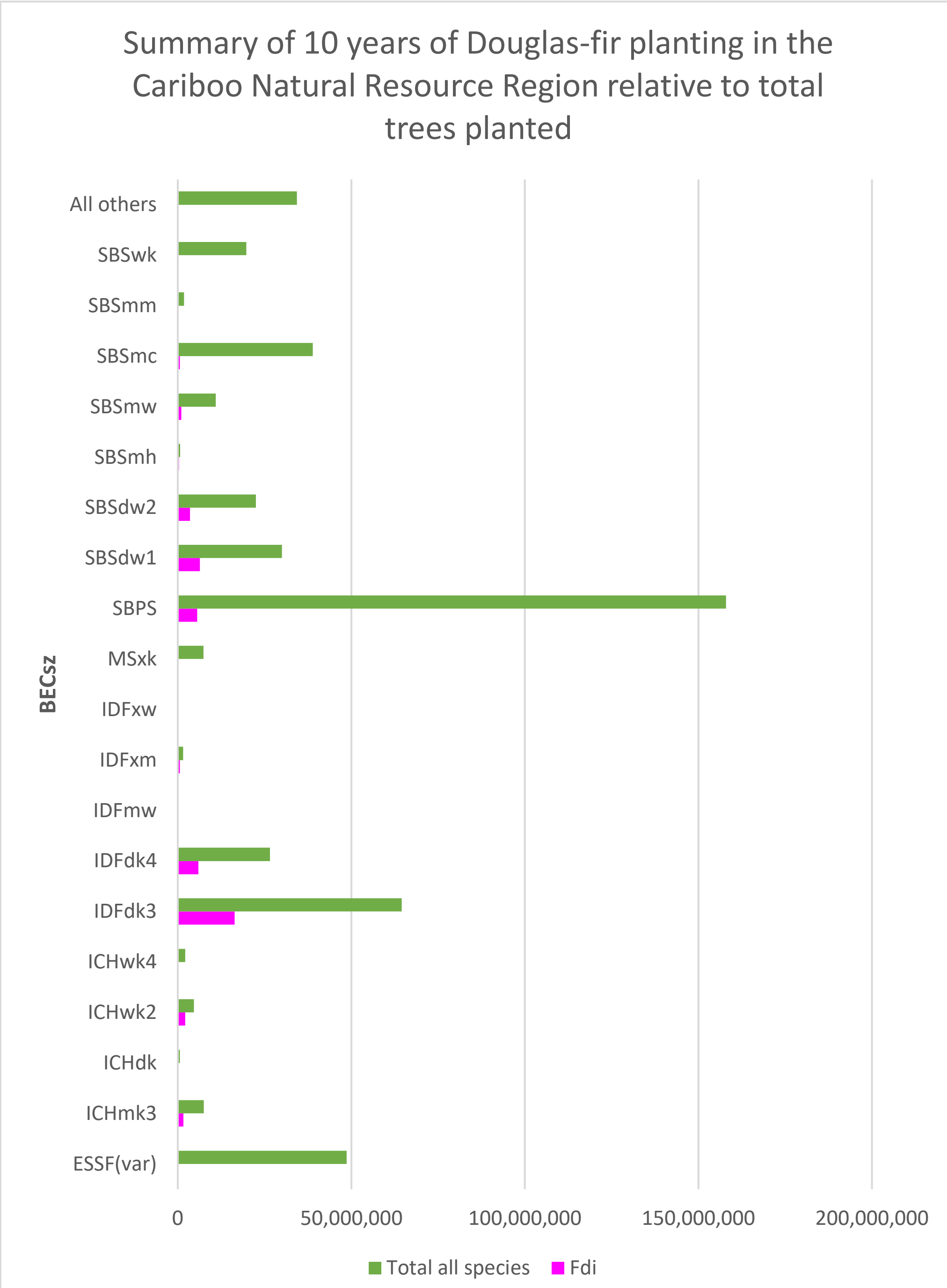

Figure 4. Summary of 10 years of Douglas-fir planting in the Cariboo Natural Resource Region relative to total trees planted.

1.1 Project Objectives

Current practices are heavily dominated by clearcut with reserves and planting. The aim of this report is to review the current practices when planting Fdi in the Cariboo Natural Resource Region. This review recommends Best Management Practices for improving planting survival success in open managed scenarios (clearcut with reserves or wildfire scenarios).

2. Approach

2.1 Data gathering and preparation

The data gathering phase was undertaken in partnership with research scientists, nursery specialists, district staff, and licensee silviculturists that chose to engage for this report. The intention was to access data from recent planting treatments with a significant Douglas-fir component, as well as review industry practices, current research, and nursery cultural practices. This approach clearly is biased towards planting in scenarios with lower amounts of overstory retention. The interviews touched on many topics, however, not all topics were discussed with each licensee representative as the list of topics evolved and grew through discussions within the interview process. These conversations help inform the best existing practices when managing to reforest stands where reforesting with Fdi has significant challenges.

Most of the findings in this report resulted from field reviews of the plantations reported by the licensees, BC Timber Sales and ministry staff. While survey results were provided in many instances, each of these sites had complexities beyond the summarized reports. Each of the plantations had instances of good survival and performance as well as instances of poor survival and performance. Most of the recommendations for improved practices, found in this report, are based on ocular assessments of trends gathered over many sites.

This review focused on relatively recent harvesting and planting. Field visits were conducted in late October and into November. Natural regeneration trends on the most recently harvested sites could not be fully witnessed because of the snow cover.

Data gathered includes:

1. RESULTS reports of planting activities with greater than 10% Fdi planted.
2. An interview with silviculturists covering all aspects of silviculture to identify their current or planned practices for Fdi reforestation. Scope: pre-harvest review of sites, post-harvest assessments, as well as activities and practices.
3. A recommended list of field sites which have had varying treatments and results, suitable for generating discussions about silviculture practices with Fdi. For the sites visited, please see Appendix 2 to review an overview map and summary reports.
4. Literature review of the last twenty years of relevant research.

3 Frost

Frost hazard has been studied extensively in the Cariboo Natural Resource Region. Late spring and summer frost events are a significant damaging agent causing both injury and mortality in Douglas-fir. Frost is clearly identifiable. It kills freshly flushed foliage and leaders, and repetitive frost causes stem forking. Frost occurs when the temperature of any object drops below zero Celsius. Frost can occur via two pathways, radiative frost and advective frost. Radiative frost occurs when any object transfers energy from a high energy source to a low energy receiving object. In the case that applies to planted trees, energy is radiated from the ground surface (where the planted trees are) to the night sky. Since the transfer of energy is more efficient from the ground than the air above the ground, the ground cools faster than the air above. This is why frost can form when the air temperatures are above zero degrees Celsius (Stathers 1989). Advective frost occurs when air that has been cooled by radiative frost elsewhere travels downhill, like flowing water, across the landscape. Frost ponding occurs in small or large depressions when there is no longer a path for the cold air to travel further (Stathers 1989).

Figure 5 demonstrates the movement of cold air down a macroslope building up on lower slopes.

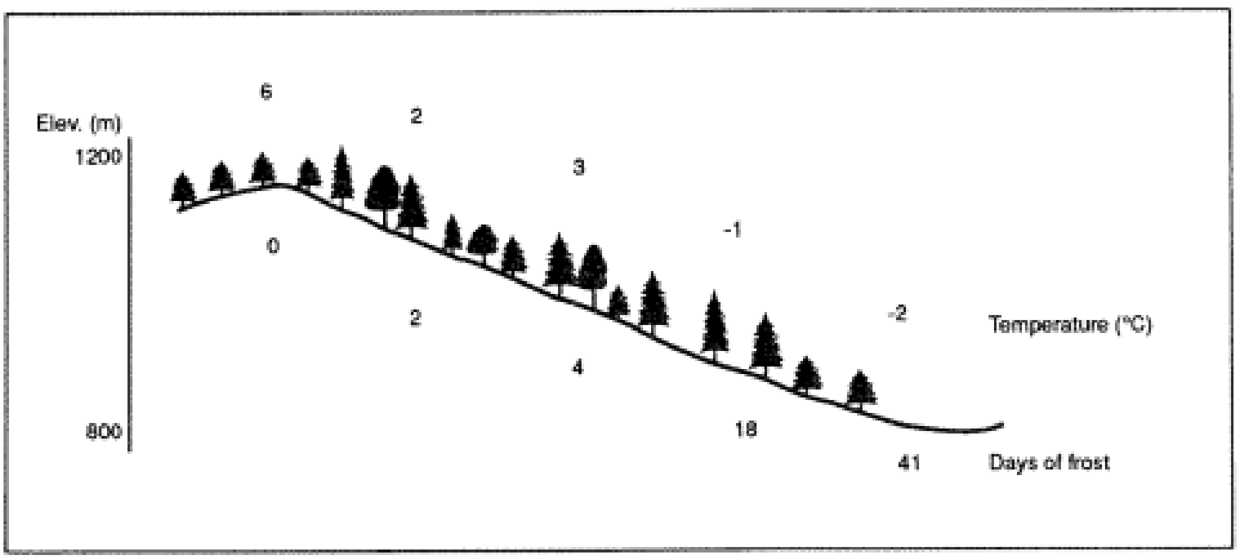

Figure 5. Minimum overnight air temperatures and number of days with frost between June 1 and August 30, 1988 on a mesoslope transect in SBSdw2 near Pantage Lake BC (Steen et al. 1990)

Frost damage occurs seasonally; spring frost occurs earlier in the growing season while late summer frost occurs later in the season prior to fall. Both frost events can occur via radiative and advective mechanisms but the damage to seedlings is quite different. Spring frost damage can kill laterals and new growth, but if the seedlings survive and outgrow the frost source there appears to be little persistent damage to the tree other than growth losses or stem forking. Late summer frosts impair the ability of trees to set down late wood lignin and can create a zone of weakness in the stem called frost-shake. These zones of weakness can act as pathways for pathogens and future growth losses. Of the two frost events, late summer frost has greater and longer-term potential for damage (Montwé et al. 2018).

Photo 2. Example Fdi seedling damaged by frost.

Photo 3. Example Fdi recovered from repeated frost damage. Notice how bushy the lower branches are.

The *FRDA report #157* (Steen et al. 1990) was an excellent first summary about frost and how it occurs, as well as a landscape level breakdown by Biogeoclimatic subzone of where to expect greater or lesser damage and mortality.

Identification and management of summer frost-prone sites in the Cariboo Forest Region. FRDA Report #157

Biogeoclimatic subzones/variants	Mesoslope position	Slope gradient	Frost hazard
Group 1:	Crest, Upper, Mid	> 5%	VL
BGxh3, xw2	Lower	> 15%	VL
IDFxw		< 15%	L
PPxh2	Toe, Depression, Level	< 5%	L
Group 2:	Crest	> 5%	VL
IDFdk1	Upper, Mid	> 15%	VL
IDFmw2		< 15%	L
IDFxm (Fraser R)	Lower	all slopes	L
SBSmh	Toe, Depression	< 5%	M
	Level	< 5%	L
Group 3:	Crest	> 5%	VL
ICHdk	Upper, Mid	> 15%	VL
ICHmk3		< 15%	L
ICHmw3	Lower	> 15%	L
ICHwk2,wk4		< 15%	M
SBSdw1	Toe, Depression	< 5%	H
	Level	< 5%	L
Group 4:	Crest	> 5%	VL
IDFdk3	Upper	> 15%	VL
IDFxm (Chilcotin)		< 15%	L
SBSdw2	Mid	> 15%	L
SBSmw		< 15%	M
	Lower	> 15%	L
		< 15%	M
	Toe, Depression	< 5%	H
	Level	< 5%	M

Table 1. FRDA157 preliminary frost hazard assessment rating. (Steen et al. 1990) (Continued on next page)

Biogeoclimatic subzones/variants	Mesoslope position	Slope gradient	Frost hazard
Group 5:	Crest	> 5%	VL
IDFdk4	Upper	> 15%	VL
		< 15%	M
	Mid	> 15%	L
		< 15%	M
	Lower	> 15%	L
		< 15%	H
	Toe, Depression	< 5%	H
	Level	< 5%	M
Group 6:	Crest	> 5%	L
MSxk	Upper, Mid	> 15%	L
SBPSdc		< 15%	M
SBPSmc	Lower	> 15%	M
SBPSmk		< 15%	H
SBSmc1,mc2	Toe, Depression	< 5%	H
	Level	< 5%	M
Group 7:	Crest	> 5%	L
ESSFdc2	Upper, Mid	> 15%	M
ESSFwk1		< 15%	H
SBPSxc	Lower	> 15%	M
SBSwk1		< 15%	H
	Toe, Depression	< 5%	VH
	Level	< 5%	H
Group 8:	Crest	> 5%	M
ESSFwc3	Upper, Mid	> 15%	M
ESSFxv		< 15%	H
MSxv	Lower	> 15%	H
	Lower, Toe, Depression	< 15%	VH
	Level	< 5%	VH

Table 1. continued. FRDA157 preliminary frost hazard assessment rating. (Steen et al. 1990)

This work has been extended and is currently summarized in an updated tool - DeLong, S. C., H. Griesbauer, C. R. Nitschke. 2011 FFESC Project B5: *Risk Analysis and Decision Support Tool Final Report*

The generation and transfer of frost throughout multiple macro and mesoslope positions is dependent on a number of factors including elevation, latitude, slope, aspect and topography. These factors have been quantified and spatially summarized both in the FRDA Report #157 as well as the latest Frost Risk Analysis and Support Tool collated by DeLong (Table 2.).

BGC unit	IDFdk4						Factors the May Increase the Hazard (from Steen et al. (1990)). **Bolded factors are more important**
Slope gradient (%)	≥15						**large upslope source area**
Slope position	Lower						**impediment to downslope cold air flow (e.g., cutblock edge)**
					Hazard Rating		**microtopographic depression, especially on level terrain**
Frost Hazard Rating				1	Very Low		cold air channel, gently sloping (e.g., creek drainage)
2				2	Low		grass-dominated vegetation on level sites
				3	Medium		north aspect
				4	High		
				5	Very High		Factors that May Decrease the Hazard (from Steen et al. (1990)). **Bolded factors are more important**
							tree or tall shrub canopy
							microtopographic crest or know, especially on level terrain
							mineral soil exposure on upper, mid- or level slope position
		Tree Species Suitability					abundant slash
	1&2	3	4	5			south or south-west aspect
	all species, caution with Cw, and Hw for category	all species except Cw and Hw, caution with Fd, Lw	At, Pl, Pa, Sb caution with Sx, Se, Bl	At, Pl, Pa, Sb			

Table 2. ***Frost hazard workbook*. (DeLong 2011)**

The *Frost hazard workbook* (Table 2.) works in conjunction with the Guide to preliminary frost hazard class ratings for clearcuts in the Cariboo Forest Region (Table 1.), from *FRDA Report #157 Identification and management of summer frost-prone sites in the Cariboo Forest Region*. Note the Factors that may increase and decrease frost hazard found on the Frost Hazard Workbook. These factors are described in detail in the FRDA report and are intended to be applied to adjust the final frost hazard of a site.

The definition of frost hazard (Table 3.) is an excellent first approximation of the potential for frost damage and mortality in Fdi and other species.

The following photos (photos 4 and 5) illustrate the need for proper stratification of sites when identifying frost hazard and applying frost hazard ratings. Strata that have different characteristics as identified in the FRDA Report #157 (Steen et al. 1990)) and the Frost Risk Analysis and Support Tool Delong (2012) will likely have different frost hazard, and this has implication for survival of Douglas-fir seedlings.

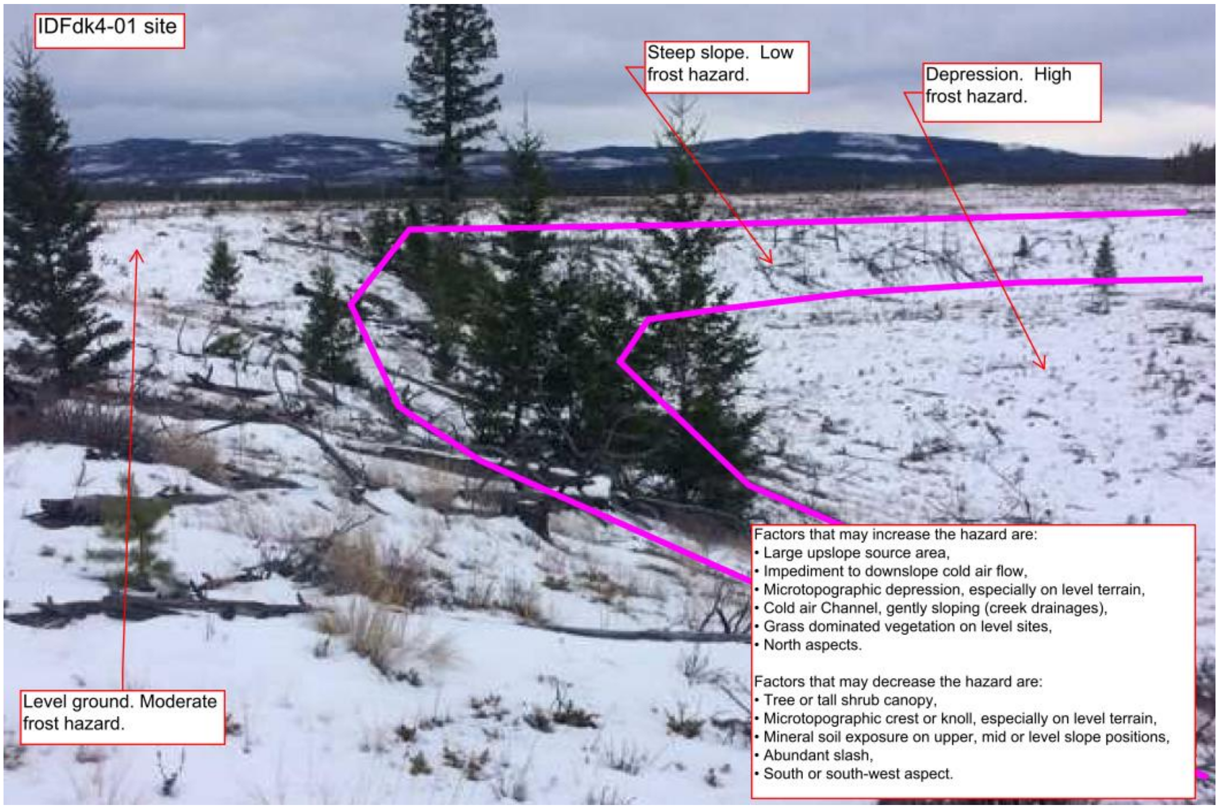

Photo 4. Example IDFdk4 site. Review the frost hazard for each of the strata within the opening.

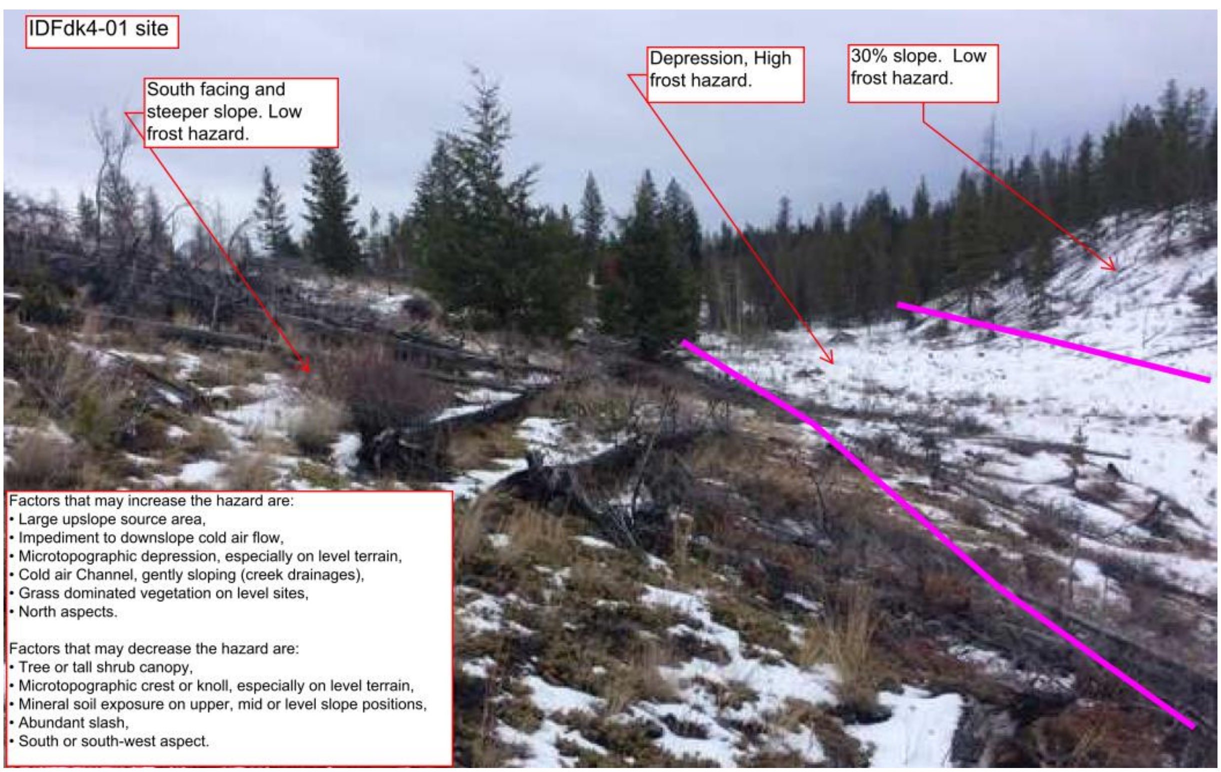

Photo 5. Example IDFdk4 site. Notice three clear and distinct strata for frost hazard mapping.

<table>
<tr><th rowspan="2">Summer frost hazard class</th><th colspan="6">Expected damage and mortality</th></tr>
<tr><th colspan="2">Douglas-fir</th><th colspan="2">Interior spruce</th><th colspan="2">Lodgepole pine</th></tr>
<tr><th>Expected incidence</th><th>Damage</th><th>Mortality</th><th>Damage</th><th>Mortality</th><th>Damage</th><th>Mortality</th></tr>
<tr><td>Very Low VL
0 in 10 years <-4°C
0 in 10 years <-8°C</td><td>None</td><td>None</td><td rowspan="2">None</td><td rowspan="2">None</td><td rowspan="3">None</td><td rowspan="3">None</td></tr>
<tr><td>Low L
1-2 in 10 years <-4°C
0 in 10 years <-8°C</td><td>Moderate</td><td>Limited</td></tr>
<tr><td>Medium M
3-6 in 10 years <-4°C
1-2 in 10 years <-8°C</td><td rowspan="3">Severe</td><td rowspan="3">Extensive</td><td>Moderate</td><td rowspan="2">Limited</td></tr>
<tr><td>High H
7-10 in 10 years <-4°C
3-5 in 10 years <-8°C</td><td rowspan="2">Severe</td><td>Moderate</td><td rowspan="2">Limited</td></tr>
<tr><td>Very High VH
10 in 10 years <-4°C
>5 in 10 years <-8°C</td><td>Extensive</td><td>Severe</td></tr>
</table>

Table 3. FRDA157 Definition of frost hazard (Steen et al. 1990)

From the frost hazard assessment worksheet and the definition of Frost Hazard Classes table, the transition for Fdi in many ecosystems between moderate damage and limited mortality (low frost hazard) and significant damage and extensive mortality (moderate frost hazard) occurs at 15 percent slope (as shown in IDFxm, IDFdk3, IDFdk4 and SBSdw2 for examples). This is an over-simplification as frost hazard recedes consistently as slopes increase beyond 15% slope and increases consistently as slopes decrease below 15%. If silviculturists were to use the average slope value for their stands, many stands that have suitable area for planting Fdi might be considered too risky to plant Douglas-fir. To maximize the amount of area that can be considered lower risk for planting Fdi, sites need to be thoroughly stratified from the perspective of frost hazard as it relates to Fdi. This should occur at the pre-harvest planning stage, but also must be reviewed and refined during post-harvest assessments. Low frost hazard areas must be spatially identified and placed on planting treatment maps for Fdi to be better targeted to those sites.

The Frost Hazard Assessment Worksheet (Table 2.) makes it clear that the first approximation must be adjusted by factors other than mesoslope position (Steen et al. 1990, as cited in DeLong 2011).

The following factors significantly increase the potential for frost damage and mortality:

- Large upslope sources where frost can form and flow from,
- Impediments to downslope cold air drainage (such as cutblock edges), and
- Microtopographical depressions or impediments to frost transfer such as upper slopes of coarse woody debris (depressions or obstacles found within otherwise steeper slopes).

The following factors have slightly higher risk for frost damage and mortality:

- Flat sites that have grass dominated vegetation, and
- North aspects.

The following factors significantly decrease the potential for frost damage and mortality:

- Tall trees providing thermal protection - the greater number of overtopping tall trees, the greater the thermal protection provided (Waterhouse et al. 2021), and
- Microtopographical crests or steeper slopes– these are areas where cold air can drain away soon after it is generated. Frost can be shed at the macro or micro scale. (Sagar and Waterhouse. 2018)

The following factors have slightly lower risk for frost damage and mortality:

- Mineral soil exposure,
- Abundant slash, and
- South or west slopes.
- Taking into consideration the above factors when stratifying a planting area, there may be opportunities to plant Fdi within portions of the opening that would otherwise be considered too high of a risk from frost damage.

Best Management Practice: silviculturists have the tools to adjust frost hazard through mature tree retention during harvest planning.

Silvicultural systems that maintain significant overstory are:

- ***Uneven-aged (group or single tree selection) and***
- ***Even-aged: shelterwood***

Figure 6, adapted from FRDA report 157, represents how the macroslope position influences frost hazard rating. The highest frost hazards are clearly in the flats and the toes of slopes. Frost is not only being created in these locations but is also flowing downslopes and pooling there. The lowest frost hazards are on the crests and on the steeper slopes. This indicates that although frost is being created in these locations, it is also flowing downslope away from these types of sites.

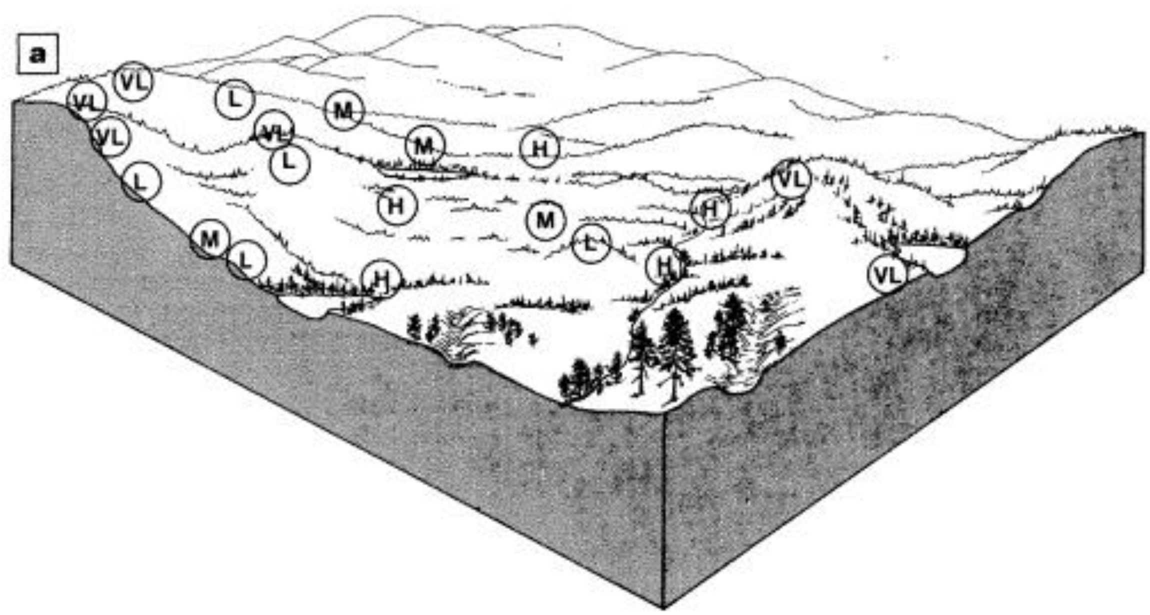

Figure 6. Sample frost hazard rating for macroslope in IDFdk3. (Steen et al. 1990)

With very little imagination this representation of a macroslope view of the IDFdk3 could represent a single cutblock that has similar complexities found throughout. The blue shading represents stratification of areas within the block most suitable for Fdi.

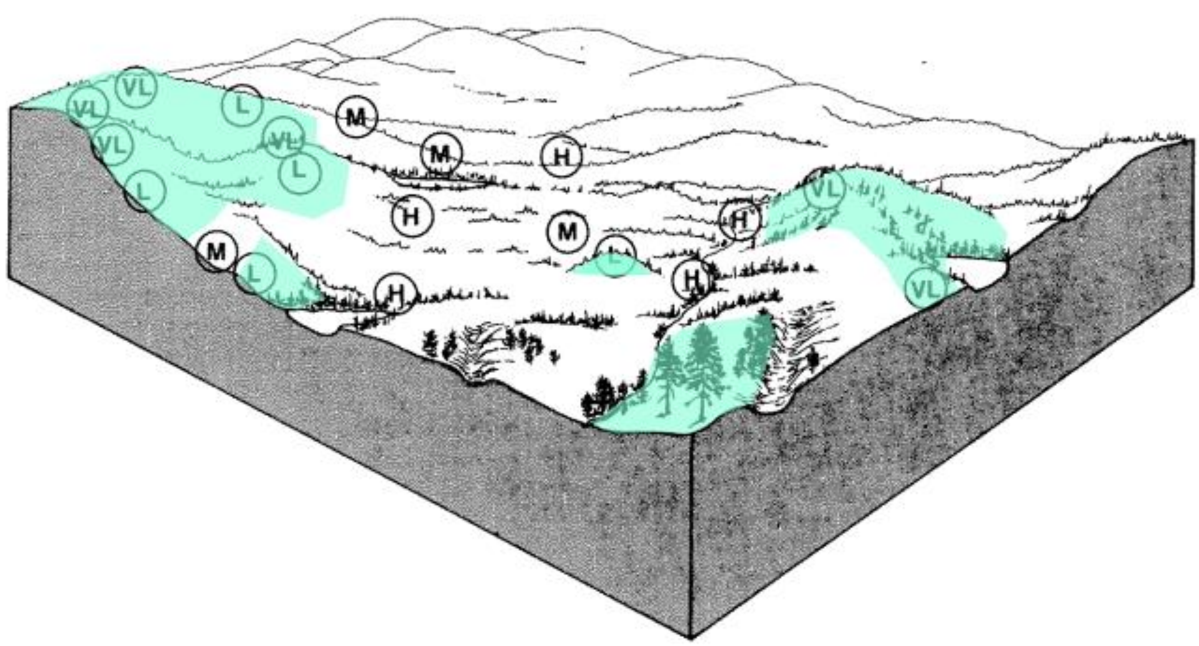

Figure 7. Sample frost hazard rating for an imaginary opening within the IDFdk3. (Original drawing Steen et al. 1990)

4 Drought

Drought hazard has been studied and reported on extensively in the Cariboo Natural Resource Region, however, it has not been quantified to the extent that frost has.

The report *Reforesting Dry Sites in the Thompson Okanagan Natural Resource Region* was completed for the Resource Practices Branch (Office of the Chief Forester) in 2020. This paper focused exclusively on drought and how to create treatment regimes to reduce mortality and damage caused by drought. Many of the findings from that report are applicable to the Cariboo Region, however, those regimes must be modified to incorporate frost management into the decision-making process. The IDF subzones within the Cariboo region all have drought mortality, though not to the extent of the Thompson Okanagan region. This is likely due to the reduced cover of pinegrass and lower daytime temperature extremes. While the Cariboo region has considerable pinegrass, it does not contribute to mortality as much, in comparison to Thompson Okanagan Region (Hegan, Pers. Obs.).

In the absence of frost as a limiting factor, the main tools for reforesting with Fdi in drought prone sites are overstory retention for shade; soil disturbance through mechanical site preparation (MSP); and prompt reforestation with large stock Fdi. In areas where frost is also a limiting factor, many of the same tools that allow Fdi to escape drought damage also mitigate for frost damage; overstory thermal protection, soil disturbance through mechanical site preparation and prompt reforestation with large stock Fdi.

Douglas-fir is relatively drought tolerant once established. Only Ponderosa pine is considered more drought tolerant. Seedlings can be considered established when their growth rates become consistent from one year to the next. Prior to establishment, Douglas-fir is very prone to drought damage and mortality. Drought damage often expresses as mortality due to the limited number of buds on newly planted seedlings. The mortality of planted Douglas-fir usually occurs in either of two periods: within the first two weeks following planting, or within the first summer following planting. As Fdi seedlings grow roots and establish more buds, the susceptibility to drought mortality diminishes.

Interviews with industry silviculturists revealed that they feel drought is much more prevalent in the IDFdk3, IDFdk4 and IDFxm, which is situated around the Fraser River and west of the Fraser River. They felt that for the SBS, which lies east of the Fraser River, drought was much less of an issue for reforesting with Fdi.

Best Management Practice: silviculturists have a tool to ameliorate drought hazard through mature tree retention during harvest planning.

Silvicultural systems that maintain significant mature tree retention are:

- ***Uneven-aged (group or single tree selection), and***
- ***Even-aged: shelterwood***

Photo 6. Example drought mortality on Douglas-fir seedling. Photo credit Sue Woermke.

There are no comments in the available literature that describes frost and drought interactions on a site. It is possible treatments that manage for drought improves the chances for Fdi seedlings to better overcome frost effects. This could occur through increased root growth, increased vigor, and the potential to grow rapidly in between strong frost years. More research is required to better understand the interaction between frost and drought mitigation strategies.

Site visit summary:

Refer to Appendix 2. Site visit overview map and reports.

Sites visited where Fdi mortality can be attributed to drought are units 24, 32, 33, and 34. These planting treatments from 2017 appear to have losses of planted Fdi that can be attributed mostly to drought. Throughout the other planting seasons witnessed, it's difficult to attribute losses of Fdi solely to drought mainly because the losses so closely follow expectations of losses due to frost. This is a really important point – it is hard to distinguish between mortality caused by drought, frost, or heat injury. This frustrates our desire to find a solution. If we take one step back and think of the problem as environmental exposure, it makes the discussion more about protection and less about the cause.

For the sites visited that were planted in 2017, all the Fdi died, even the ones that were placed on slopes that should otherwise expect little in the way of frost. It's unfortunate that none of these sites had been mechanically site prepared as no comparisons of trees planted inside and outside of prepared furrows or trenches can be made.

What is especially unfortunate is that all these sites are still stocked with lodgepole pine (Pli) and will not be filled in with Fdi – this is a missed opportunity. Also, the stand will be low density because of the loss of Fdi stocking if the Pli and Fdi were intimately mixed.

In each of the sites visited Pli had almost 100% survival. These sites were in the IDFdk4 and IDFdk3 and were raw planted. This is interesting as sites planted in the Thompson Okanagan Natural Resource Region exhibited similar losses with Fdi in 2017, but many sites there also had losses with Pli where site preparation was not completed or poorly completed. This might indicate that the sites visited are not exceptionally dry sites, relative to the Thompson Okanagan, and the combination of frost and drought impacted Fdi to a much greater extent than drought on its own. This is confirmed by Newsome et al. (2016), which showed very poor Fdi survival when raw planted, site prep improved Fdi survival. Performance of surviving Fdi continued to improve as they age in comparison to Pli. Although Pli seedlings tend to respond very well when planted following wildfires, some exceptions were noted. Mortality appeared to be caused by poor planting which causes poor root development in harsh soil types (S. Woermke Pers. Comm.). The implication is that root damage and poor microsite placement will affect the survival of Fdi.

5 Thermal Protection and Shade

Planted Fdi seedlings have greater chance of survival in the presence of mature trees that provide thermal cover on all sites in the Cariboo region. Significant thermal protection is essential on sites with significant frost hazard – sites that are in mesoslope positions where frost hazard is moderate or greater, as defined by Steen et al. (1990). Thermal protection by shading is critical to reduce heat injury. It also stops advective frost, and it reduces transpiration demands. It isn't just about frost but also about drought and heat stress. Shading (as in a shelterwood overstory) reduces grass and shrub competition (Ashton and Kelty 2018). A given seedling can experience surface temperatures of greater than 50^{o} Celsius and less than -4^{o} Celsius on the same 24-hour period in July. Shelter is the critical intervention for good survival of Douglas-fir, even in the ICH.

High quality sources of thermal protection and shade:

- Retention of mature conifer or deciduous overstory trees (in shelterwood or single-tree selection system or other retention system),
- Retention of mature conifer or deciduous overstory, in large clumps (in even-aged silvicultural systems),
- Partial or complete retention of fire-killed mature trees.

Photo 7. Example overstory retention to provide shade and thermal cover. IDFdk3-01 site, lodgepole pine salvage with Fdi overstory retention. Photo credit – Colin Hegan

The retention of significant overstory for thermal protection can ameliorate site conditions where moderate frost hazard is expected based on biogeoclimatic zone (BGC), subzone and mesoslope position. Even sites expected to have moderate to high frost hazard can be reforested with Fdi if significant overstory thermal protection is provided. Using a uniform shelterwood silvicultural system can minimize growing season frost events because the dense canopy slows radiative cooling (Waterhouse et al. 2021; Sagar and Waterhouse 2018; Day et al. 2011).

Photo 8. Example overstory retention to provide shade and thermal cover. IDFdk3-01 strip shelterwood on 35% slope. Photo credit – Colin Hegan

Best Management Practice: when planning for reforestation, increasing thermal cover (leaving overstory retention) is an important tool to reduce environmental impacts on seedlings.

Thermal cover protects from undesirable temperature extremes in several ways:

1. Shading slows the initiation of flushing (bud break) allows seedlings to avoid frost during the early spring,
2. Reduction in frost severity by protecting seedlings from radiative cooling,
3. Reduction of daily high temperatures by providing shade,
4. Reduces the potential for direct damage to seedlings from sun scald, and
5. Thermal cover is required for Douglas-fir establishment as it mitigates environment damage.

Shading from live trees and brush must also be considered a form of competition for light and moisture.

There must be a balance between the required amount of shade at establishment and the access to light and moisture (M. Isaac-Renton Pers. Comm.).

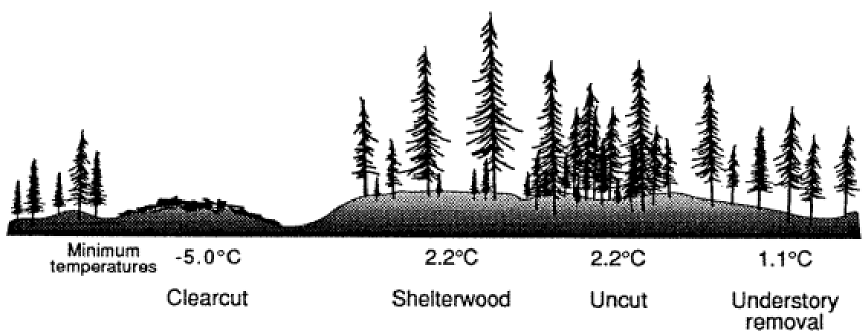

Figure 8. Daily minimum ground surface temperatures for various overstory cutting treatments at Lubrecht, Montana 1978. Hungerford and Babbitt as cited in Stathers 1989)

Site visit summary:

Refer to Appendix 2. Site visit overview map and reports.

Numerous sites were visited which would type as moderate frost hazard using the tables found in Steen, et al. 1990, but ignoring the factors that may decrease frost hazard.

Sites 17, 18, 19, 48, 49, 50, 51, 53, and 57 all had significant sections that were observed as partial cuts. These areas initially type as moderate frost hazard because they had less than 15% slope in the IDFdk3, IDFdk4 or SBSdw1. Moderate frost hazard has an expectation of significant damage and extensive mortality for planted Fdi on clearcut sites. Within the most extremely frost-prone, depressional areas within these partial cuts, planted Fdi displayed consistent damage and mortality, but not to the extent expected, presumably due to the overstory canopy. Mortality and damage were not measured; however, it was considerably less than in an equivalent clearcut. Within the partial cuts 5-15% slopes, there was almost no damage or mortality in the planted Fdi. This matches the observations and research findings where the basal area retentions (above 15 m^2/ha) used in a uniform shelterwood effectively minimized frost damage on moderate frost hazard sites (Waterhouse et al. 2021).

Best Management Practice: for sites with moderate frost hazard, employ silvicultural systems such as shelterwood in SBS and selection systems in IDF. These will significantly reduce frost damage and mortality.

Even-aged silvicultural systems are not appropriate for the IDF because this means converting from an uneven-aged, multi-layered stand structure to an even-aged stand structure. This may cause large gaps where frost will affect regeneration performance. (M. Waterhouse Pers. Comm.).

Secondary sources of thermal protection and shade:

1. Mechanical site preparation,
2. Obstacles such as stumps, downed logs, aspen clumps, or brush, and
3. Retention of mature trees in patches or as individual stems.

The microsite position of these relative to the trees is important for shading – e.g., plant on the north-facing side.

These three secondary sources still provide some thermal protection and some shade in the absence of larger sources of thermal or shade protection.

Site visit summary:

Refer to Appendix 2. Site visit overview map and reports.

Most of the sites visited had examples where Fdi seedlings planted adjacent to obstacles were performing better than those planted into the open. These trees consistently had less frost damage than those planted in the open. Sites 4, 5, 7, 8, 10-2, 14-2, 24, 28, 35, 37, 38, 39, 41, 42, 43, 44, 45, 46, 47-1, 47-2, 51, 52, 54, 55, 56, 58 and 59 all had consistent source of Fdi seedlings planted adjacent to obstacles that were performing better than the adjacent open planted Fdi. In some cases, the trees planted adjacent to these sources of thermal protection and shade were the only Fdi trees witnessed on site (especially if the frost hazard was high or very high).

Best Management Practice: Where overstory thermal protection is not available; planting prescriptions, planting contracts, planting preworks, and planting inspection systems should be designed to place the Fdi seedlings in or adjacent to (by order of importance): MSP spots, aspen, taller brush, larger stumps, rocks, downed slash and shorter stumps.

These are sources of thermal protection but not a source of shade (to mitigate drought and frost impacted Fdi):

- Lodgepole pine saplings, and
- Aspen saplings.

There has been discussion of using planted lodgepole pine to act as a nurse crop to protect planted Fdi. Two of the sites visited were research trials with planted Pli and aspen intended to overtop the planted Fdi and provide thermal protection. It is important to consider that Pli saplings could provide thermal protection for growing Fdi, but at the same time those same Pli must be thought of as competition. Too many overtopping Pli could repress Fdi growth while too few may not provide the required protection.

Underplanting of sapling sized lodgepole pine was not witnessed in the Cariboo site reviews, however it has been attempted in the Thompson Okanagan with very poor results due to drought (Pers. Obs. Hegan)

Site visit summary:

Refer to Appendix 2. Site visit map and reports.

Two of the sites visited (units 56 and 58) had Fdi planted immediately adjacent to aspen or Pli intended to act as a nurse crop. These trials are too recent to provide any observations as the adjacent Pli and aspen weren't providing thermal or shade protection because they were the same size as the planted Fdi.

Lodgepole pine acting as nurse crops was not commonly witnessed because most of the sites visited were younger plantations from the last six years of planting. Two of the older sites (units 40 and 48 both with moderate frost hazard) visited had instances of frost damaged Fdi releasing once the adjacent planted Pli started to provide considerable thermal protection. In both sites the Fdi was initially growing very slowly, and then released after they surpassed one metre tall. The release height of the Fdi appeared to coincide with the adjacent Pli reaching approximately 3m tall and approximately 30% crown closure. On both sites the Fdi appeared to be quickly catching up to the adjacent Pli.

Source of moisture retention, but does not contribute to frost protection:

- Red rot (well-rotted wood that is incorporating into the soil profile):

Red rot does not provide thermal protection or shade to the planted tree but does provide a moisture cap for soil. Planting through red rot into the mineral soil horizon provides shading to the soil and protects the root collar of planted seedlings. Where raw planting is incorporated into any regime, planting through or immediately adjacent to red rot is recommended. Red rot needs to be 'smearable' and the lower third of the plug preferably/ideally in mineral soil. Red rot on drier sites rarely has the characteristics necessary for seedling survival. Fdi prefers red rot over other species. This has an added benefit of protection from pinegrass as pinegrass will not grow into red rot. This speaks to the importance of retaining CWD for future recruitment of red rot. Red rot is not a suitable growing medium on dry sites. Seedling roots should be planted fully within the mineral soil horizon.

Best Management Practice for improving Fdi establishment and regeneration success on frost and drought prone sites in the Cariboo Natural Resource Region:

- ***Retain more mature overstory as frost hazard and or drought hazard increases.***
- ***These should be distributed throughout the site in clumps or individuals to provide thermal protection and shade to every portion of the areas where Fdi will be planted.***
- ***As frost and drought hazard increases, the retention level should increase correspondingly. Stems identified for retention should be expected to survive to the next rotation.***
- ***Retaining a low-density overstory exposes it to wind throw risk, as well as abiotic and forest health agents.***
- ***Important factors that increase windthrow risk include tall thin trees, shallow rooting due to clay pans in the soil and amount of exposure due to the prevailing wind.***
- ***Retain vigorous advanced regeneration wherever possible. The retention needs to stay alive and standing to have the benefit you are looking for.***

Photo 9. Example of Douglas-fir thriving within brush that is providing shade and some thermal protection. This site is IDFdk3-01 on flat ground. It is an example location of the few surviving trees on this site. Photo credit – Colin Hegan

Photo 10. Example of Douglas-fir planted through decomposing red rot (planted into mineral soil below). Red rot cap provides protection from pinegrass and allows the soil beneath to retain moisture longer in the spring. Note that this does not provide any frost protection. Photo credit – Colin Hegan

6 Mycorrhizal networks

The retention of mature Douglas-fir in the harvesting phase helps improve a support network of mycorrhizal fungi.

Dr. Suzanne Simard has described specific trees that are critical for several important forest ecological functions as 'hub' or 'mother' trees. Mother trees are the largest trees in forests that act as central hubs for vast below ground mycorrhizal networks. They support young trees or seedlings by inoculating them with fungi and ferrying them the nutrients they need to grow. While it is true that the largest trees do support larger mycorrhizal networks and facilitate greater transfer of nutrients and carbon to regenerating trees, other mature trees also provide these services.

The amount of ectomycorrhiza (EMF) inoculum increases with greater overstory retention. Dr. Simard and her students have shown that connection to mycorrhizal network is beneficial for seedlings, but the fact that there is greater inoculum potential on sites with greater overstory retention shouldn't be discounted. Fungal hyphae are more successful at water and nutrient acquisition than are fine roots, primarily due to their smaller size. Many EMF also have robust enzymatic machinery that can 'mine' organic matter and even minerals in the soil for nutrients. Any scenario where there is more EMF inoculum potential (e.g., proximity to retention trees) will result in greater root colonization of seedlings, and usually result in better seedling performance. This is an important distinction - it's the fungi that are providing the benefit. There may be an added benefit from the mycorrhizal network as well, but ultimately, it's the fungi providing that benefit, not necessarily the 'mother' tree (Pers. Comm. Philpot).

Hub trees for mycorrhizal networks are "foundational" because they even out resource availability and create favorable local conditions for tree establishment, which is fundamental to the structuring of the whole forest community. Conserving hub trees and mycorrhizal networks during forest management therefore appears important to the conservation, regeneration, and restoration of interior Douglas-fir forests (Simard 2009). The benefits to seedlings from EMF fungi is to improve water and nutrient acquisition abilities (Pers. Comm. Philpot).

Retention of mature Douglas-fir can help mitigate some of the effects of drought and frost beyond simply providing shade and thermal protection. "Proximity to residual trees increases root growth and EMF [ectomycorrhizal fungi] abundance and diversity of seedlings. Residual trees may accelerate the establishment of mycorrhizal communities associated with mature forests. (Cline 2004)".

The inoculation of nursery seedlings with mycorrhizal fungi is a current standard in seedling nursery cultural practice. These mycorrhizal fungi are often fully replaced by native fungal communities within one year of planting. Success of inoculating nursery seedlings with EMF is mixed - often there is no impact on height or growth (Pers. Comm. Philpot).

7 Planning

7.1 Pre-harvest signoff on site plans

Many licensees require the company silviculturist to sign off on site plans, preferably after walking the site or interviewing development crews. This is a very good practice and helps silviculturists understand and weigh-in on conversations related to silviculture commitments their organization is taking on. For example, if a commitment to reforest with a small percentage of Fdi is taken on in an area considered to be moderate to high frost hazard, site amelioration will be required such as commitments to thermal cover retention and aggressive site preparation. In the absence of proper planning for these commitments the organization has a high probability of not achieving their targets.

If an opening is improperly stratified important commitments or opportunities for reforesting with Fdi could be easily missed. Another possible consequence of improper stratification into treatment units is an over commitment to Fdi in portions of the opening which will have significant challenges to reforestation. This can lead to a shift of attention away from a portion of the opening that is very suitable for Fdi regeneration, towards a portion of the opening that is poorly suited for Fdi.

Inclusion of silviculturists in site plans and harvest plans allows the silviculturist to better incorporate reforestation efforts with Fdi on the areas that have the greatest chance of successful establishment and growth.

- Options to improve planted Fdi success in the planning phase include:
- Partial cutting in strata where Fdi will be planted, for thermal protection, shade, stocking and to act as a seed source,
- Leaving the stratum stocked through residuals or understory retention of advanced regen,
- Retain more mature overstory as frost hazard and or drought hazard increases. These should be distributed throughout the site in clumps or individuals to provide thermal protection and shade to every portion of the areas where Fdi will be planted. As frost and drought hazard increases, the retention level should increase correspondingly. Stems identified for retention should be expected to survive to the next rotation. Retaining a low-density overstory exposes it to wind throw risk and forest health agents, and
- Retain vigorous advanced regeneration wherever possible. The retention needs to stay alive and standing to have the benefit you are looking for.

Best Management Practice: A silviculture forester should have input and signoff on all Site Plans in order to review openings to help plan and prepare for reforesting sites prone to heat stress, drought and frost.

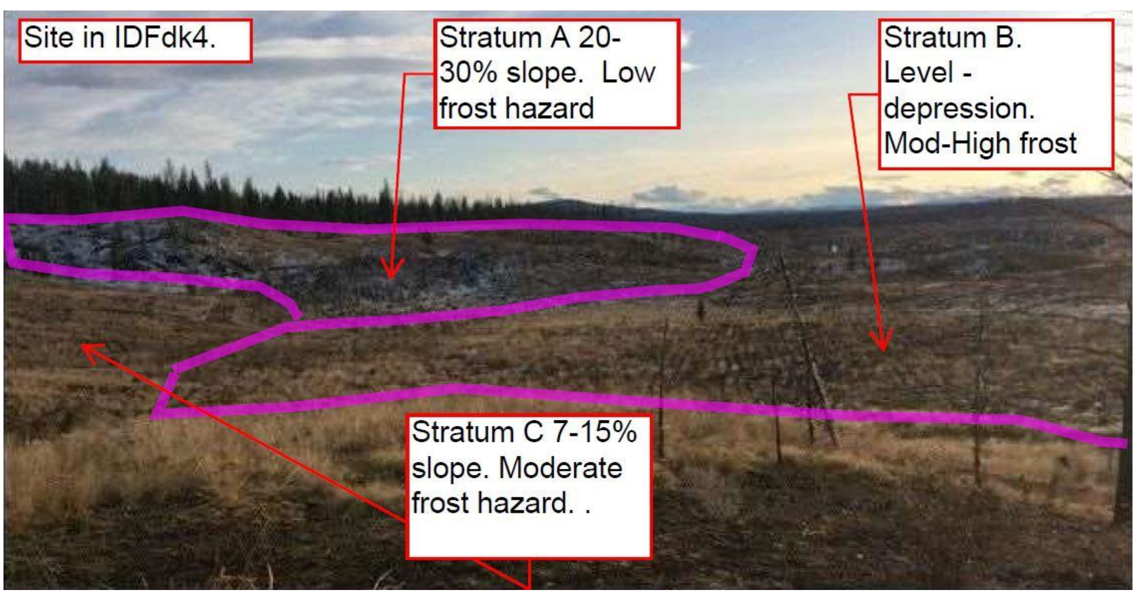

Photo 11. Example IDFdk4 site showing recommended stratification for standards unit and planting planning.

Root disease, particularly Armillaria root rot (*Armillaria ostoyae*) and laminated root rot (*Phellinus weirii*), should strongly influence the reforestation plan where those diseases exist.

Best Management Practice: Silviculturists should review sites prior to-harvest through the lens of the frost hazard assessment worksheet, separating areas with different values. Sites should be stratified as thoroughly as possible to identify regimes that will work across strata. A field guide to forest site identification and interpretation for the Cariboo Forest Region (Steen and Coupé 1997) and Steen et al. 1990 for the frost hazard classification should be used to classify these sites.

There are some planning considerations when determining which trees to retain. The largest Douglas-fir trees are most likely to be the most windfirm. Retaining a low-density overstory exposes it to wind throw, and the planning for that retention should pay attention to wind throw risk. Retaining tall slender trees (>100 HDR) means you are keeping narrow crowns which provide less thermal protection, and it is at higher risk of loss to wind throw, snow breakage, and bark beetles. "*Planning the retention is more complex than just saying 'Leave everything over 70 cm' although that's a start. The retention needs to stay alive and standing to have the required benefit*" (K. Day Pers. Comm.).

7.2 Post-harvest assessments

Like pre-harvest signoff, post-harvest assessments (PHA) are the main opportunity to identify risk and plan a treatment regime or set of treatment regimes for an opening.

- Review the site plan to make sure it's correct and the limiting factors have been identified,
- Review the potential for significant drought effects and heat stress - in particular steep slopes on hot aspects,
- Review the site for low, moderate, and high frost hazard areas using the frost risk hazard assessment tool and map these for further inclusion on planting treatment maps or mechanical site preparation treatment maps,
- If the site has two or more areas with different frost hazard ratings, identify a regime of treatments that either address all the constraints across the entire area, or set up separate treatment regimes which address each area's frost risk rating (try to keep this as simple as possible),
- Review the site for limiting factors that will affect Fdi such as nonproductive areas, saturated areas, or areas likely to become saturated. Include these areas on maps for future inclusion in planting treatment maps so they can be identified easily to the planters. These locations can be exactly mapped or roughly mapped, but it is very helpful that they end up on future treatment maps,
- Identify restricting soil layers that would require deeper mechanical site preparation treatments,
- All areas that are considered constraints should be mapped and tracked for future use and review,
- Review the adjacent openings to see how those progressed and learn any lessons applicable to the newly harvested site,
- Think about issues that will affect the success of any chosen treatment regimes such as: spring access, bridges, avalanche chutes, access roads which will have significantly more snow or ponding water than the area to reforest, on block access, and cattle grazing intensity, and
- Root disease, particularly *Armillaria* and *Phellinus*, should strongly influence the reforestation plan.

All of these should be reviewed under the lens of what Fdi will need to survive and thrive. If a plan is set up to only meet stocking standards, the target stocking standard may be met but without the success of Fdi and the inclusion of Fdi in planting plans becomes a wasted effort for all involved. When including Fdi in planting and reforestation plans, Fdi must be considered above all other species because frost and/or drought effects on Fdi will be the limiting factors on these sites.

Best Management Practice: When planning tree species for planting, strongly consider that Fdi has improved long-term drought tolerance compared to other species. While it may be easier to establish Pli species initially, this does not create a stand that is resilient to future drought events. It is also important to note that establishing a stand of Pli where Fdi was harvested is species conversion and this is poor forest management practice.

Best Management Practice: Silviculturists should review sites during post-harvest assessments through the lens of the frost hazard assessment worksheet, separating areas with different values. Sites should be stratified as thoroughly as possible to identify regimes that will work across strata. A field guide to forest site identification and interpretation for the Cariboo Forest region (Steen and Coupé 1997) should be used to classify these sites.

It's important to note, most openings are not uniform and likely have diverse limiting factors across each site. Portions of openings that behave differently must be addressed separately and not lumped prior to consideration. Only after these areas have been considered independently, may they be grouped together for treatment, and only if the considered treatments will work on all areas. Often site plans lump these areas together if they are dispersed- Example IDFdk3 01(80%) 03(20%). Dispersed site series still need to be reviewed separately even if they are within the same standards unit (refer to BGC and subzone classification table). The silviculturist should review the site plan, visit the field, and evaluate the dispersed strata for appropriate treatments.

7.3 Natural regeneration

Best management practice: On sites where reforesting with Fdi is challenging, natural regeneration should be encouraged as much as possible through overstory Fdi retention (thermal cover, shade, and seed source) and retention of other taller stems. Mechanical Site Preparation will maximize survival of germination by reducing pinegrass competition. Preferably, these tools should be employed where they have the best chance of success such as on steeper slopes versus flat areas and where clumps of mature stems are present rather than scattered individual mature stems.

Site visit summary

Natural regeneration was viewed in the field visits and provides clues to improving stocking and health for planted Fdi. Please refer to Appendix 2 – Site Reviews.

None of the sites visited used natural regeneration as a primary vehicle for Fdi reforestation. This is likely because the set of stands included in the review were those that had significant planting of Fdi. The process of natural regeneration was witnessed at nearly all the older sites to different degrees. This review focused more on relatively recent harvesting and planting, and because this review was conducted in late October and into November, natural regeneration trends on the most recently harvested sites could not be fully witnessed because of the snow cover.

Some sites were nominally Clearcut with Reserves. Many of these sites have strata within them that have significant retention that mimic the characteristics of a shelterwood. Significant healthy Fdi germination was noted where retention is much higher, and slopes are greater than 20%. Sites that included this scenario are Units 3, 41, 45, 47 and 49.

On older sites that were nominally Clearcut with Reserves planted with Pli, natural Fdi regeneration appears to occur regularly depending on the slope and number of mature Fdi retained. For example: flatter sites with only modest overstory retention did have some natural Fdi regeneration at low to modest incidence and only within 10m of the retained mature trees. These Fdi natural regen often occurred adjacent to coarse woody debris, stumps, rocks or within brush clumps. Many of these Fdi naturals appeared to have very slow height increment until approximately 1m tall. These Fdi trees start putting on strong height growth only after the planted Pli started providing thermal protection. These Fdi trees eventually caught up to the planted Pli.

These Fdi may not be tall enough to be counted as Free Growing within the late free growing time requirement, but these Fdi can be reserved to act as thermal protection for future rotations.

Situations where Fdi natural regeneration has success provides a clue for improving survival of planted Fdi.

One item to consider is that Pli at too high a density will suppress the Fdi until the Pli is harvested. Research is required to identify the optimal density of planted Pli where it can provide benefits of thermal protection and still allow Fdi to overcome environmental constraints and eventually thrive.

Lessons from site visits:

On frost prone sites, natural regeneration establishes best adjacent to obstacles such as coarse woody debris, stumps, rocks and inside brush.

On the same older sites that had steeper slopes and scattered retained mature overstory, Fdi natural stocking increased but not enough to be considered fully stocked. The trend appears to be consistent: as overstory thermal protection increases, survival and speed of release improves in both natural and planted Fdi.

Best management practice: an increase in overstory retention improves survival and speed of release of natural and planted Fdi.

Photo 12. Example IDFdk4 site. Older harvesting. Note the natural Douglas-fir regeneration adjacent to mature retention. This was consistently witnessed on most older sites. Photo credit – Colin Hegan.

8 Mechanical Site Preparation (MSP)

Please refer to *Fundamentals of Mechanical Site Preparation FRDA Report 178*

Research has shown the advantages of MSP in reducing both frost and heat damage and vegetation competition, while at the same time increasing moisture availability (Hope 1991). In the Cariboo Region there are many ecosystems where both frost and drought are significant driving forces, sometimes to equal extents.

Mechanical site preparation can reduce the surface temperature extremes between day and night. During the day surface temperature heating is reduced as heat is absorbed deeper into the soil. During the night this heat energy releases heat back towards the seedling. The effect of MSP on summer frost damage is a reduction related to nighttime heat re-radiation and grass removal – greater mineral soil exposure had a greater frost mitigation effect. The effect of MSP on drought is related to moisture collection in the trench and an increased access by seedlings to soil moisture at greater depth. For all three effects, the magnitudes of the effects for soil temperature, drought and frost increases with the severity of disturbance. Aggressive site preparation (e.g., deep ripping with a winged subsoiler) is required for Fdi to achieve moderate survival in the IDFdk3. Please note that this is also impacted by soil colour, slope and aspect, and planting microsite selection (Newsome et al. 2016). Planted trees on the sunny side of a trench, oriented east to west, will see increased surface temperatures which can increase drought mortality and sun scald.

It appears unlikely that MSP can change a site to such an extent that it can completely mitigate frost impacts on sites that are high or very high frost hazard.

Sites where the frost hazard varies from low to moderate may be worth treating the entire site to ensure suitable Fdi regeneration across the whole area. If half of an opening is low frost hazard and the other half is moderate frost hazard, dispersed equally throughout the opening, it is worth considering site preparation treatment on the entire opening. In this example Fdi can be planted on the entire opening, increasing the Fdi percentage on the steeper ground and decreasing Fdi percentage on the less steep slopes. The value of this treatment is the potential to expand the range of Fdi throughout the entire opening and ensure that the most suitable mesoslope positions are put in the best position to succeed with Fdi. Site preparation helps against advective frost, but not the accumulation of cold air at the bottom of slopes.

Within openings where low and moderate frost hazard can be easily mapped and stratified, consider expanding the MSP treatment onto the gentler slopes to modify the site into behaving like it is a low frost hazard. The MSP treatment could expand from low frost hazard into moderate frost hazard areas that are between 10-15% slopes. The MSP could also be extended into areas immediately adjacent to existing thermal cover at timber edges and adjacent to clumps of mature Fdi retention. A ten-metre buffer around these trees will ensure the roots of mature trees are not damaged.

Sites that are extensively moderate frost hazard are good candidates for targeted MSP. To extend where Fdi is normally considered for planting, review the portions of openings that have low frost hazard. Many flat openings have small sections where Fdi is suitable – either there are areas where the slopes are greater than 15% or there is existing thermal cover. These areas can be targeted for MSP to increase the probability that Fdi will survive when planted. It may appear that the cost is prohibitive to site prepare small areas because the cost of mobilizing and demobilizing equipment can significantly increase the cost/ha of treatment, however when viewed under the lens of the entire opening the MSP treatment cost is still reasonable.

In the IDF subzones, MSP is recommended in the form of deep penetration. MSP treatments and contracts must be designed to ensure that aggressive site preparation is achieved. Treatment prescriptions and contracts should include measurable specifications on depth of penetration and width of treatment. Where strongly developed clay-rich root-restricting layers are present, these will need to be addressed with an MSP treatment that can break through this layer (Newsome et al. 2016). Deep ripper plow or excavator raised screefs should be prescribed for these areas. Where Bt restricting layers are absent or within 10cm of the surface, deep ripper plows, excavator raised screefs, and disc trenching are suitable. It is important to pay attention to the depth of any root restricting areas and avoid planting directly into them. The intention of the MSP is to break through this layer to provide room for future roots to grow, however the restricting layer itself provides a challenge for newly planted seedlings.

A Bt horizon is a restricting soil horizon that is comprised of compact clay that restricts root growth. For more information refer to the Soils of Canada website at soilsofcanada.ca

Best Management Practice: In situations where Fdi is planned for planting, Mechanically Site Prepare the site using ripper plow, or disc trencher where Bt restricting layer is absent. Mechanical Site Preparation can expand the area where Fdi is at lower risk for frost damage and mortality.

Photo 13. Example IDFdk4 site. Ripper plow. Photo credit –Mike Madill.

Treatment type	Treatment description	Effects on vegetation	Effects on risk of summer frost damage	Effects on drought	Effects on soil temperature
Untreated control	Seedlings were planted directly into surface soil with no screefing. There was no disturbance of soil or surrounding vegetation.	No effect	No effect	No effect	No effect
Hand screef	30 × 20 cm patches were created by shovel screefing, with the intention of removing surface vegetation and forest floor material. Minor exposure of mineral soil occurred, and the treatment created slight depressions, the depth of which depended on forest floor depth.	Vegetation was removed in small patches; root mat was slightly broken up	Limited effect	Minor reduction related to grass removal and creation of slight depression (IDF only)	Little effect
Leno	A Leno scarifier created very shallow, linear (40 × 100–150 cm) scarified patches. Little soil disturbance occurred and the Bt layer was not broken. Two seedlings were planted in each linear Leno patch, in the centre width-wise and ~10 cm from either end.	Vegetation was removed in strips; root mat was broken up	Slight reduction related to nighttime heat re-radiation and grass removal	Minor reduction related to grass removal	Reduced daytime surface temperature; release of heat during the night
Ripper tooth	A ripper tooth (not winged) was used to break through the Bt layer and create narrow, deep, continuous furrows that were up to 40 cm deep and 10–20 cm wide. The bottom of the furrow closed up, leaving a 5–10 cm deep trench with reduced bulk density. Seedlings were planted into the bottom of this trench.	The ripper tooth cut vertically through roots, but above-ground vegetation was only slightly pulled away from the furrow	Slight reduction related to nighttime heat re-radiation and grass removal	Reduction related to moisture collection in the furrow and access to soil moisture at greater depth	Reduced daytime surface temperature but less than in treatments with greater mineral soil exposure
Ripper plow	A Merritt ripper plow was used to create a 30–40 cm deep and 40 cm wide continuous trench with large berms. Mineral soil was exposed over ~30% of the treated area and the Bt layer was broken, which reduced bulk density. Seedlings were planted in the trench bottoms.	Vegetation removed; root mat broken up	Reduction related to nighttime heat re-radiation and grass removal	Reduction related to moisture collection in the trench and access to soil moisture at greater depth	Reduced daytime surface temperature and release of heat during the night
Disc trench	An MM passive disc trencher created continuous shallow, scarified patches ~30 cm wide (different from trenching produced with a powered trencher), with an adjacent poorly defined berm of loosened soil. Surface soil was removed, but the Bt layer was not broken. Seedlings were planted in the trench bottoms at all sites.	Vegetation was removed in a narrow scarified strip; grass root mat broken up	Reduction related to nighttime heat re-radiation and grass removal	Slight reduction related to moisture collection in the shallow depression and removal of vegetation	Reduced daytime surface temperature; release of heat during the night
V-plow SBSdw1/2 only	A V-plow was used to create continuous plows that were 2.5–3 m wide, exposing mineral soil over ~50% of the treated area. Soil was disturbed to a depth of ~10 cm and the Bt layer was not broken. Seedlings were planted on either edge of the plow strip, which allowed them to access nutrient-rich material at edge.	Vegetation was removed in wide strips	Reduction related to nighttime heat re-radiation and grass removal	Reduction related to vegetation removal	Reduced daytime surface temperature; release of heat during the night; greater soil warming than in treatments with less mineral soil exposure

Table 4. Treatment descriptions and potential effects on vegetation, risk of summer frost damage, drought, and soil temperature (Newsome et al. 2016)

Photo 14. Example IDFdk4 site. 10-20% slope. Ripper plow furrow breaking up the Bt restricting layer at 30cm deep. Photo provided by Mike Madill

Regardless of the mechanical site preparation chosen, it's extremely important to manage treatment contractors closely and:

- Control the season of the treatment – best survival of seedlings is found where there have been no intervening seasons between MSP and planting to allow ingression of pinegrass. Example – October of the year prior to planting,
- Set up MSP contracts with the end results clearly identified and indicating where a second pass will be required – this should be measurable,
- For MSP preworks discuss the situations where the contractor must make a second pass, travel slower, and/or put more down pressure on the equipment. Conduct field discussions to discuss these expectations,
- Review the contractor's equipment on site. Ensure it's capable of achieving the desired results, and
- Be present during the operator's first days of work as well as occasionally during the remainder of the treatments. Ensure that the equipment is producing the desired results and adjust where necessary.
- Walk with the contractor to review the work area to discuss where the treatment has succeeded and failed to meet expectations.

This process identified, is like what is required of a planting program in that they must be managed closely, and a feedback loop must exist to ensure you achieve the necessary disturbance. Control of a site preparation program is equally as important as a planting program.

Photo 15. Example of poor disturbance on single pass disc trenching. Note the flat, compact soils which are very difficult to provide adequate disturbance. Photo provided by Clayton Franz

Photo 16. Example of good disturbance on single pass disc trenching. Photo provided by John Hopper

9 Planting Considerations

9.1 How seedlings grow

How spring seedlings grow should be reviewed by all silviculturists before they identify sites and implement treatment regimes. Seedlings need to progress through several stages prior to full establishment.

The first challenge is overcoming planting shock by growing roots (Grossnickle 2012). In this stage, the seedling connects to the surrounding planting medium, which is strongly correlated to site attributes, site preparation practices, vegetation management, operational silviculture decisions, planting stock choices and nursery cultural practices.

For dry sites, it's critical the seedling establish roots quickly before it exhausts its internal moisture and carbohydrate supply. Larger plug sizes are helpful when attempting to grow the first set of roots. It is extremely important to get Fdi seedlings established early to overcome planting shock prior to the onset of summer drought. For frost prone sites there is a risk of frost damage to planted Fdi seedlings.

Best Management Practice: Plant as early as possible following snow and frozen ground free conditions. A larger plug size may help mitigate for spring frost damage. Larger trees are more likely to have their terminal bud out of the frost pool.

The second challenge is overcoming the summer drought period. This is strongly reliant on how effectively and early the seedling has overcome planting shock; the seedling must have grown roots and closed leaf stomata. "Seedlings can be exposed to a wide range of environmental conditions during the establishment phase, some of which may be extreme enough to exceed their ability to physiologically tolerate environmental stress." (Grossnickle and MacDonald 2018). This is the period where root to shoot ratios become important and where a well-balanced tree is important for survival. Root to shoot ratio is defined by the Oxford Dictionary as "The ratio of the amount of plant tissues that have supportive functions to the amount of those that have growth functions." Another way to state this is that the root to shoot ratio is the ratio of root mass relative to the mass of stem and foliage.

These first two stages are important for all the silviculture decisions made on the site: species choices, stock size, nursery practices, MSP choices, and planting decisions. While it is extremely important to identify issues surrounding initial establishment, species and choices which make for easy establishment may not be the best selections for long term resilience on the site. The silviculturist must not lose sight of the longer-term objectives for forest management.

9.2 Species selection

Seedlings have different levels of drought tolerance by species at different times in their development.

Douglas-fir appears to have the most difficulty in overcoming planting shock, particularly on extremely dry sites. Once seedlings have fully established the relative resiliency of species to survive shocks such as drought events is quite different – established Fdi is much more resistant to periodic drought than Pli. Because of this, Fdi will be the most desirable species to occupy extremely dry and very dry sites as these species can better withstand periodic drought than other species.

While it may be easier and cheaper to establish pine species initially, this species is less resilient to future drought events and much more susceptible to forest health damaging agents. Establishing a stand of Pli where Fdi was harvested is species conversion and this is unacceptable forest management.

On most sites visited, Pli had better survival than Fdi as Fdi is the species that has the most difficulty overcoming planting shock. Other species have been planted such as spruce, larch and ponderosa pine but these species were not witnessed on the sites visited. These other species may have been planted at very low numbers, but they were not noted in the walkthroughs. This does not correlate with the longer-term resilience and ability to thrive on dry sites. While it may be easier to establish pine species at the beginning, this does not create a stand that is resilient to future drought events. (DeLong et al. 2019).

9.3 Seed selection: Progeny and class

The province's chief forester established the Chief Forester's Standards for Seed Use. These standards require that seed used to establish stands on crown land must be conform to specific transfer rules.

There are two classes of seed determined by their source. Seed collected from natural parent trees found in the forest is B-class seed. Seed collected from tested parent trees at seed orchards is called A-class seed.

The silviculture practitioner is legally required to use A class seed; this is outlined in the Chief Forester's Standard for Seed Use. In the Cariboo Natural Resource Region, Fdi A-class stock is available for planting except for most of the IDFdk4 and IDFxm.

Until recently the system of seed transfer (from seed collection source to seed areas of use) was governed by the Geographic Based Seed Transfer (GBST) as identified in the Chief Forester's Standard for Seed Use. A new system was created in 2017 called Climate Based Seed Transfer (CBST) and has since been amended into the Chief Forester's Standard for Seed Use.

An item that needs to be reviewed is, the genetic trait that is being selected for in A class seedlots is usually growth. Selection for drought tolerance or frost avoidance would be beneficial in the Cariboo.

Drought:

Like the discussion about stock type, seedlot type selection may influence the root to shoot ratios of the planted stock. The theory is that stock with larger root plugs relative to the green shoots will have lower moisture demands relative to the ability to access ground moisture. This is important where moisture is limiting.

Research is underway to determine how to better identify drought tolerant stock and it appears that the current rating of A-class seedlots for growth might track closely with drought tolerance. Since seed that originates from natural stands has not been tested for growth potential, the best opportunity for ranking and selecting for drought tolerance will be A-class seed. Early findings are that selecting for growth does not adversely affect tolerance for drought. (Darychuk et al. 2012). Drought tolerance is likely to be heritable (R. Ribiero, Pers. Comm.).

Frost:

Research indicates that there is significant variation within Fdi for cold hardiness and that this trait appears to be heritable. The variation is sufficiently large that artificial selection for frost hardiness should be readily achieved (St. Clair 2006).

Frost tolerance can better be described as the ability to withstand frost when it occurs. Cold hardiness changes with time and is related to phenological adaptations. Cold acclimation in fall occurs gradually. Seedlings accrue cold hardiness over time, influenced by temperatures as well as photoperiod. If a seedling has developed at least partial cold hardiness in the fall, it may be less impacted by a moderate cold event but could be impacted by a more severe cold snap. In winter, the same tree can tolerate extremely cold temperatures because it is fully cold hardy.

Spring de-acclimation is linked to heat-sum accumulations after meeting a chilling requirement. Trees stay dormant because the cold temperatures keep them that way, but they 'monitor' for warmth. Once they reach a certain warmth threshold (heat sum requirement), they initiate growth, lose cold hardiness, and become more vulnerable to cold. The high-risk periods for frost are the earliest part of the growing season and the latest part of the growing season (early spring and late fall). This is when cold events are likely to occur, and the young trees are not fully hardened off and new growth has lignified. Frost risk can be seen as the interplay between the probability of a severe frost event occurring and the potential for damage (consequence) given it's timing in relation to cold acclimation and de-acclimation.

Trees are often genetically adapted to cold/frost risk in their local environments by recognizing cues to acclimate and de-acclimate at the right time. Tree species or populations that evolved under milder environments (e.g., Fdc) have higher heat sum requirements. It takes more consistent warming for growth initiation to occur. Tree species or populations from more continental climates often have lower heat sum requirements. The cold keeps them dormant, but at the first sign of warming, they start to grow because they're "confident" that summer is near, and they have a short growing season. Under climate change the problem is that there is a growing asynchrony between this finely tuned system of "knowing" when risks to growing are low. Due to a growing maladaptation to emerging climates, the Fdi from the northern part of the range (Cariboo) may become more at-risk to spring frost damage (van der Kamp and Worrall 1990). Drier climate has more potential for frost.

The traits associated with early spring flushing and late fall dormancy are under strong genetic control. Due to selective pressures, frost tolerance can be managed by choosing appropriate seed to transfer into sites as well as through creation of select seed that can avoid frost by being dormant during the riskiest times of the year -early spring and late summer. (M. Isaac-Renton Pers. Comm.).

With regards to seedling transfer in general, provenances from northern regions are sensitive to spring frosts, while the more productive provenances from central and southern regions are more susceptible to fall frosts. Cold adaptation should remain an important consideration when implementing seed transfers designed to mitigate harmful effects of climate change (Montwé et al. 2018).

Both Rehfeldt (1983) and Darychuk et al. (2012) indicate that gains in growth appear to come at the expense of frost tolerance. "…selection pressures in Douglas-fir have resulted in a trade-off between cold hardiness and high vigour" (Darychuk et al. 2012). "Gains in growth potential were associated with delayed bud set and increased susceptibility to early fall frosts. For tree improvement to increase the growth potential of Douglas-fir without inadvertent degeneration of adaptation, selections must be based on several traits" (Rehfeldt 1983).

If selecting for multiple traits is required for seedlings targeted to frost prone sites, it will be important to create new A class seedlots that select for frost avoidance, and not necessarily just growth. The greatest frost potential in the Cariboo is the IDFdk4 which is not currently covered by an A class Seed Planning Zone. The frost potential in all ecosystems is sufficiently high to warrant consideration in all areas.

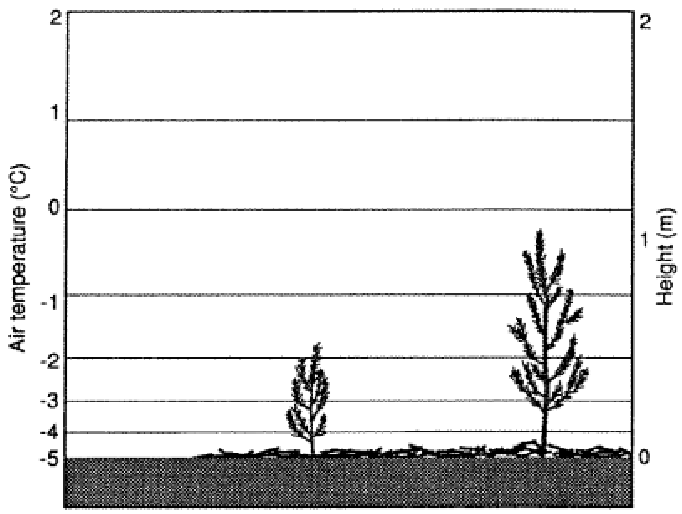

Figure 9. Stratification of cold air near the ground surface during a clear calm night (Stathers 1989). The small tree cannot grow out of the frost pool because of repeated frost damage

Further research is required for these items:

- Further outline the correlation between seed origin, and drought tolerance with interior Douglas-fir,
- Further outline the correlation between seed origin, and frost avoidance with interior Douglas-fir, and
- Develop A-class seedlings that maximize both drought tolerance and frost avoidance.

Best Management Practice: Sowing requests. When choosing B class seed:

- ***Select provenances that are drier than the target planting site, Example, for IDFdk3 site, the preference is to use seed sourced from IDFxm or drier as opposed to IDFdk3 (although IDFdk3 would be acceptable).***
- ***Select seed from similar subzones to the target planting site. Example, for an IDFdk3 site, the*** **preference would be to select seedlots sourced from IDFdk3 (local) as opposed to IDFdk5 (Kootenays).**
- **Avoid selecting seedlots from considerably north or south of the target planting location. This will reduce exposure of the seedlings to early season frost (in the case of extremely northern seedlots) and late summer frosts (in the case of extremely southern seedlots),**

9.4 Seed selection: Germination percentage

A very important consideration when choosing to seed for drought or frost constrained sites is the germination percentage of the seedlot. Germination percentage of each seedlot is tested periodically by the province – this sampling and testing gives a good estimate of the number of seeds that will germinate and helps provide direction to nurseries about how many seeds per cavity they should place in each plug-in order to fulfil the requested number of trees.

For seedlots with very low germination percentages, the likelihood is high that none of the seeds placed in a styroblock cavity will germinate. During the growing process, nursery personnel weed the cavities in which more than one seedling has germinated, and transplant some of the surplus seedlings to vacant cavities. Those transplanted seedlings have a disadvantage relative to the initially successful seedlings - they undergo transplant shock, have delayed growth, and may not completely fill the cavity with roots.

For drought and frost prone sites, it is recommended to avoid seedlots with germination percentages below 85% to reduce the probability of transplant shock in the nursery.

Photo 17. Plug Styroblocks in nursery during weeding. Note the empty cavity and the cavities with more than one seedling. Where cavities are empty seedlings are transplanted from cavities with more than one seedling Photo provided by John Hopper.

9.5 Stock selection: container size and type

Nurseries need to create seedlings with plant attributes that allow for the best chance of success. Desirable levels of these plant attributes can increase the speed with which seedlings can overcome planting stress and become coupled to the forest restoration site (Grossnickle 2012).

9.5.1 STOCK SIZE

Like the discussion about seed type – container size selection may influence the root to shoot ratios of the planted stock. Seedlings grown in larger container cavities will have larger roots.

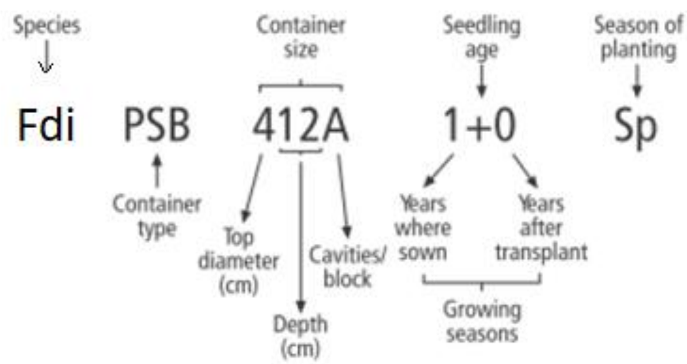

Figure 10 Example of stock size nomenclature. Provincial seedling stock type selection and ordering Guidelines. 1998. Province of British Columbia

Discussions with nursery services as well as nursery contractors indicate that root and shoot size typically trend together – larger root cavities will grow larger shoots. There are no clear trends indicating which factors and practices impact differing root to shoot ratios between stock, seedlots, request keys and nurseries. Differences may be more related to varying nursery cultural practices, though practitioners also observed shifting ratios between greenhouses as well as where seedlings were positioned within greenhouses.

In field evaluations it's clear that larger stock sizes have better survival rates than smaller sizes on drought prone sites. This is likely caused by the improved capability of a larger root plug to produce new roots once it's planted in field conditions. Greater focus should be placed on the ability to grow new roots in out-planting trials at nurseries where seedlings are targeted for extremely dry or very dry sites. Larger seedlings are also generally better able to recover from frost damage than smaller seedlings (Daintith and Newsome 1996). Larger trees are more likely to have their terminal bud above a frost pool.

Best Management Practice: seedling requests: grow the appropriate size stock for the drought and frost risk. Larger stock should be considered as risk increases.

	Large	Medium	Small
Fdi	512A	412A	412B

Figure 11 Example Fdi stock size. Source BCTS recommended seedling stock type selection. Interior/Spring

Larger stock is recommended to mitigate risk of drought mortality. Large stock sizes were observed to perform the best and recommended where mechanical site preparation is not possible or planned or in replant situations where MSP will not be revisited (Hegan 2020).

Medium sized stock is recommended to be paired with appropriate mechanical site preparation when planting in sites prone to drought, as well as sites where frost hazard is not consistently low.

Smaller stock may be planted in sites where frost hazard is consistently low, and drought effects are mitigated by north aspects. There are even smaller stock sizes being grown for Fdi – 310B. These are not recommended for frost or drought prone sites.

Best Management Practice: In situations where the preferred reforestation scenario cannot be followed due to circumstances outside of the silviculturist's control choose the largest available stock size to improve chance of success. This includes scenarios such as, range issues, access constraints, or fire. There will be situations where this is not possible, such as extremely rocky or shallow soils.

Site visit summary

Stock size was viewed in the field visits. Please refer to Appendix 2 – Site Reviews.

There was very little variation in stock size noted amongst most of the units planted on these sites. Most of the licensees used 412B or 412A stock size with their Fdi. There were very few sites where part of the opening was planted to one stock type and another stock type planted in the remainder of the site.

There was one site visited where 412A A-class stock was planted immediately after disturbance and 310B B-class stock was planted two years later. This site is a salvage clearcut in the IDFdk3 following a wildfire. The slopes vary between 25% and 0% allowing review of different slopes and aspects. The 412A stock immediately released and was approximately 0.5m tall after 3 growing seasons – these trees had no drought or frost effects. The 310B stock is alive and straight but dealing with minor to moderate frost damage but very little drought effects. This is only one site and there is enough variability in the two treatments to limit recommendations (three growing seasons versus two, planting proximity date to the two disturbances (wildfire and harvest), A class seed versus B class as well as 412A vs 310B).

The previous review in the Thompson Okanagan indicates a strong link between stock size and drought tolerance with larger stock size having greater drought tolerance than smaller stock sizes.

Further research is required directly comparing stock sizes and frost tolerances.

9.5.2 CONTAINER TYPE

Most of the stock type grown for the Cariboo are 1+0 PSB (Plug – Styroblock). This is a spring stock sown in styroblocks to create plugs, boxed in bundles of 10-20, frozen in one year, then thawed and planted the following year.

An alternative to 1+0 PSB is 1+0 PSI (Plug – Styroblock, Individually Wrapped) where the same process is followed with the exception that the seedling plugs are individually wrapped prior to boxing and freezing. This stock type is intended to be planted frozen and does not need to be thawed prior to planting.

Individually wrapped trees will improve the ability to get trees into the ground on the first openings in a planting program. The thawing process can take between two to three weeks for PSB stock to be available. Planting managers must anticipate when the first planting units will be ready to plant – this often leads to planting managers making conservative choices and starting the planting programs later. If PSI stock is used, planting can start as soon as the sites are determined to be ready to receive trees.

After the first few blocks of a program are finished, PSB stock is acceptable. There are cost considerations for PSI stock: it takes more effort to wrap than PSB, therefore nursery costs are slightly higher; poorly wrapped bundles can cause planters difficulties separating the trees, extensive bottom roots may freeze together causing increased planting effort; and increased wrappers and garbage need to be addressed. It is important to note that many stands where Fdi is targeted have the potential for late spring frosts.

It is recommended to plant PSI stock on the first sites of a spring planting program where there are considerable sites prone to drought. This is ideal for getting planting programs started as early as possible which promotes a longer period of root growth prior to the seedling shutting down.

Site visit summary

Most seedlings planted on these dry sites were plug-styroblock (PSB) container type. One licensee exclusively uses frozen plugs-styroblock individually wrapped (PSI) container type (Sites 40). Planting with PSI stock is a relatively recent occurrence and only one site was viewed that had been planted frozen with individually wrapped seedlings.

No conclusion can be reached with regards to container type and reduced frost damage based on the site visits.

Photo 18. Stock size examples for Fdi. Seedlings provided by Alan Rasmussen, MOF. Photo credit Kyla Petkau, Forsite.

9.6 Planting season stock type

9.6.1 SPRING PLANTING STOCK TYPE

The vast majority of Fdi that is planted in the Cariboo is scheduled for early May to maximize the spring moisture window. These trees are requested in the fall (year 1), sown in the spring, hardened off for the fall (year 2), and cold stored as frozen trees over the winter. Trees are then planted the following spring (year 3).

9.6.2 SUMMER PLANTING STOCK TYPE

Summer planting should be avoided on all dry sites because summer stock isn't available in early spring.

Summer trees may be considered in higher elevation, steeper, north facing slopes where soil moisture is still available in July.

Summer trees are requested in the fall (year 1), sown in late winter in greenhouses, hardened off for late spring (year 2), and lifted and planted usually after July.

9.6.3 FALL PLANTING STOCK TYPE

Fall planting has been suggested as a potential solution to get seedlings growing quicker. Fall seedlings are similar to summer trees but are hardened off to be available for planting in early September. Fall planting is not a recommended treatment on many sites. A quick review of soil moisture trends for dry sites shows that soil moisture is still at the lowest point each year into October, and even significant rain events may not change the overall soil moisture until the season has become unsuitable for planting, with temperatures too low for the seedling to grow enough roots and sustain itself through the winter.

Fall planting may be a useful strategy on sites that are not obviously prone to drought. A benefit that must be considered is that these trees have been hardened off for the year and are unlikely to experience late summer frost damage in the year of planting. Another benefit is the seedlings can grow roots in the fall and early spring, adjusting phenologically so that it has a better chance of adapting to environmental conditions that occur the next growing season (Vyse 1988 as cited in Stathers 1989). Within the Cariboo Natural Resource Region, fall planting is currently only considered in the ICH as indicated in the 1998 update of the Provincial Seedling Stock Type Selection and Ordering Guidelines.

Best Management Practice: Fall planting is not recommended where there is higher risks of drought and late summer frosts.

Sites visited that had fall planting of Fdi are units 2, 3, and 4. The silviculturists responsible for these sites monitored soil moisture and weather conditions very closely before planting these trees. They indicated that weather patterns on the Cariboo plateau can follow weather cells and rain events may not broadcast across the entire plateau. Fall weather can be unpredictable and it would be wise to have multiple sites lined up that could accept fall stock. In the event the targeted site had poor moisture, choose the site that had the greatest moisture and lowest risk. A poor second option is to hold Fall stock over in cold storage and plant them as Spring trees. Nursery specialists indicate that this is a poor fallback option as the seedlings will not be as hardened off as actual spring stock prior to boxing and freezing.

More research is required to determine if fall planting can be added to the suite of treatments available to silviculturists in the Cariboo.

9.7 Fertilization at the time of planting

Fertilization was not reviewed in the field. Fertilizer packs may help planted seedlings increase root volume to withstand future drought or frost events once seedlings have established.

More research is required to determine if adding additional fertilizer at the time of planting will increase Fdi survival and the ability to withstand drought events and outgrow frost hazards.

9.8 Nursery Considerations

Once seedlots, container size and type, and season are chosen and summarized in a Request Key, seedlings are grown using nursery cultural practices intended to grow the best and most balanced seedling within recognized morphological tolerances (which include height and stem caliper). A Request Key is a unique identifier that can be used to manage the growing of a seedling at a nursery. It can be used to review the choices made in a seedling request including: the sowing year, organizational unit, species, seedlot, container size, seedling age, planting season and count number.

Prior to the Province releasing seedlings for use, Root Growth Capacity (RGC) testing is conducted on a small sample of each request key to rate the seedlings on a scale of 0-3 where:

- 0 = no new roots,
- 1 = all seedlings have roots less than 10mm,
- 2 = between 1-100% of seedlings have root growth greater than 10mm, and
- 3 = all seedlings have root growth greater than 10mm.

Each RGC test uses a 16-tree sample and plants these seedlings in nursery greenhouse conditions. Root growth is measured on all seedlings after 7 days. If there are issues these are confirmed after a further 7 days.

- Samples that achieve 2 or 3 on all 16 samples are released for use.
- If 1-3 seedlings score 1 or 0 the seedling's user will be notified with suggested options: plant at a higher density or change the request key percentage within a planting unit. The user will be made aware of the risks with that request key.
- If 4 or more seedlings have a 0 or 1 score, then it is recommended the request key not be planted. This scenario is rare. (A. Rasmussen Pers. Comm.).

Further testing is warranted to ensure that seedlings targeted for drought or frost prone sites can grow roots under stressful field conditions. The form and scope of testing should be reviewed by licensees and the Province to better understand and help improve nursery cultural practices for seedlings planned for extremely dry sites. Seedlings with improved drought or frost stress tolerances could have improved success in overcoming planting shock.

More research is needed to advance nursery cultural practices to improve initial drought or frost tolerance for seedlings targeted for dry or frost prone sites, including:

- Drought acclimatization of seedlings,
- Frost acclimatization of seedlings,
- Stock size recommendations,
- Top pruning recommendations (drought),
- Improved root growth testing and testing under more stressful conditions, and
- Recommended practices and trials for a feedback loop between silviculturists and nurseries for seedlings planted on site.

Increased effort is needed to identify and track which seedlings are targeted for drought or frost prone sites. This could simply be creating a new field in SPAR for silviculturists to identify the request keys requiring different treatment. Silviculturists should increase their communication with nurseries to help with solutions for these request keys. Some examples of conversations silviculturists could be having with nurseries could be regarding plug size, stress testing, top pruning, increased root-testing, and creating a feedback mechanism for silviculturists to communicate their findings from the field.

10 Planting program preparation

Prompt reforestation is critical to achieving successful plantations.

Following harvesting, several factors occur that make reforestation more challenging as time progresses:

- Pinegrass will increase in ground cover. This could increase frost hazard through the trapping of cold air. This will increase drought effects through increased transpiration of water out of the soil,
- As agronomic species increase in intensity, cattle pressure also increases. The first year following harvesting usually has low cattle intensity because there's no food on site. However, cattle learn and will return to sites with good food sources,
- Access may be degraded or removed. This impacts the ability to get machinery on site to adequately site prepare plantable spots. Degraded road systems will also increase stress on trees when transported by truck or ATV. Because Fdi seedlings usually have less cohesive plugs than other species, mechanical damage affects Fdi disproportionally, and
- Some residuals will blow down, reducing shade and thermal protection for planted seedlings as well as blocking access for MSP operators to effectively treat all areas, and planters delivering trees to portions of the openings.

As the time between harvest and site preparation increases, the value of site preparation in creating a suitable vegetation-free condition decreases rapidly. Similarly, as time increases between site preparation and planting, the value of the site preparation in creating suitable vegetation-free conditions also decreases rapidly. Site preparation and planting must be timed together to occur at the earliest possible planting date with the least amount of time between site preparation and planting. Site preparation has its best value if completed in the fall prior to planting, if completed before the soil freezes for the winter.

Best Management Practice: Trees intended for drought or frost prone sites must be sown at the earliest opportunity. It is not recommended to wait until harvesting is completed before sowing for trees.

This speaks to the need for better pre-harvest planning. Many of the critical survival issues can be assumed prior to a post-harvest assessment, and prior to site plan signoff (brush and forest health issues may not be). Discrepancies with the initial plan can often be addressed through adjustments, seedling sales, and MSP contracts.

Early planting is critical for reforestation success on drought prone sites. Trees must be planted as early in the growing season as possible while still avoiding the worst of spring frost events. This will allow the planted trees to take advantage of the greatest amount of time where moisture is sufficient for seedlings to grow roots, set new branches and buds and then shut down in time for the summer drought.

10.1 Planting contract implementation

Strong emphasis must be placed on planting expectations for Douglas-fir. This is accomplished through:

- Communicating expectations at the time of pricing (viewing),
- A quality prework, planting prescriptions, and
- Prompt feedback to the planting contractor.

There are critical quality assurance components to address with the planters including:

- Microsite,
- Shading,
- Planting medium,
- Site preparation location,
- Natural depressions,
- Minimum inter-tree distance,
- Planting quality elements like air pockets, j-roots, too shallow and too deep planted trees - are very important, and
- Delays or reworks should be avoided.

To accomplish this, planting contract implementers must:

- Understand the site limitations for growing Fdi,
- Understand the prescribed locations where those limitations will have the least impact on Fdi seedlings,
- Be present on the first days of planting Fdi on site, to provide ongoing feedback to planters so they can successfully place the trees in the correct microsites and locations within the planting unit, and
- Have the authority to enforce reworks and corrections so that seedlings are placed in the locations and microsites prescribed.

Photo 19. Example of planting prescription that targets obstacles for the Douglas-fir seedlings. Photo credit – Colin Hegan

Best Management Practice: Include language in planting contracts indicating where Fdi is expected to be planted. Communicate this clearly at planting viewings. Provide planting prescription maps with explicit language and locations where Fdi is expected to be planted. Keep these clear and simple.

It's better to work with a planting contractor, understanding the immense pressures on their supervisors in the early stages of any planting contract. Working with the contractor to ease into their planting contract means being on site every day for the critical initial days or week - working with them on their understanding of how to plant trees, where to plant the Fdi, and how they will best survive. This includes providing leniency on payment issues while they work through seasonal growing pains. This give and take approach works best as all parties attempt to deliver the best quality product with maximum potential of success for seedlings in these critical environments.

Planting contractors are immensely busy organizing the logistics of a planting camp in addition to training new planters and organizing the normal flow of seedlings from cold storage to final planting. As a result, interpreting planting prescription instructions as to where Fdi should be planted may be missed with significant potential for trees to be delivered to the wrong area. Also, planting supervisors and foremen may have limited understanding of the requirements for Fdi as well as the consequences of planting Fdi in inappropriate locations. To relieve planters of the burden of interpreting brief instructions, planting prescriptions and maps must be specific as to the expectations of where Fdi is expected to be planted.

- In a scenario where a large opening has a small stratum where Fdi is ideally suited to reforestation, such as steeper slopes and greater numbers of residuals, this section should be stratified on the map as a separate planting unit with its own seedling allocation. This spatial representation should be identified prior to harvest, confirmed, and adjusted at the post-harvest assessment, and available for all planting treatments that include Fdi,
- If only a small portion of the planting unit should, or should not receive Fdi, this must be clearly hatched on the map with text indicating that Fdi should or should not be planted there. (Example 1. in the instance where only two boxes of Fdi are allocated to a planting unit: Example 2. The entire planting unit is suitable for Fdi except for one steep draw),
- If the locations where Fdi should be planted is dispersed throughout a planting unit and cannot be clearly indicated on a map, more communication is required to direct the planters where to plant Fdi. More communication should occur both at the prework as well as on the first days of planting to ensure the complicated prescription is understood and the planting supervisors and foreman clearly understand what is expected of them,
- The micro-site selection for Fdi should be clearly specified. Examples: north or east-facing side of stumps, and downhill side of obstacles or coarse woody debris, which act as impediments to frost transfer, and
- In all cases, a clear description of where the Fdi should be planted should be indicated in a planting prescription with wording in the contract indicating the consequences of placing Fdi in the incorrect location. Fines should be considered the last step once all the other efforts are exhausted.

Best Management Practice: Prior to receiving quotes for planting pricing, an office viewing must discuss the expectations for planting Fdi. This must include: the location and microsite planting requirements, and the tools that will be made available to the planting contractor to achieve success.

If clear expectations are not available to planters at the time of pricing, it becomes very difficult to implement planting programs which require considerable effort such as complex microsite selection for Fdi. There are considerable pressures on planting foremen and supervisors, they are managing numerous staff, logistics and safety. If planting maps do not clearly describe where Fdi is to be planted, there is a much greater chance the Fdi will be planted in the wrong locations.

Best Management Practice: Planting prescriptions must have maps that spatially identify the location where Fdi is expected to be planted.

Recommendations:

- Planting implementation preworks should include education on where Fdi is suitable and a review of planting maps where Fdi planned for each planting unit is spatially identified. Implementation preworks should also anticipate non-compliance from planters and discuss a plan to steer planters in the direction of full compliance,
- During the planting program, planting implementers should communicate daily how effectively species microsite placement is working and evolving, specifically the Douglas-fir component of the seedling allocation, and
- Planting implementers should be invited to extension field trips for the purpose of discussing where and under what circumstances Fdi should be included in planting treatments. This field trip should include a fulsome discussion of micro-site selection.

Photo 20. Example of IDFdk3 drought prone site. The site is snow and frozen ground free but the road might need to be plowed to enable early planting. Photo credit – Tristan Tyler.

11 Brushing

Vegetation control for aspen and woody brush species should be avoided on sites where frost, drought and heat stress are a concern. Most vegetation species, except for pinegrass, will provide some level of thermal cover and shade protection. This overrides most concerns related to competition for moisture. There are scenarios where tall herbs and forbs can cause snow press damage on planted trees, these should be identified and dealt with separately where this occurs.

There are examples of direction from the province to allow accepting some aspen or brush when determining free growing status. The purpose of these documents is to help reduce unnecessary brushing treatments in circumstances where the aspen or brush is beneficial to crop trees.

One document is the *Policy Guiding the Use of Modified Free Growing Criteria within the SBSPxc and IDFdk4 within the Williams Lake TSA.* This guidance indicates that trembling aspen may be considered non-deleterious to crop trees –for mesic site series or drier IDF or SBPS (Newsome and Heineman as cited by Pedersen 2011). This direction is beneficial with reforesting Fdi–as Aspen retained during brushing treatments can contribute to shade and thermal protection.

Another document is an appendix in the *Silviculture Surveys Procedures Manual 2020 - South Area – Williams* Lake, *Quesnel and 100 Mile TSA's (SBPSmk, SBPSdc, SBSdw1, SBSdw2, IDFdk3, and IDFdk1 only*) Alternative FG Guidance. This document improves the previous definition of free growing trees in the presence of brush or aspen (MOF 2020). Note, there is no IDFdk1 in the Cariboo Natural Resource Region.

Brushing should only be considered where competition with brush species is forecast to cause crop tree mortality based on field observations of the crop trees, and not solely on brush presence. All alternatives should be explored before brushing is considered where Douglas-fir regeneration is still susceptible to negative environmental effects from drought and frost.

Approximately 2% of the total hectares planted in the IDF are brushed each year. This is based on a review of the last 10 years of brushing and planting in the IDF. It does not appear brushing is a significant contributor to frost damage to Douglas-fir in the IDF.

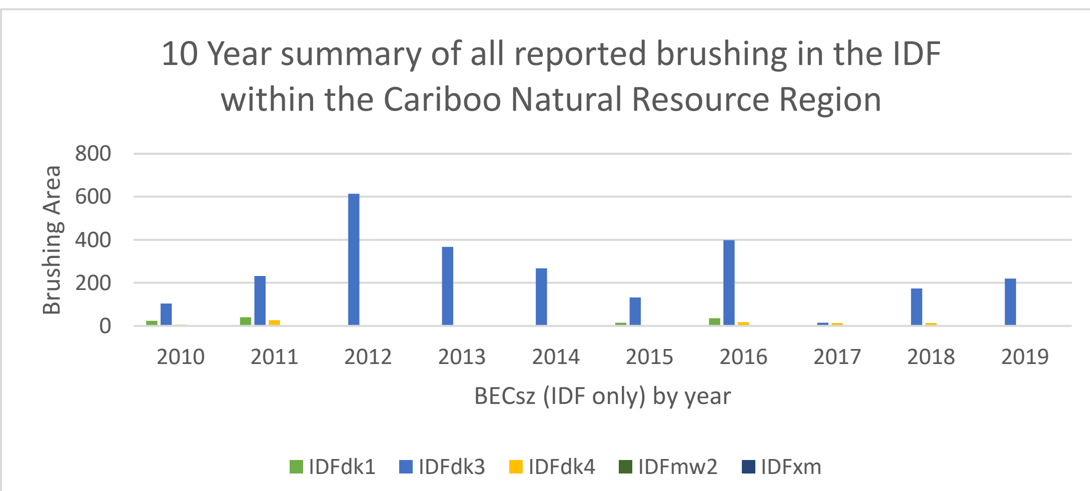

Figure 12 10 Year summary of all reported brushing in the IDF. Cariboo Natural Resource Region.

Best Management Practice: avoid brushing treatments unless crop tree mortality is imminent. Brush and upland aspen can provide necessary thermal protection for Douglas-fir.

Photo 21. Example Douglas-fir growing very well adjacent to brush. In many of the units visited these were the best Douglas-fir trees on site. Avoid brushing unless the survival of the tree is at stake. Photo Credit - Colin Hegan.

12 Planting treatment scenarios

Fdi planting treatments have been summarized into variations of four similar scenarios. Each scenario is described, with recommendations into three categories: Treatment Unit setup (organization), Planting treatment maps (spatial), and Planting treatment direction (text).

The planting units throughout the Cariboo Region can be managed using the following approach, regardless of BEC as the major driving forces are Frost Hazard, and Drought Hazard.

Best Management Practice: Frost hazard should be assessed, and the treatment area fully stratified using DeLong's Frost Hazard Workbook. The stratification must be adjusted based on additional considerations, such as overstory thermal cover, meso-scale topographic crests and depressions, increases in upslope frost source, and impediment to downslope cold air drainage. In addition, Drought hazard should be assessed and closely typed using A Field Guide to Forest Site Identification and Interpretation for the Cariboo Forest Region (Steen and Coupé 1997) – focusing on xeric sites, rocky eskers, obvious non-productive (NP), and steeper south facing slopes.

Scenario 1. This planting treatment is characterized by predominantly low frost hazard throughout. Small sections of ground exist that are not suitable for planting Fdi such as wet areas, and depressional terrain associated with draws or creeks. There are no obvious stratifiable areas of higher frost or drought hazard.

Planting treatment units: This scenario can remain as one planting unit with a defined species allocation. Increase the allocation of alternative species to reforest the areas that are not suitable for Fdi.

Planting treatment map: The planting map provided to the planters does not require stratification, however representation of the areas where Fdi should not be planted should be attempted wherever possible and Fdi must not be planted in these areas. This can be achieved using swamp symbols or hatching where there are obvious wet areas and hatching in the vicinity of the depressional areas. Notes with arrows should be used to clearly identify the areas where Fdi should not be planted. One example of how to represent these comments is provided below.

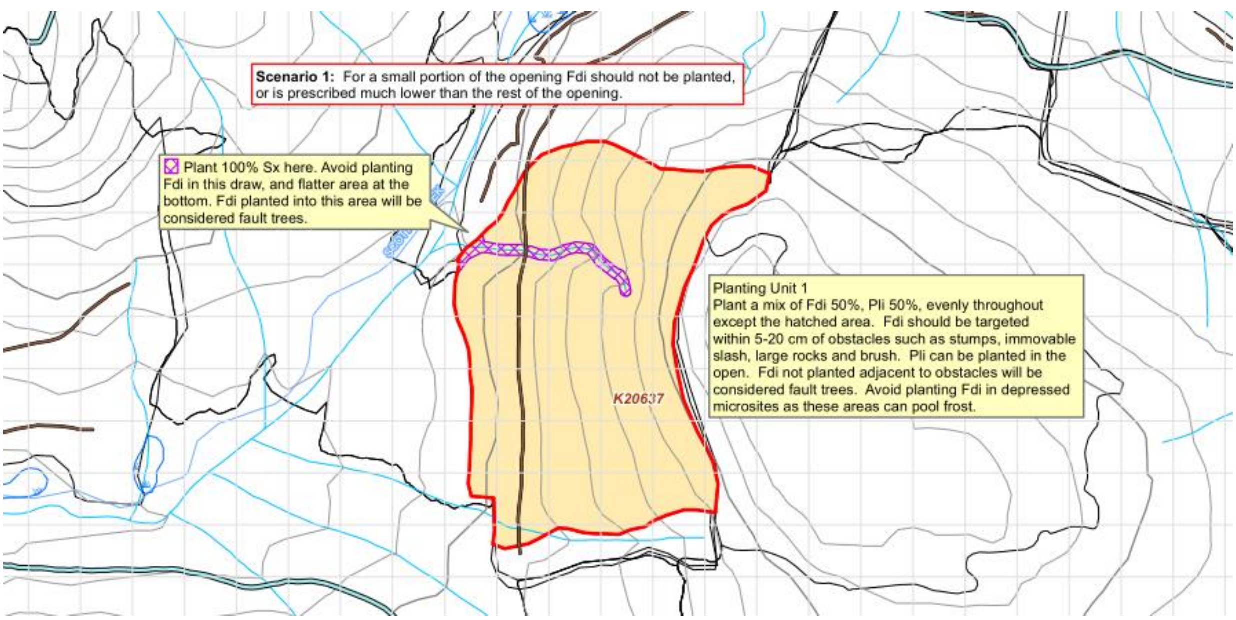

Figure 13 An example map clip from a planting prescription map, for planting scenario 1

Planting treatment prescription (example text please adjust as required).

Plant a mix of Fdi 70%, Pli 30%, evenly throughout except the hatched area. Fdi should be targeted within 5-20 cm of obstacles such as stumps, immovable slash, large rocks, and brush. Pli can be planted in the open. Fdi not planted adjacent to obstacles will be considered fault trees. Avoid planting Fdi in depressed microsites as these areas can pool frost.

Sx must be planted in the wet area identified (see map). Avoid planting Fdi within 5m of wet areas and depressional areas identified on the map or elsewhere throughout the planting unit. Fdi planted into these scenarios will be considered fault trees.

Discussion for scenario 1: This scenario assumes considerably larger Fdi allocations that are mostly suitable throughout. These trees should have reduced risk of frost damage and frost mortality relative to Fdi planted into moderate frost hazard. There will always be areas where Fdi should not be planted at all such as draws, the lower timber edge, and swamps – these should be typed out as best as possible on the planting map.

Include language in planting contracts that indicate Fdi will be considered fault trees if the planters do not follow the prescribed direction. The contract should provide clear direction for planters and implementers that is relatively easy to follow. It is difficult for planting implementers to enforce general directions on how Fdi should be planted. Clear direction at the contract stage, fully described at the prework, and supported by quality maps should ensure implementers, contractors and planters all understand how the Fdi should be planted. The result is improved survival and performance of planted Fdi and less risk for the planting contractor.

Photo 22. Example SBSdw1 site. Most of the site is 30% slope and low frost hazard. Avoid planting Fdi into the draw. The licensee has targeted 100% spruce into this area and 70% Douglas-fir on the steeper slope above Photo Credit - Colin Hegan.

MSP is recommended for all areas where Fdi is planted, and significant drought or frost potential exists. MSP is recommended if there is doubt about whether the treatment unit is low frost hazard or if it is trending towards a moderate frost hazard. Acceptable MSP treatments are ripper plow, excavator raised screefs, or disc trenching where restricting Bt layers are absent. MSP is not required for areas with very low frost hazard and low drought potential.

Scenario 2. This planting treatment area is characterized predominantly by moderate frost hazard throughout. Within the main treatment area small sections of ground suitable for planting Fdi are identified, such as meso-scale topographic steep slopes, meso-scale topographic crests or areas with significant thermal protection such as residual Fdi cover.

Planting treatment units: This scenario can remain as one planting unit with a defined species allocation. Increase the Fdi allocation for the areas more suitable for Fdi.

Planting treatment map: The planting map provided to the planters does not require stratification into separate planting units. Attempt to represent the areas where Fdi is to be planted wherever possible. Fdi must be planted in these areas at significantly increased percentage, preferably 100%. This can be achieved by hatching obvious steeper slope areas and hatching in the vicinity of increased mature Fdi retention. Text boxes with arrows should be used to clearly identify the areas where Fdi percentage should be increased.

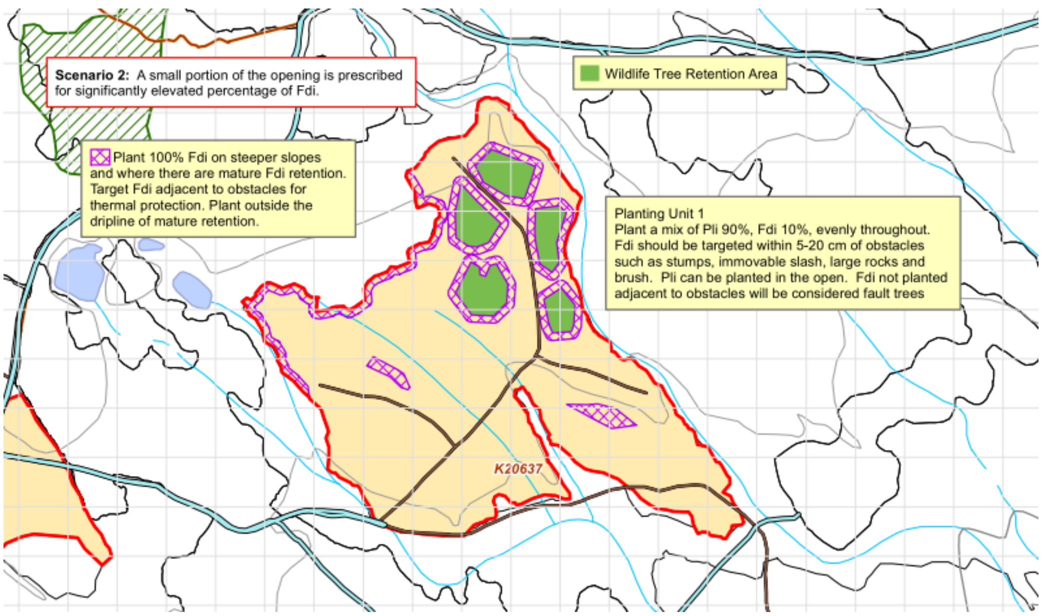

Figure An example map clip from a planting prescription map, for planting scenario 2

Planting treatment prescription (example text, please adjust as required).

Plant a mix of Pli 90%, Fdi 10%, evenly throughout. Fdi should be targeted within 5-20 cm of obstacles such as stumps, immovable slash, large rocks, and brush. Pli can be planted in the open. Fdi not planted adjacent to obstacles will be considered fault trees.

Plant 100% Fdi on steeper slopes and areas with mature Fdi retention (see map).

Discussion for scenario 2: This scenario allows for a considerable increase in planting of Fdi in preferred locations within the planting unit. These trees should have reduced frost damage and mortality relative to Fdi planted into moderate frost hazard.

Fdi planted into moderate frost hazard should be targeted into microsites adjacent to minor thermal protection such as brush, stumps, and large rocks. These trees are still likely to have frost damage but may release once the surrounding Pli overtop them and begin to provide thermal protection. These Fdi are likely to have increase chances for frost shake but, if they survive, will contribute thermal protection and a reduction in frost hazard for the next rotation. Frost shake occurs with late summer frost damage when the late wood lignin is not laid down for the year leaving a gap in the tree rings – this gap can act as an entry path for pathogens, causing further damage. Outward visible signs of frost shake can appear as the outer bark covered in sap that has exited these wounds.

Mechanical site preparation is recommended to mitigate drought in areas that have lower frost hazard and higher Fdi percentages in the planting prescription. Targeted MSP is recommended for these areas –resulting in a higher cost/ha but a lower total cost than treating the entire opening.

Photo 23. Example IDFdk3 site. Douglas-fir planted adjacent to a timber edge that provides thermal protection. Photo Credit - Colin Hegan.

Scenario 3. This planting treatment is a mix of Scenario 1 and 2 and requires stratification into different planting units (PU). A mappable portion of the planting area is very suitable for Fdi (in this case PU 1), and the remaining area is not well suited for Fdi (in this example PU 2). With different prescriptions for these two strata, it is best to create and manage as two planting units.

Planting treatment units: This scenario is characterized by two distinct planting units with a defined species allocation for each.

Planting treatment map: The planting map provided to the planters Includes two clearly mapped and described planting units.

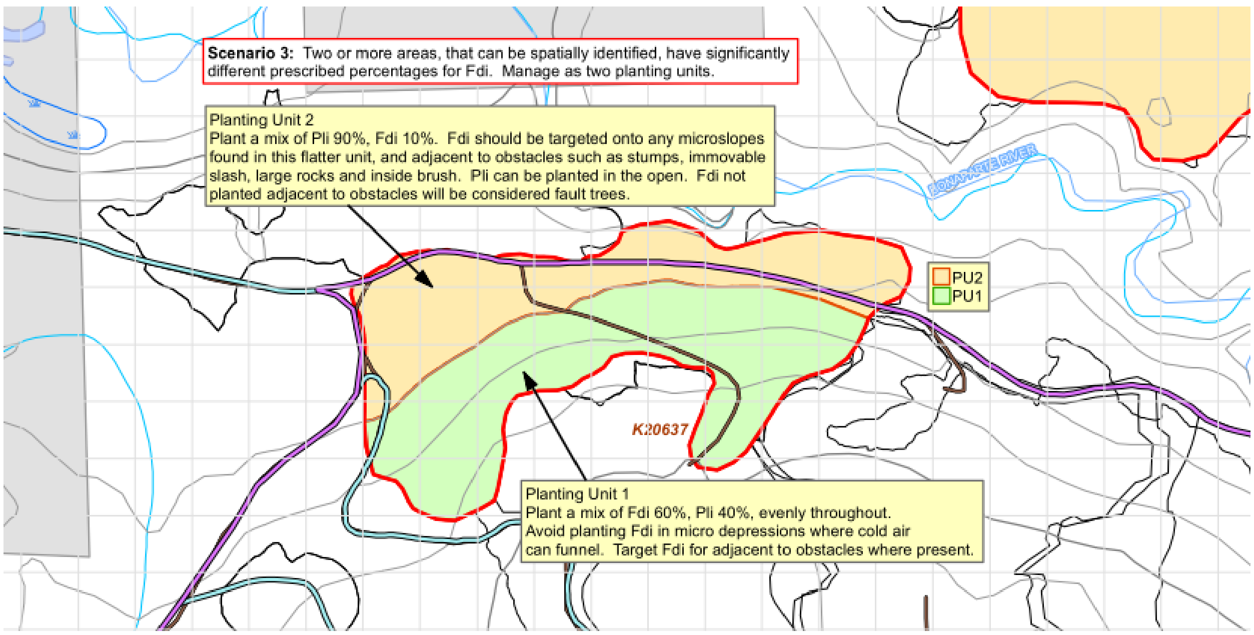

Figure 15 An example map clip from a planting prescription map, for planting scenario 3

Planting treatment prescription (example text, please adjust as required).

PU 1. Plant a mix of Fdi 60%, Pli 40%, evenly throughout. Avoid planting Fdi into micro depressions where cold air can linger.

PU 2. Plant a mix of Pli 90%, Fdi 10%. Fdi should be targeted adjacent to obstacles such as stumps, immovable slash, large rocks and inside brush. Pli can be planted in the open. Fdi not planted adjacent to obstacles will be considered fault trees.

Discussion for scenario 3: This scenario allows for a considerably higher percentage of Fdi in one of the planting units. There is a history in the Cariboo of directing planters at prework meetings to plant Fdi in the steeper areas and avoid depressional areas. This scenario clearly defines where a higher percentage of Fdi can be planted to ensure the prescription is achieved.

(PU 1 example) Targeting the Fdi for this area allows for a considerable increase in planting of Fdi in the best locations within this planting unit. These trees should have reduced frost damage and frost mortality relative to

Fdi planted into the moderate frost hazard planting unit (PU2). Prescriptions up to 100% Fdi should be considered for areas that have low frost risk.

(PU2 example) For the Fdi planted into moderate frost hazard all Fdi should be targeted for adjacent to minor thermal protection such as brush, stumps, and large rocks. These trees are likely to have frost damage but may release once the surrounding Pli overtop them and begin to provide thermal protection. Frost shake damaged Fdi will contribute thermal protection for the next rotation, reducing frost hazard in the future.

Mechanical site preparation is recommended to mitigate drought in areas that have lower frost hazard and higher Fdi percentages in the planting prescription. Targeted MSP is recommended for these areas –resulting in a higher cost/ha but a lower total cost than treating the entire opening.

Photo 24. Example IDFdk4 site. Douglas-fir planted in the area with 20-30% slope is doing very well. The Douglas-fir planted onto the adjacent bench had 100% mortality. Target Douglas-fir to the portion of the opening where it will survive the best. Photo Credit - Colin Hegan.

Scenario 4. This scenario is a combination of Scenario 1 and 2 but is not conducive to stratification into planting units because the low and moderate frost hazard areas are dispersed throughout.

Planting treatment units: this scenario should be one planting unit, with an approximation of how much area is suitable for Fdi and how much is poorly suited to Fdi.

Planting treatment map: The planting map provided to the planters does not require stratification, however an attempt to describe the areas suitable for planting more Fdi is warranted.

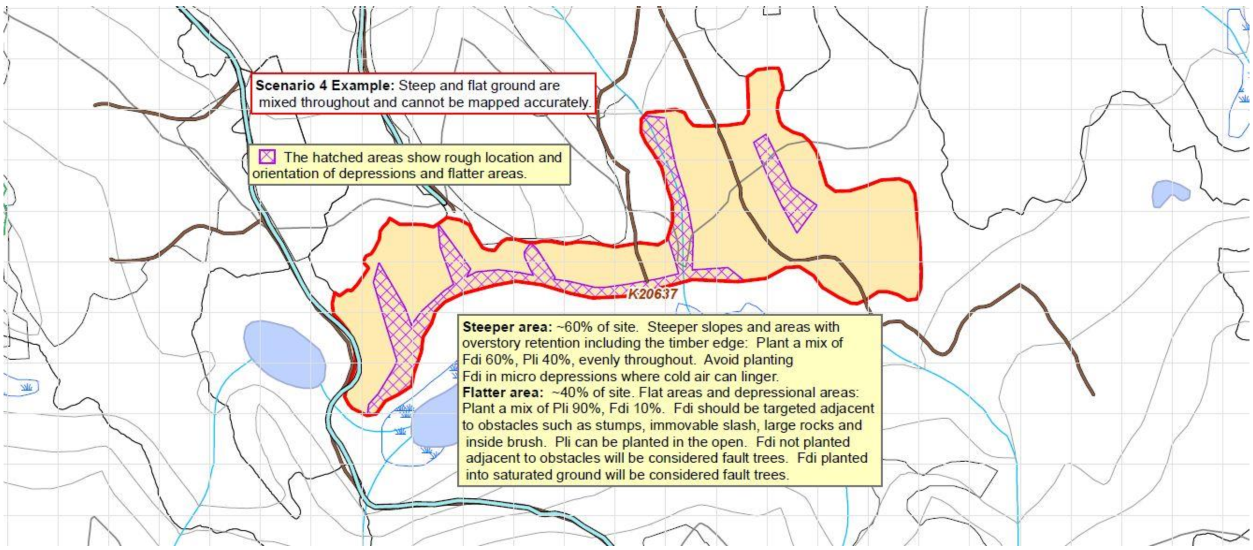

Figure 16 An example map clip from a planting prescription map, for planting scenario 4

Planting treatment prescription (example text, please adjust as required).

Steeper slopes and areas with overstory retention including the timber edge: Plant a mix of Fdi 60%, Pli 40%, evenly throughout. Avoid planting Fdi in micro depressions where cold air can linger.

Flat areas and depressional areas: Plant a mix of Pli 90%, Fdi 10%. Fdi should be targeted adjacent to obstacles such as stumps, immovable slash, large rocks and inside brush. Pli can be planted in the open. Fdi not planted adjacent to obstacles will be considered fault trees. Fdi planted into saturated ground will be considered fault trees.

Discussion for scenario 4: This scenario allows for a considerable increase in the Fdi percentage in one part of the planting unit, however it is dispersed, making it difficult to describe spatially and map. This scenario requires considerable direction to the planters at the prework as well as in the field by implementation staff or the contract coordinator. Consequences of planting Fdi into unacceptable areas require very strong communication and language in the contract, at the prework and during the first days of planting to be enforceable.

Mechanical site preparation is very difficult to target for the most suitable sites. Two options are available as best practices: broadcast treatment of the entire planting area, and targeted MSP.

13 Survival surveys - post planting review, walkthrough or survey scheduling regime for sites where Fdi is planted, and frost or drought can be anticipated.

A suggested schedule for reviewing planting units that are actively managed for drought is:

1. Fall walkthrough of a planting sample - enough to get a keen sense of the issues and when the next walkthrough should occur. Walking these sites in the same year as planting will provide a sense of which details and microsites in the prescription are working best. There will be examples of microsites doing well, and others where survival is questionable. In a weak moisture or strong spring frost event year, an early site revisit may be the only opportunity to understand which microsites might have allowed trees to survive, had the season experienced improved moisture or less frost. Stressed seedlings may still be alive but are likely to die later in the summer or over the first winter. This walkthrough will allow the silviculturist to best rank the microsites in terms of suitability on dry sites. If the first walkthrough or survey doesn't occur until following years, the lessons will be missed. An emphasis should be placed on checking root development for both the surviving seedlings as well as those that died – this is a critical component of understanding where the greatest successes and failures lie. Digging up trees can help surveyors understand whether planting quality or any other explanations contributed to stress or mortality.
2. First survey the year following planting - the first detailed survey must be early enough to determine if retreatment is required. This survey should focus on the reasons for planting success as well as failure and provide detailed recommendations on how to adjust the planting prescription or suggest an entirely new approach is warranted. The licensee silviculturist should be intimately involved in preparing surveyors to undertake these surveys and be prepared to walk sites in the event of plantation failure.
3. Following the first survey, a two-year survey cycle is recommended until Fdi are firmly established.

In all surveys and walkthroughs where Fdi is planted and frost or drought can be expected, excavating a representative sample of trees to see how the roots are progressing is recommended.

Best Management Practice: Sites that are actively being managed for Fdi, in areas where frost or drought is anticipated, should have accelerated reviews or surveys of any planting treatments.

13.1 Identification, coding, and reporting

While it's important to identify sites where there are risks of frost or drought to planted Fdi, it's equally important to track decisions reached at the pre-harvest or post-harvest (or other) stages.

Licensees should internally code openings or strata to identify them as needing strong attention for treatment.

- Name and identify the anticipated level of frost impact for the strata – embed this coding into the user's database as a searchable item. This will act as a reminder for the creation of treatment regimes at the time of post-harvest assessment. Tracking the number of sites requiring special attention and treatment regimes will allow a licensee to understand the scale of strata where Fdi is at considerable risk,

- Name and identify a treatment regime for each anticipated level of frost impact. This will help formalize a process the licensee has decided will have the best chance of success,
- Name and identify a survey regime. This will allow for easier communication with survey crews and ensure an appropriate review period is planned,
- Outline factors surveyors need to address when surveying sites where reforestation with Fdi is a concern. Review treatment regimes and the situations where they are appropriate with the survey crew,
- Distinguish between fill-planting (PL-FP-CTAIN) and replanting (PL-RP-CTAIN) when reporting internally and to RESULTS. This will help summarize the scope and scale of any plantation failures,
- When reporting internally, add a separate searchable descriptor for re-plants that are (in the opinion of the licensee) caused by drought or frost, and
- When creating sowing requests, distinguish between seedlings targeted for drought or frost prone sites and all other seedlings so these request keys can be treated differently. Communicate with nurseries so they can grow the best tree possible for these sites.

14 Surveyor education

Many surveys and surveyors focus on items such as well spaced and free growing trees but neglect to discuss the missed opportunities caused by Fdi mortality. It may be easier to meet stocking standards with the Pli that survived, but it is incredibly important to understand where Fdi succeeds and fails.

A strong recommendation, that will improve reforestation efforts with Fdi, is to provide extension to surveyors. Surveyors should be educated on which conditions Fdi grows best. This will allow them to provide feedback to silviculturists on which portions of openings are succeeding or failing and why. This information can be used for future treatment plans to prescribe species percentages, site preparation, and to provide important feedback on instances where Fdi is failing. Extension should be in the form of courses, presentations, field visits, and contract language/ prework sessions where reforesting with Fdi is highlighted. The assessment expected of surveyors includes stratification and discussion based on slope, terrain, thermal protection, and frost hazard assessment breakdown of each stratum. This should help increase the probability of plans succeeding and increase the detail and extent of treatments where Fdi is included in planting prescriptions.

Site visit summary: In many of the sites visited there was considerable Fdi planted, but over much of the openings it was difficult to determine where this Fdi was planted and how it was performing. Successfully reforesting sites with lodgepole pine is much easier than reforesting with Douglas-fir. On many sites there was significant Fdi planted throughout openings with high mortality where considerable frost damage and extensive mortality should have been expected. In these same openings there were portions that should be considered favorable to growing Fdi that were planted to mainly Pli. Once these stands are stocked it is easy for the surveyor to indicate that the larger stratum has achieved stocking success (with Pli) when it would be better to discuss the missed opportunity for Fdi. This approach would provide a helpful feedback loop for future planting treatments on similar sites.

Best Management Practice: provide surveyors with access to silviculture extension such as courses, presentations and field trips focused on reforesting with Fdi. Further focus surveyors' attention on this issue by

highlighting Fdi reforestation opportunities in survey contract documents and preworks with greater emphasis on where Fdi can survive and thrive.

Recommendations:

- Prescription templates provided to surveyors for planting prescriptions should include a section on where Fdi is suitable for planting – this should include spatial representation on the treatment map,
- Survey preworks should include education on where Fdi is suitable and indicate that detailed spatial direction on where to plant Fdi is a requirement for completed surveys, and
- Surveyors should be invited to extension field trips for the purpose of discussing where, and under what circumstances, Fdi should be included in planting treatments.

15 Informal Trials (Tests)

Silviculturists should conduct their own trials in their operating areas to expand knowledge and improve future successes. Any treatment regime identified should be subject to testing and adjustment. Note, these trials shouldn't be confused with research trials which have a much more rigorous approach.

All trials should be documented with clear distinction on maps where these have occurred. The number of variables needs to be managed. If you want to know about environmental impacts, hold the other variables the same (planting year, season, instruction, stock type, site prep, etc.). If you want to know about cultural variables, keep the environmental variables constant. Doing trials across other blocks improves the reliability of results, because you aren't extrapolating from a single site. Trials should be conducted on the same opening and the same standards unit where possible. Trials need a control population of the same size as the treatment. Think carefully what you should describe as a control and include it in the trial. Research samples should be a specific selection of treatment and control trees. Research trees should be tagged or staked, so that you can return to the same trees in subsequent measurement/review periods.

Trials size could be:

1. Larger scale where half an opening has one treatment, while the other half has another.
2. Smaller scale where a 20m x 20m section is treated slightly different. These have value as anecdotal support for theories or where an existing regime works but slight changes are suspected to improve results, but also may fail.
3. Very small areas of high-density planting should be established as a common practice on all extremely dry or dry sites to allow for multiple excavation over multiple seasons. These should be easily accessible, mapped and made available to surveyors for review and commenting.

Below are examples of tests a silviculturist may perform to further knowledge:

- Establishment of min-max thermometers at grass height to record extreme temperatures observed by seedlings,

- Seedlot progeny – seed sourced from drier sites vs seed sourced from moister sites (for drought testing), and from northern or higher elevation sites and southern or lower elevation sites (for frost testing),
- Stock size. Plant some 512A, 412A, 412B, 309 sized Fdi and compare how they do over different seasons,
- Planting depth – test deep, normal, flush, and even shallow plug placement,
- Planting microsite – obstacle planting location, test aspect, stumps, rocks, brush. Test Fdi on burned landings,
- Planting stock – top pruning at nursery or on site adjusting the root to shoot ratio,
    - Ask nursery to top prune several boxes of trees prior to hardening off, track these and test them.
    - Alternative is to manually top prune trees following planting.
- Nurse crop planting - planting Fdi under established or establishing trees,
- Nurse crop planting - planting Fdi in conjunction with other trees or vegetation,
- Mechanical Site Preparation – size of spot,
    - Plant multiple locations on prepared spot.
- Mechanical Site Preparation – disturbance %,
    - Test different size or intensity of the same disturbance.
- Mechanical Site Preparation – one treatment type versus another,
    - Plant multiple locations on prepared spot.
- Raw planting – have planters plant a box of trees on recently harvested sites scheduled for MSP and planting at a further season,
    - Test stock size, microsite location and species survival.
- Planting timing – leave small areas to plant in subsequent or prior weeks to test root growth and survival,
- Planting timing – fall planting, and
- Fertilizer application – treat versus no treatment.
    - Different types of fertilizer treatments can be included.

If small scale size of tests is chosen, plant at high densities to cover as many diverse microsites as possible to rank effectiveness.

Best Management Practice: Small operational trials are an extremely cost-effective way of testing for appropriate regimes most likely to work in an area. Silviculturists should engage with their local research silviculturist to improve trial design, expand questions worth testing, and to help drive research project ideas.

This is important. If trials are designed with some rigour, their results will be more widely accepted and applicable.

16 Recommendations

The following general practices are recommended as the risk for drought and frost mortality increases.

Planning and Harvesting:

- Retain more mature overstory as frost hazard and or drought hazard increases. These should be distributed throughout the site in clumps or individuals to provide thermal protection and shade to every portion of the areas where Fdi will be planted. As frost and drought hazard increases, the retention level should increase correspondingly. Stems identified for retention should be expected to survive to the next rotation. Retaining a low-density overstory exposes it to wind throw risk and forest health agents,
- Retain vigorous advanced regeneration wherever possible. The retention needs to stay alive and standing to have the benefit you are looking for. This is not a recommendation to return to diameter limit cutting,
- Use the Frost Hazard key provided to identify sites at higher risk for frost. Stratify sites requiring more thorough attention and include Fdi in planting plans. Track these areas in a database for future review and use,
- Avoid harvesting xeric patches, lava fields, or rock knobs,
- Include silviculture staff in cutting permit development planning, and
- Successes and failures of Fdi seedlings should be tracked and reported to an internal review mechanism that rewards successes and allows for continual improvement.

Mechanical Site Preparation:

- Greater soil disturbance decreases both drought and frost risk. Where drought and frost risk increases, increase soil disturbance accordingly,
- Manage mechanical site preparation programs carefully: Identify the required level of disturbance, and monitor these treatments to ensure the required level of treatment is achieved, and
- Mechanical site preparation treatments can be targeted within openings to the areas where Fdi is likely to succeed, such as adjacent to thermal cover as well as on steeper slopes,

Planting:

- As risk for drought increases, larger planting stock size is recommended,
- As frost risk increases, larger planting stock size is recommended,
- Place seedling requests as soon as possible, preferably prior to harvesting, and
- Create a detailed planting prescription identifying specific microsites and the location within the opening where the Fdi seedlings should be planted to maximize survival – this spatial location should be clearly identified on planting maps. Clearly communicate this strategy to planters at: the planting viewing, the planting prework and the first days of planting to ensure Fdi is delivered to the correct sites, planted in the correct locations, and on the best microsites.

Surveys:

- For the sites at greatest risk for drought and frost mortality, conduct a fall walkthrough following planting,
- Increase the survey frequency. The first full survey on the riskiest site should be no later than one year following planting,

- Surveys should include a component of seedling root excavation to allow for better feedback on plantation success, and
- Surveyors should be given greater direction on information required when assessing the driest sites as well as sites with the greatest risk of frost.

Testing areas:

- Silviculturists should create informal trials to test ideas about increasing seedling survival on frost prone sites. These trials should be documented so that surveyors can look for the results and help inform treatment prescription recommendations, and
- Provide a location where surveyors can excavate a few seedling's roots. These areas should not be within the testing areas.

Gaps where further research should be conducted:

- Develop seedling quality testing for nurseries that better focuses on root development in stressful conditions. Review PSI vs PSB survival success in drought and frost conditions,
- Review planting depth and plug temperature related to survival success in higher drought and frost conditions,
- Review plug size relative to survival success in drought and frost conditions,
- Review seed progeny survival success in drought and frost conditions,
- Research and breeding of A-class seedlings that maximize drought tolerance, and
- Research and breeding of A-class seedlings that maximize frost avoidance (growth timing).

Operational practices: Gaps where further development is warranted:

- Terminology: recommend all licensees and ministry staff adopt PL-RP for sites that have been planted and need to be replanted,
- RESULTS (and licensees' databases): recommend that a new objective be put into RESULTS so replants or planting treatments, caused by drought or frost mortality, are easy to identify,
- SPAR: recommend an additional field be included in SPAR to identify request keys targeted for extremely dry or frost prone sites. This will flag a request for a nursery for special cultural practices, such as early sowing, and
- Develop improved nursery seedling quality testing that measures root growth in conditions similar to what the seedling can expect once out planted.

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Appendix 1 Overview Maps of Fdi planting within DCC, DMH and DQU.

Appendix 2 Site Reviews

Appendix 3 Policy guiding the use of modified Free Growing survey criteria within the SBPSxc and IDFdk4 subzones in the Williams Lake TSA

Appendix 4 Surveys Procedures Manual May 2020. Alternate FG Guidance

Appendix 5 A Field Guide to Identifying Summer Frost-prone Sites in the Cariboo Forest Region: a supplement to FRDA Report 157 (Steen et al. 1990).

Appendix 6 Literature Review

This is a list of abstracts from papers reviewed for this report. The papers were provided by research scientists and MOFLNRO staff.