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Repression Density Treatment Decision Key

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1. INTRODUCTION

1.1 Project Background

A 2015 field trip conducted by Forests for Tomorrow (FFT) in the BC interior reviewed the policy of *maximum density* and treatment options to improve stand productivity in young, high density stands. Resulting from that trip and subsequent discussions was agreement on the need to review and possibly revise FFT funding criteria for repression treatment options, and the need to develop a new stand level decision tool to aid in application of treatments.

The focus of concern was the issue of height growth repression in young, high density stands of lodgepole pine (Pl), interior Douglas-fir (Fd), and western larch (Lw) – and specifically the loss of productivity from repression and the potential for treatments to avoid that loss. Although considerable research has been done on the issue of density management of fire-origin Pl, there is little information on Fd or Lw, or on high density post-harvest regenerated (PHR) Pl stands. Thus the FFT project team agreed to revisit the issue of the maximum density policy as applied under the FFT program.

1.2 Project Goal and Objectives

The goal of this project was to develop decision support aids to help administer treatments in young, high density stands of Pl, Lw, and Fd. The agreed on approach was to develop the decision aids by bringing together research results, growth and yield simulations, financial analyses, and expert opinion in a relatively simple and practical form to guide stand-level decisions.

The two main objectives to achieve that goal were to:

1. Develop the stand-level decision key; and
2. Revise the FFT funding criteria for treatment of high density stands likely to enter repression.

1.3 Project Scope

This project focuses on stand-level decisions. We assume that those decisions will be developed under the appropriate forest level analyses indicating that treatment of repressed stands is a priority at the forest level.

1.4 Project Team

This work was completed for Weyerhaeuser Company Ltd., Princeton Timberlands by Eleanor McWilliams, RPF, Jim Thrower, RPF, Ian Cameron, RPF, Steve Jones, RPF, and Ed Collen, RPF. Ministry of Forests, Lands and Natural Resource Operations staff overseeing and contributing to this work included Mike Madill, RPF, Jim Goudie, RPF, Neil Hughes, RPF, Matt LeRoy, RPF, Walt Klenner, P.Ag., Mike Ryan, RPF, Al Powelson, RPF, Monty Locke, RPF, Kevin Derow, RPF, Leith McKenzie, RPF and Lyn Konowalyk, RPF. Funding for this project was provided by the Forests for Tomorrow program.

2. LITERATURE REVIEW

2.1 INTRODUCTION

The intent of the literature review was to find information specifically related to the goals of this project; not a comprehensive review of all literature. We cite literature where applicable and include our opinions and observations where we believe it adds to the understanding of this very complex topic.

The focus of the literature review was on young, high-density stands (2 m or less in top height) that could potentially become repressed with potential to respond to juvenile spacing. Information was specifically sought to help answer the questions:

a) What are the observable characteristics of stands likely to go into repression (e.g., stand origin, species composition, stand density, site productivity, etc.)?
b) What magnitude and range of site index reductions can be expected?

2.2 DEFINITION OF REPRESSION

Mitchell and Goudie (1980) first characterized repression in Pl as "…*curtailed height growth which begins before the dominant trees attain a height of 2 or 3 meters if 50,000 or more seedlings are established per hectare. The severity of repression is related to the level of initial stocking*." Their work and subsequent work has shown that repressed stands differentiate into crown classes, express dominance, and self-thin, although at a rate slower than expected from the inherent quality of the site. The term "repression" as a categorical descriptor of this phenomenon has supplanted "stagnation" and "suppression"—terms once in common use. The fact that repressed stands continue to grow and develop, albeit at a reduced rate, indicates that stands have not stopped growing as implied by "stagnation". The reduction in height growth of dominant trees distinguishes repression from "suppression", which is now usually reserved for describing the growth losses incurred by trees that lapse into the lower crown classes.

2.3 REPRESSION AND SITE INDEX

Repression of height growth has an obvious effect on the estimation of site index, and there are many observations of reduced site index in repressed stands. Measurements of the height-growth trends of the dominant trees in repressed stands through stem analysis techniques (Mitchell and Goudie, 1980) and through repeated measures of fixed-area plots (Huang et al 2004) indicate that repressed stands tend to grow as if the site quality had been reduced. In other words, interpreting repression as a loss of site index is a realistic analogy and leads to realistic expectations of the growth and future yield of repressed stands.

Huang *et al.* (2004) summarized the results of several paired plot studies in fire origin and PHR stands indicating differences of 3 – 6 m in site index (Table 1). These differences are likely in large part due to repression in the fire-origin stands, but other factors such as climate change may also contribute. Key information lacking from these studies is densities of the fire-origin stands at establishment. The current Weyerhaeuser study on TFL 59 (Thrower 2013) is one of the few examples where high-density fire-origin stands have been measured in the first years after fire.

Table 1. Lodgepole pine mean site index values from mature fire-origin and post-harvest regenerated juvenile stands comparisons with other studies (Table 4 from Huang et al. 2004).

			Mean Site Index (m)			
Study	**Sample design**	**Sample size**	**Fire origin**	**Post harvest**	**Diff.**	**% change**
Udell and Dempster revisited	Paired-plot	22	13.4	18.09	4.69	35.01
Merritt (Weyerhaeuser 1994)	Paired-plot	25	16.48	19.44	2.96	17.96
Merritt (Weyerhaeuser 1994)	Classical TSP	67	16.03	19.22	3.19	19.9
Okanagan Falls (Weyerhaeuser 1995)	Paired-plot	9	13.32	19	5.68	42.6
Okanagan Falls (Weyerhaeuser 1995)	Classical TSP	32	13.8	19.1	5.3	38.41
Morice (Goudie 1996)	Paired-plot	42	16.14	19.88	3.74	23.17
Lakes (Goudie 1996)	Paired-plot	56	15.37	20.12	4.75	30.9
Lakes (Goudie 1996)	Relocated TSP	14	16.6	20	3.4	20.48
Vanderhoof (Goudie 1996)	Paired-plot	12	14.93	21.05	6.12	40.99
Cariboo (Nussbaum 1998)	Paired-plot	60	13.3	19.2	5.9	44.36
Kamloops (Nussbaum 1998)	Paired-plot	56	15.7	19.8	4.1	26.11
Nelson (Nussbaum 1998)	Paired-plot	10	14.8	18.7	3.9	26.35
Prince George (Nussbaum 1998)	Paired-plot	96	17	21	4	23.53
Prince Rupert (Nussbaum 1998)	Paired-plot	74	16.5	20.1	3.6	21.82
Alberta Land & Forest Service (2000)	Vertical pairs	86	14.27	17.27	3	21.02
Weldwood (The Forestry Corp 2002)	Paired-plot	90	13.58	18.47	4.89	36.01
Weyerhaeuser Grande Prairie (2002)	Classical TSP	39	14.99	18.3	3.31	22.08

Note: Diff., mean post-harvest site index minus mean fire-origin site index; % change, percent change in mean post-harvest site index over mean fire-origin site index and is defined as Diff. divided by the mean fire-origin site index; TSP, temporary sample plot.

The spacing and fertilization trial at Fish Lake (40 km SE of Prince George) suggested a loss of almost 8 m on a potential site index of 19 m (Farnden and Herring 2002). This fire-origin stand had average densities 122,000 to 700,000 /ha at age 18 years (after fire).

2.4 Repression in Pl, Lw and Fd

There are numerous examples of high density, fire-origin Pl stands experiencing repression. Repression can occur in pure stands of Lw (Schmidt 1965) with an associated loss in site index. However, there appears to be fewer occurrences of repression in Lw because it is found most commonly in mixed stands (Schmidt and Shearer 1990). Repression might occur in Fd, but cases where Fd regenerates in the high densities are relatively rare. A review of Fd silvics (Day 1996) did not mention repression.

For this project, we will focus on repression in Pl where it occurs in high numbers in pure or mixed stands. We will examine the role of Lw and Fd, particularly in mixtures with Pl, but we will not examine any potential repression effects in Lw and Fd.

2.5 Development of Pl, Lw and Fd Mixtures

The US Forest Service website describes Pl and Lw as early seral species that often compete after fires. Pl will perform better on the drier or more exposed sites, but Lw will out-compete the Pl on other sites. They describe Lw–Pl stands with as little as 10% larch that eventually become dominated by Lw. This is similar to what is being observed on TFL 59 following the 2003 fires (Thrower 2013) where Lw are the tallest trees in high density mixtures of Pl, Lw, and Fd. On the one site where Lw is leading, 10 years after the fire the tallest Lw are about 50% taller than other species.

Lw is a fast growing pioneer species that often outgrows other species in terms of juvenile height growth. Parent *et al.* (2010) state "*One of larch's greatest attributes is its rapid juvenile (i.e., first 20 years) height growth. This rapid growth quickly gets the seedling above competing brush and other associated tree species so it can get control of the site. While sufficient upper-soil moisture is necessary to enable this growth, its fast growth enables its roots to penetrate lower water levels, sustaining it during periods of drought once it is established*." Owens (2008) states "*Very rapid height growth, equal to or better than its associated species, occurs in western larch until about 12 years of age. It then maintains a comparable or better growth rate than many associated species*."

The species commonly associated with Lw in BC are Pl and Fd. The developmental patterns of such mixtures are strongly influenced by the pattern and magnitude of the height-growth trends of the component species (Larson 1992, Oliver and Larson 1996). Usually Lw has a height-growth advantage over both Pl and Fd. Lw reaches breast height 1-2 years sooner than Pl (Nigh and Everett 2007) and the site index of Lw is usually 1m-2m higher than Pl on the same site (Nigh 1995). There are additional differences between Lw and Pl in the pattern of height growth. They exhibit similar growth up to about age 50, but after that the growth-rate of Pl declines relative to that of Lw (Schmidt and Shearer 1990). The advantage of Lw over Pl will persist beyond 100 years (Schmidt and Shearer 1995). In summation, we should expect Lw to grow faster in height than Pl, and if Lw does get ahead it will say ahead for at least the first 100 years. If present in sufficient numbers, Lw will dominate mixtures with Pl.

2.6 Stand Origin Impacts on Repression

Some recent research and considerable observational information is highlighting the apparent difference in stand origin on the dynamics of height growth repression. Most research on height growth repression in Pl has been done in very high density fire-origin Pl stands. And there is clear evidence that repression does occur – and can be quite severe – in those stand types. However, evidence is increasing that height-growth repression may not occur in high density PHR Pl stands.

Recent observation and study shows that PHR stands differ significantly in temporal and spatial distribution from fire-origin stands. The hypothesis of some practitioners is that these differences result in PHR stands not entering repression at the same densities levels that would result in repression in fire-origin stands. Fire-origin stands typically regenerate over a very short time period (1-2 years), where PHR stands can regenerate over 12 or more years (JS Thrower 2001). Furthermore, the spatial distribution of PHR stands is more clumpy than fire-origin stands. Both of these differences result in a much wider distribution in the level of inter-tree competition among trees than occur in fire-origin stands.

This phenomenon is shown in a study being conducted by Weyerhaeuser Company Ltd. near Princeton, BC (Thrower 2014). The site is in the MSxk Biogeoclimatic subzone at 1,430-1,530 m elevation. The 46 ha area was logged in winter 1988-89. The area regenerated immediately to almost pure Pl with stand densities ranging from about 60,000 to 120,000/ha. The study includes three spacing treatments (different residual densities) and unspaced controls. Fifteen (15) years after harvest, site index and height growth was virtually the same in the spaced and unspaced area. The estimated site index in the spaced areas is 17 m and 18 m in the unspaced control areas. This suggests that the density levels regenerating in this PHR stand (60,000-120,000/ha) were not sufficiently high to induce height-growth repression.

2.7 Site Productivity Impacts on Repression

Many practitioners believe there is an interaction between site quality and stand density relative to the onset of repression. There is nothing in the literature (that we found) documenting this phenomenon (thus suggesting a research need). The belief is that on some lower quality sites – height growth repression occurs at lower densities than on higher quality sites. Without understanding this interaction, we cannot identify a single density level at which fire-origin Pl stands will experience repression.

Thrower (2013) states that anecdotal evidence over many years of observing height-density relationships in Pl suggest that stands growing on areas with relatively high site indices do not show height growth repression. This could be because they are not limited in site resources, or that stands do not regenerate at extremely high densities on high productivity sites. This is true for the sites in TFL 59 that have 10 year’s measurement. The site index for these sites is estimated to be approximately 20 m and no repression has been observed to date with initial densities about 200,000/ha. Other studies (e.g., Blevins *et al*. 2005, Farnden and Herring 2002) have shown that older repressed Pl stands respond very well to fertilizer suggesting that nutrient limitations contribute to repression.

2.8 Density Impacts on Repression

The density level at which fire-origin Pl stands enter repression is not known. Estimates vary among studies and making inference from observed trends is complicated by suspected interactions with site productivity, stand origin (noted above) and other factors.

Mitchell and Goudie (1980) suggested that repression can occur when initial densities exceed 50,000 stems/ha based on their work in fire-origin stands in the Chilcotin. The current study on TFL 59 (Thrower 2013) demonstrates that even very high densities don’t guarantee the onset of repression. This area had 200,000 initial total stems/ha on index 20 and no repression has been observed 10 years after the fire.

By contrast, the Barnes Creek study (Carlson and Johnstone 1983) suggests that repression may occur at lower initial densities. That trial was established to examine the impact of planting density on height and other attributes. Unfortunately, the high density treatments of the experiment were in extremely small plots (2 x 2 m),[1] which has likely resulted in lower site index estimates. In addition the small plots would have a large edge effect. Plots in the Barnes Creek experiment were established with trees planted from 2,500 to 160,000 stems/ha. The data from this trial was used to model repression in TIPSY (Section 2.11). The percentage loss in site index as a function of initial density using the function in TIPSY is shown in Table 4 (Section 2.11). A low level of repression is indicated to start at an initial density of about 20,000 stems/ha; however, this point in the fitted function is very sensitive to the model form and the limited amount of data.

2.9 The Onset of Repression

Mitchell and Goudie (1980) indicate that repression occurs very early in stand development – and in some cases soon after establishment before stands reach 1 – 2 m in height. The amount of repression (as measured by site index loss) also varies with initial stand density, typically increasing as stand density increases.

It is not possible to know if a repression has occurred in a very young stand. One indicator is comparison with nearby areas of different density showing different heights – all growing on the same site and soil conditions. Another indicator is comparing observed height with the height expected at a given age for the site using the SIBEC approach. This is relatively crude but can be useful in some cases. The best estimates for early height growth in Pl are from Nigh and Love (1999) (Table 2). These early top heights can be converted to predict differences in top height at any age as a function of difference in site index (Table 3). For example, if there is a 5 m difference in site index, then stands at age 3 would have an 18 cm difference in top height. The ability to detect these small differences in operational surveys should be tested. Presumably the larger the loss in site index the easier it would be to observe, assuming there is reasonable confidence in the estimate of potential site index.

[1] Estimated reductions in site index can be confounded by the small plot sizes typically used to sample high density stands. In BC top height is defined as the height of the largest diameter suitable tree on a 0.01 ha plot. In theory, using the largest tree from a plot less than 0.01 ha underestimates top height and thus underestimates site index. This confounding must be acknowledged when using site index estimates from small plots.

Table 2. Predicted height (cm) as a function of site index and total age (Nigh and Love 1999). Values in red are extrapolated beyond the data used to fit the equations.

Total								**Site Index (m)**							
Age	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
1	1	1	2	2	3	3	4	4	5	5	5	6	6	7	7
2	3	5	6	8	10	11	13	15	16	18	20	21	23	25	26
3	6	10	13	17	20	24	27	31	34	38	41	45	48	52	55
4	10	16	22	28	33	39	45	51	57	63	68	74	80	86	92
5	15	23	32	41	49	58	67	75	84	92	101	110	118	127	135
6	20	32	44	56	67	79	91	102	114	126	138	149	161	173	185
7	26	41	57	72	87	102	117	133	148	163	178	193	208	224	239
8	33	52	70	89	108	127	146	165	184	203	221	240	259	278	297
9	39	62	85	108	130	153	176	199	222	244	267	290	313	335	358
10	46	73	100	127	154	181	207	234	261	288	315	342	369	395	422
11	54	85	116	147	178	209	240	271	302	333	364	395	426	457	488
12	61	96	132	167	202	238	273	308	344	379	414	450	485	520	556
13	69	108	148	188	227	267	307	346	386	426	465	505	545	584	624
14	76	120	164	208	252	296	340	385	429	473	517	561	605	649	693
15	84	132	181	229	278	326	374	423	471	520	568	617	665	714	762
16	91	144	197	250	303	355	408	461	514	567	620	672	725	778	831
17	99	156	213	270	328	385	442	499	556	613	671	728	785	842	899
18	106	168	229	291	352	414	475	537	598	660	721	783	844	906	967
19	114	179	245	311	377	442	508	574	639	705	771	837	902	968	1034
20	121	191	261	331	400	470	540	610	680	750	820	890	959	1029	1099

Table 3. Predicted difference in height (cm) as a function of total age and difference in site index. Values in red are extrapolated beyond the data used to fit the equations.

Total	**Difference in Site Index (m)**									
Age	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
1	0	1	1	2	2	3	3	4	4	5
2	2	3	5	7	8	10	12	13	15	17
3	4	7	11	14	18	21	25	28	32	35
4	6	12	18	23	29	35	41	47	53	58
5	9	17	26	34	43	52	60	69	77	86
6	12	23	35	47	59	70	82	94	106	117
7	15	30	46	61	76	91	106	121	137	152
8	19	38	57	75	94	113	132	151	170	189
9	23	46	68	91	114	137	159	182	205	228
10	27	54	81	107	134	161	188	215	242	268
11	31	62	93	124	155	186	217	248	279	310
12	35	71	106	141	177	212	247	283	318	353
13	40	79	119	159	198	238	278	317	357	397
14	44	88	132	176	220	264	308	352	396	440
15	48	97	145	194	242	291	339	388	436	484
16	53	106	158	211	264	317	370	423	475	528
17	57	114	172	229	286	343	400	457	515	572
18	61	123	184	246	307	369	430	492	553	615
19	66	131	197	263	329	394	460	526	591	657
20	70	140	210	280	349	419	489	559	629	699

2.10 Impact of Spacing on Repression

Reductions in site index from height growth repression can be mitigated by early spacing. Evidence suggests that the earlier the spacing the greater the mitigation of the site index loss. We believe that if treated very early (e.g., when trees are 30 – 50 cm tall), that most or all of the potential site index loss can be avoided. In contrast, evidence suggests that spacing later in stand development may have little or no impact on releasing stands from height growth repression. JS Thrower (1993) reported some indications of reducing the impacts of repression (as measured through site index) in two of three spaced approximately 30-year old fire-origin Pl stands. Farnden and Herring (2002) also found differing results of trees responding to additional space relative to their age and years in repression.

Mitchell and Goudie (1980) showed a dramatic difference in height between trees within 30-40 cm of the road edge and trees further into the stand (approximately 5 m versus 1-2 m at age 18). The trees on the road edge had the additional space (and resources) from regeneration forward. In contrast, Farnden and Herring (2002) reported for the same site, that 20 years after a strip thinning that occurred when the stand was 17 years old, that "*there is no height growth evidence from this trial to suggest the best edge trees have a competitive advantage over the best trees in the middle of the residual strip*." Work by Reid *et al.* (2003, 2004) suggests that physiological differences that develop over time in repressed trees may contribute to the limited response to spacing

2.11 Repression As Modelled in TIPSY

Repression is currently modeled in TIPSY as a loss in site index a function of initial density. The site index reduction was modelled using data the Barnes Creek study (Carlson and Johnstone 1983). The function estimates the loss in site index as a function of initial square spacing (Figure 1). The percent loss (Table 4) was determined by dividing realized site index by the maximum (plateau) in the original fitted equation (approximately 22 m -Figure 1). Stems/ha equivalents for the various levels of square spacing are shown in Table 5. Farnden and Herring (2002) also fit site index as a function of the stand density at total age 19. It is shown here to compare with the TIPSY equation (Figure 1).

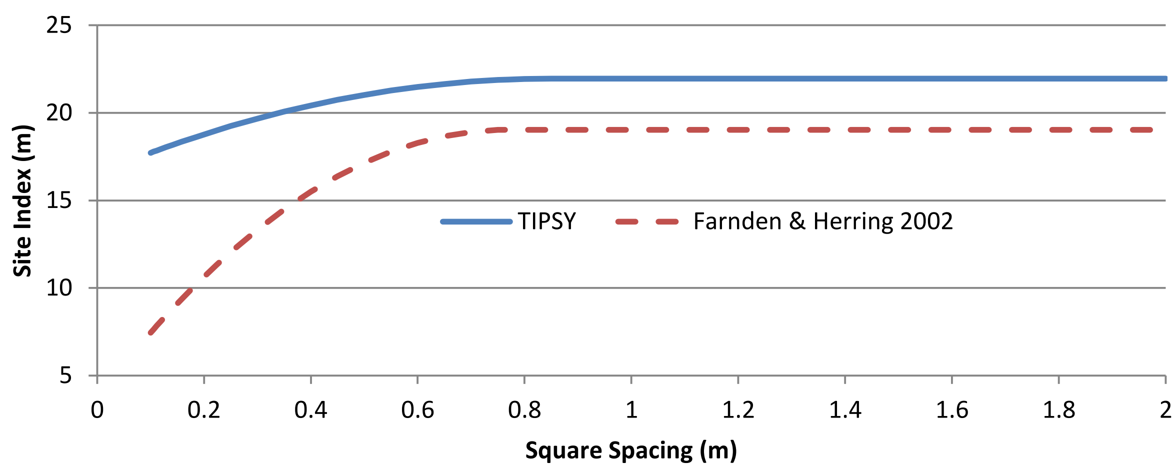


Figure 1. Site index as a function of **initial** square spacing as used in TIPSY, and square spacing at **19 years after** fire establishment from Farnden and Herring (2002).

Table 4. Site index loss in TIPSY as a function of initial density. Estimates in red below the line are extrapolations.

Density (stems/ha)	Site Index Loss
15,000	0%
20,000	1%
25,000	2%
50,000	6%
75,000	8%
100,000	10%
150,000	12%
200,000	13%
300,000	15%
400,000	16%
500,000	17%

Table 5. Stems/ha and square spacing equivalents.

Stems/ha	Square Spacing (m)
10,000	1.00
30,000	0.58
50,000	0.45
100,000	0.32
200,000	0.22
300,000	0.18
400,000	0.16
500,000	0.14

Assuming the initial stand densities in the Farnden - Herring study were higher than those measured in 1980 (19 years after the 1961 fire), the curve should be shifted to the left an unknown amount to make it comparable to the TIPSY function. The Farnden-Herring curve begins to show a slight decrease in site index at about 17,000/ha (square spacing approximately 0.77 m) indicating this is where low levels of repression begin (compared to low levels of repression starting at 14,000/ha in the TIPSY function). Shifting the Farnden-Herring curve to the left would make this point occur at a lower square spacing (a higher density). The Farnden-Herring curve also bends more steeply, suggesting pronounced repression at the higher densities (lower square spacings). The limited data from these two studies demonstrates the variability in the amount of repression and densities where it may occur.

Translating the predicted percentage losses in site index to absolute losses using both the TIPSY function and the Farnden and Herring (2002) function results in the values shown in Table 7 and Table 6. Note that the Farnden and Herring predictions are adjusted to reflect initial total stand density. This was done by assuming an annual survival rate of 97% that has been observed in other trials (Johnstone and van Thienen 2004, Thrower 2013). These results show that approximately 87,500 and 110,000 initial total stems/ha for site indices 22 and site 19 respectively (the approximate site indices of the two trials), are predicted as the densities where a 2 m site index loss occurs. The results on these sites are contrasted by the current study on TFL 59 (Thrower 2013) that is approximately site index 20 with 200,000 initial total stems and no repression indicated 10 years after the fire.

Table 7. Absolute site index losses (m) predicted by TIPSY function by total initial stems/ha for potential site index 22 (the approximate site index of the Barnes Creek site).

Total Initial Stems/ha	Site Index Loss (m)
10,000	0.0
25,000	0.4
50,000	1.2
75,000	1.8
100,000	2.2
150,000	2.6
200,000	3.0
300,000	3.4
400,000	3.6
500,000	3.8

Table 6. Absolute site index losses (m) predicted by Farnden and Herring 2002 function (adjusted to initial stand density) by total initial stems/ha for potential site index 19 (the approximate site index of the Fish Lake site).

Total Initial Stems/ha	Site Index Loss (m)
10,000	0.2
25,000	0.5
50,000	0.9
75,000	1.4
100,000	1.8
150,000	2.7
200,000	3.5
300,000	5.0
400,000	6.3
500,000	7.5

2.12 POST SPACING DENSITY

There has traditionally been vigorous debate in BC over the appropriate level of trees to leave after spacing. Previous thinking of many practitioners was to maximize tree diameter and piece size by spacing to relatively low densities. Now it is more generally accepted that higher post-spacing densities are preferred to provide a buffer for unexpected future mortality (e.g., for forest future or climate change concerns) and to improve wood quality and increase stand value. The poor wood quality found in stands previously spaced to 1200 stems/ha is illustrated in Figure 2.

Figure 2. Example of a Pl stand spaced to 1200 stems/ha. Note the large branches on the lower bole.

Several studies have shown the Pl branch size increases and wood quality decreases as stand density decreases (e.g., Ballard and Long 1988, Johnstone and Pollack 1990, Middleton et al. 1995, JS Thrower 1999). To address wood quality and forest health issues post-spacing densities are being targeted in the 3,000 – 5,000/ha range when manual spacing is employed. Higher post-spacing densities are difficult to achieve in practice because the narrow distance between trees makes it difficult for people to move through the stand with brush saws or chain saws.

Manual spacing is difficult, time-consuming and expensive in very dense stands. Mechanical or chemical strip spacing is efficient in very high density stands but can leave high stand densities in the leave strips. If the width of the spaced and leave strips are the same, the treatment is effectively removing half the trees. So if starting with 500,000/ha, strip spacing still leaves 250,000/ha (or more precisely 500,000/ha on one-half the area and none on the other one-half).

There is very little research on the response of the trees on the edges of strips as opposed to the center. In theory, if stands are strip spaced early and the edge trees respond (grow at a non-repressed rate), there may not be a need for additional treatments. This is an area that warrants future study, as the cost of the second spacing to get down to 3,000 – 5,000 stems/ha is typically significantly more than the first treatment.

2.13 SUMMARY

While there have been numerous studies over the past 30 years on repression in fire-origin Pl stands, there still remains a significant lack of information needed to make informed decisions about repression density treatments. The key points are:

- Repression has been commonly observed in high density fire-origin Pl stands, and much more infrequently in very high density fire-origin Lw stands.
- Repression has not been observed in high density fire-origin Fd.
- Repression has not been observed in high density PHR stands of any species.
- Lw, if established early, has rapid early height growth and will generally overtop and dominate other species.
- Repressed Pl stands grow and develop in a similar manner to unrepressed stands but at a slower rate.
- Repression can be modelled as a loss in site index.
- The magnitude of repression varies with initial stand density and site quality.
- Evidence suggests that the earlier the treatment of repression the greater the mitigation of the site index loss.
- There is not sufficient information to predict absolute values at which repression occurs in fire-origin Pl stands. Therefore, practitioners should acknowledge this uncertainty in decisions regarding treatments of repressed and potentially repressed stands.

3. FINANCIAL ANALYSIS METHODS

3.1 Objective

One objective of this project is to revise the FFT silviculture funding criteria to identify stands in repression or likely to go into repression where spacing treatments could provide a positive return on investment. The primary objective of the financial analysis was to develop simple tools that would provide the information necessary to meet this stated project objective.

3.2 Overview

Repression is modelled as a loss in site index. The primary benefit of treating repressed stands is to realize as much of the actual site potential as possible. This results in faster growth rates and reduced rotation lengths. There is limited information on the actual losses in site index so the approach taken was to determine how much money could be spent to gain back the site potential.

The financial analysis tools are designed to answer the question "what is the maximum treatment cost that can be incurred to result in the treatment having a site value equal to or greater than the no treatment option at a 2% discount rate?" With these values informed treatment decisions can be made using a risk analysis approach that utilizes treatment costs, a range of estimated gains in site index, and the potential for forest health losses.

3.3 Growth and Yield Simulations

All growth and yield simulations were done with TASS II. The matrices of runs completed for Pl stands along with the model inputs used are summarized in Table 8, Table 9, and Table 10. Seven spacing options were simulated:

1. Patch 2
    a. Strip spacing in a cross-hatched pattern 2 x 2 m when the top height trees are 30 cm tall (Figure 3).
    b. Leave patches are also 2 x 2 m.
2. Patch 2.7
    a. Strip spacing in a cross-hatched pattern 2.7 x 2.7 m when the top height trees are 30 cm tall.
    b. Leave patches are also 2.7 x 2.7 m
3. Patch 2 + Brushsaw
    a. The Patch 2 treatment plus additional spacing with the top height trees are 1.3 m tall.
    b. The treatment is done to leave five small clumps of trees in each of the 2 x 2 m leave patches from the first spacing. These five small clumps are in the pattern of five on a dice (Figure 4).
    c. This is done by taking a 67 x 67 cm square out of the center of each of the 2 x 2 m leave patches.
4. Patch 2.7 + Brushsaw
    a. The Patch 2.7 treatment plus additional spacing with the top height trees are 1.3 m tall.

   b. The treatment is done to leave five small clumps of trees in each of the 2.7 x 2.7 m leave patches from the first spacing. These five small clumps are in the pattern of five on a dice.
   c. This is done by taking a 90 x 90 cm square out of the center of each of the 2.7 x 2.7 m leave patches.
5. Strip 2.7 30 cm
   a. Strip spacing in rows, leaving strips 2.7 m wide and clearing 2.7 m strips in between.
   b. Done when the top height trees are 30 cm tall.
6. Strip 2.7 2 m
   a. Strip spacing in rows, leaving strips 2.7 m wide and clearing 2.7 m strips in between.
   b. Done when the top height trees are 2 m tall.
7. Traditional
   a. Traditional manual spacing down to 4,000 stems/ha when the top height trees are 2 m tall.

The TASS outputs included total and merchantable volumes/ha, stems/ha, top height, predominant height, basal area/ha, and quadratic mean diameter.

Table 8. TASS II run matrix for pure Pl high density stands.

Variable	**Levels**	**# of Levels**
Species	Pl	1
Site Index	7 - 24 in steps of 1 m	15
Initial Density	100,000 stems/ha	1
Regeneration	Natural	1
Spatial	Random	1
Temporal	All trees regenerate in year 1 to mimic fire origin	1
Spacing	None, patch 2, patch 2 + brushsaw, patch 2.7 + brushsaw, patch 2.7, strip 2.7 30 cm, strip 2.7 2 m, traditional	8
Reps		5
OAFs	OAF1 = 0.85, OAF2 = 0.95	1
Total Runs		720

Note that five repetitions (reps) of the TASS runs for the high density Pl runs were completed. There are a number of stochastic components in TASS that draw random numbers from some statistical distribution. Examples are drawing the tree coordinates for random distributions used to mimic regeneration patterns or the random assignment of genetic variability to individual trees. These factors can vary from one simulation to the next and affect the output statistics. The results of the five reps for each simulated scenario are averaged for analysis and reporting.

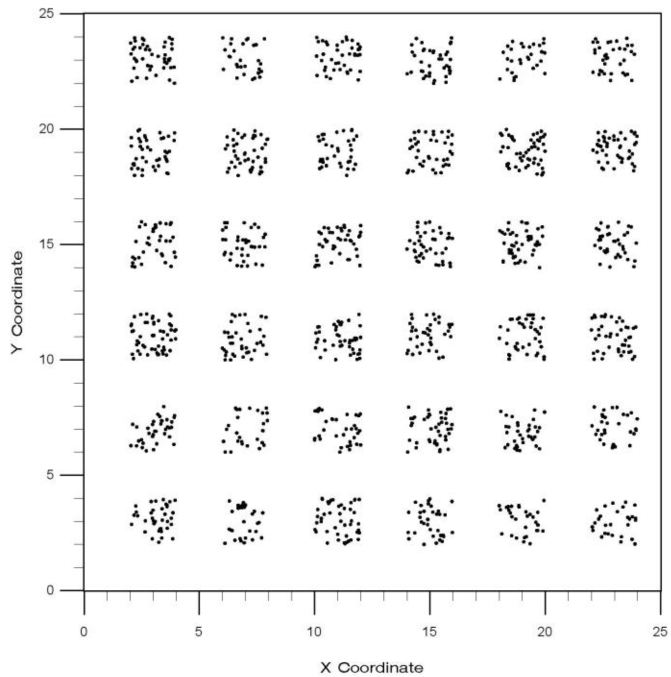


Figure 3. Pattern of leave trees after chemical strip thinning. Approximately 24,000 trees/ha remaining.

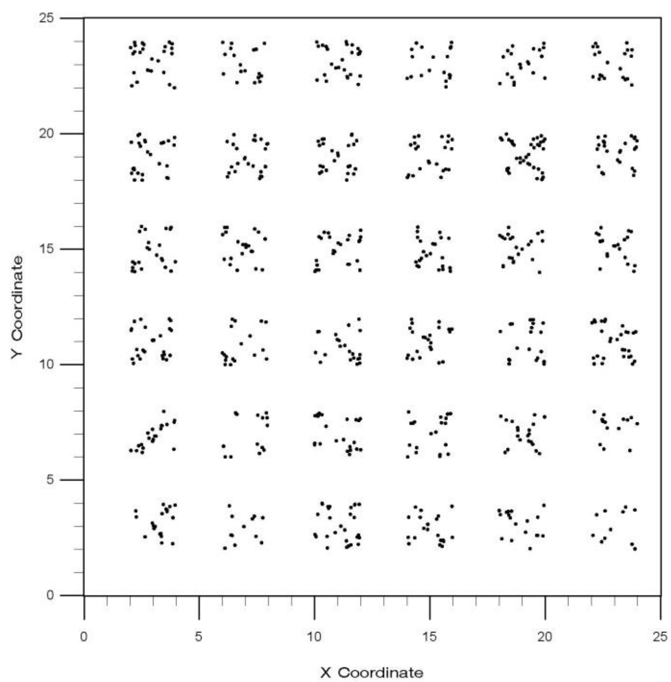


Figure 4. Pattern of leave trees after chemical strip thinning plus brushsaw thinning. Approximately 12,600 trees/ha remaining.

Table 9. TASS II run matrix for pure Pl future stands.

Variable	Levels	# of Levels
Species	Pl	1
Site Index	7 - 24 in steps of 1 m	18
Planting Density	1,600 stems/ha	1
Natural Density	1,000 stems/ha	1
Spatial	Planted - square, Naturals - random	1
Reps		1
OAFs	OAF1 = 0.85, OAF2 = 0.95	1
Total Runs		18

Table 10. TASS II run matrix for Pl and Lw fire-origin stands.

Variable	Levels	# of Levels
Species	Pl, Lw	1
Site Index	Pl 20, Lw 21.1	1
Pl Density	50,000 stems/ha	1
Lw Density	4,000 stems/ha	1
Spatial	Random	1
Temporal	All trees regenerate in year 1 to mimic fire origin	1
Reps		1
OAFs	OAF1 = 0.85, OAF2 = 0.95	1
Total Runs		1

3.4 BUCKING SIMULATION

The TASS simulated trees were bucked into logs using a 30 cm stump and 10 cm top diameter. Logs lengths were based on a preferred nominal length of 16’ with shorter logs bucked at 2’ increments to a minimum of 8’. A trim allowance of 4” was used for all logs. The last portion of the merchantable tree length (from the top of the last log to the 10 cm diameter merchantable limit) was retained to reconcile tree and log volume.

These bucking procedures reflect how most trees in the interior are currently manufactured into sawlogs (proportionately the highest use of interior logs).

3.4.1 Log Quality Classes

All simulated stands were of sufficiently high densities to assume that branch size (large branches in lower density stands) would not be a significant factor in determining log quality. Logs were assigned to quality classes (low, medium, high) based on the following logic:

1. If the log is the top (last or only) log in the tree it is low quality.

2. If the tree has two logs then the first log is medium quality in spaced stands and high quality in unspaced stands.
3. If the tree has three logs then the first log is high quality and the second log is medium quality.
4. If the tree has four or five logs then logs 1 and 2 are high quality, and the remainder below the top log are medium.
5. If the number of logs is six or greater then logs 1, 2, and 3 are high quality, and the remainder below the top log are medium.
6. If the log is 50% or more within the live crown the log quality class is reduced by one.

3.5 Site Value Analyses

Site value (SV)[2] analyses were used to rank silviculture treatment opportunities. The standard way of calculating SV results in it being the present value of all cash flows produced by an infinite series of identical rotations. SV differs from the NPV of a single rotation because SV recognizes the cost of prolonging the start of the next rotation, while NPV of a single rotation does not. For this analysis it was assumed that whether or not a high density natural stand was spaced, that after harvest it would be regenerated with a combination of planting (1600 trees/ha) plus 1000 naturals. Furthermore, it was assumed that the stand would continue to be managed under this planted plus natural regime infinitely into the future. This slightly modified approach to calculate SV is used as it does not make sense to assume an infinite series of high density naturally regenerated stands, particularly when most of these high density stands are fire origin. Details of SV and NPV calculations are presented in Appendix I.

3.6 Revenue and Cost Assumptions

3.6.1 Discount rate

The FFT prescribed discount rate of 2% was used to evaluate spacing treatments.

3.6.2 Silviculture costs

Survey costs were fixed at $20/ha and assumed to occur at year 1. Planting costs for the future stands were assumed to be $850 per hectare to plant 1600 trees.

[2] Site value is also referred to as bare land value, soil expectation value and land expectation value.

3.6.3 Log values

Log values are assigned using the log sorts in Table 11.

Table 11. Log sorts and values.

<table>
<tr><th colspan="2">Log Size Class</th><th colspan="3">Log Quality Class</th></tr>
<tr><th colspan="2">Top Diam (in)</th><th>Low</th><th>Medium</th><th>High</th></tr>
<tr><td>Small</td><td>4.1 - 6.0</td><td>Small Utility (SL-US)
($50/m³)</td><td>Small Sawlog (SL-Sm)
($65/m³)</td><td>High Quality Small Sawlog
(SL-HQ)
($80/m³)</td></tr>
<tr><td rowspan="3">Medium</td><td>6.1 – 8.0</td><td rowspan="6">Utility Sawlog
(SL-Ut)
($55/m³)</td><td rowspan="6">Standard Sawlog
(SL-St)
($70/m³)</td><td rowspan="3">Standard Peeler
(PL-St)
($90/m³)</td></tr>
<tr><td>8.1 – 10.0</td></tr>
<tr><td>10.1 – 12.0</td></tr>
<tr><td rowspan="3">Large</td><td>12.1 - 14</td><td rowspan="3">Peeler Large
(PL-Lg)
($95/m³)</td></tr>
<tr><td>14.1 – 16.0</td></tr>
<tr><td>16.1 – 18.0</td></tr>
<tr><td rowspan="3">Oversize</td><td>18.1 – 20.0</td><td rowspan="3">Oversize Utility
(OS-Ut)
($60/m³)</td><td rowspan="3">Oversize Sawlog
(OS-SL)
($70/m³)</td><td rowspan="3">Oversize Peeler
(OS-PL)
($90/m³)</td></tr>
<tr><td>20.1 – 22.0</td></tr>
<tr><td>22.1 +</td></tr>
</table>

3.6.4 Harvest and road building costs

Road building costs were estimated as \$150 per hectare. Harvesting costs (\$/m^3) (Figure 5) were estimated as:[3]

Merch volume ≥ 100 and < 150 m^3/ha: $Cost\ (\$/m^3) = -0.07 \times MVol + 32.32$

Merch volume ≥ 150 and ≤ 400 m^3/ha: $Cost\ (\$/m^3) = -0.01 \times MVol + 23.33$

Merch volume > 400 m^3/ha: $Cost\ (\$/m^3) = 18$

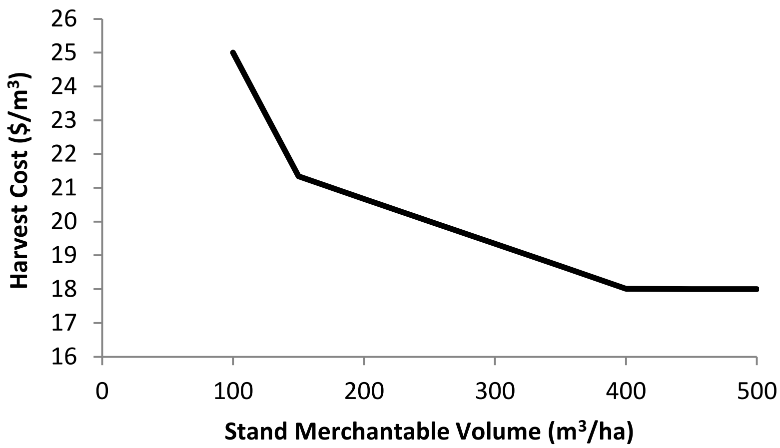


Figure 5. Harvesting costs (\$/m^3) as a function of merchantable volume (m^3/ha).

[3] These cost estimates were developed by Jim Thrower through discussions with logging contractors in the BC interior using modern equipment in the stand types similar to those simulated in this project. These estimates were reviewed and confirmed by Deric Manning (Logging supervisor Weyerhaeuser Company Ltd.).

4. FINANCIAL ANALYSIS RESULTS

4.1 GROWTH AND YIELD SIMULATIONS

4.1.1 Pure Pl Stands

Example output from the TASS simulations is shown in Figure 6 and Figure 7. Both figures show merchantable volume (12.5 cm dbh limit with no OAFs) versus stand age for various combinations of treatments and site indices. It is important to note that the strip and patch thinning reduced merchantable volume for a given site index (Figure 6). The primary benefit of any successful repression density treatment is increasing the growth rates and shortening the rotation length by moving to a higher site index (Figure 7, Figure 8). If a spaced stand was not actually repressed, the strip and patch spacing will reduce the merchantable volume and the site value (Figure 6).

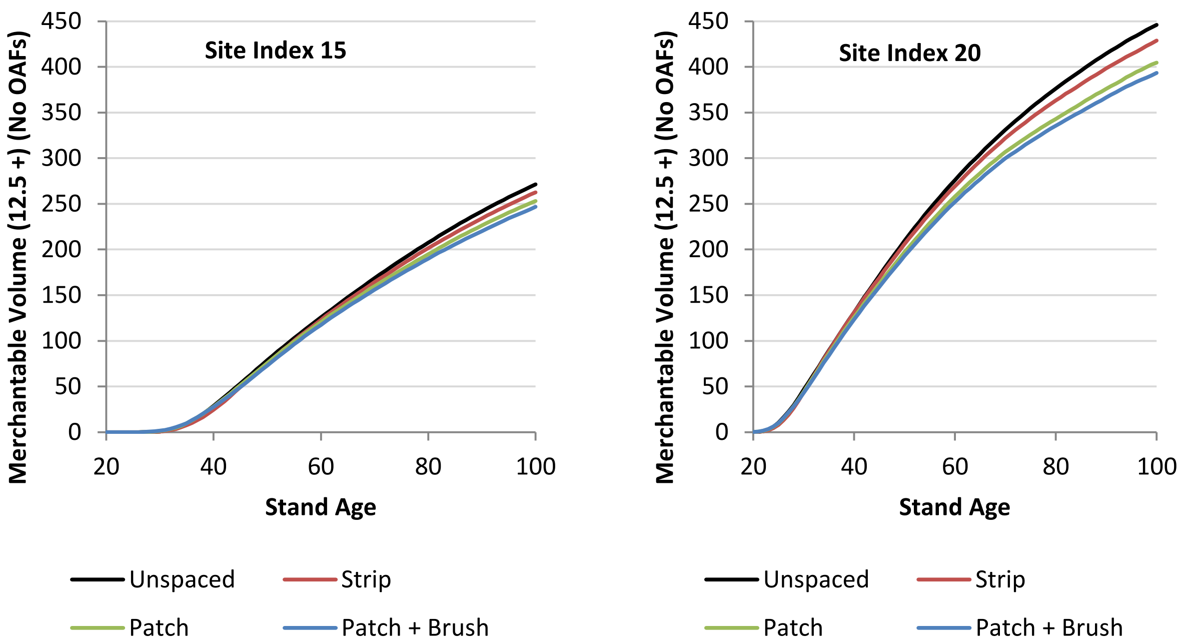


Figure 6. Merchantable volumes (12.5+, no OAFs) versus age for site index 15 (left) and site index 20 (right). All stands with an initial densities of 100,000 stems/ha.

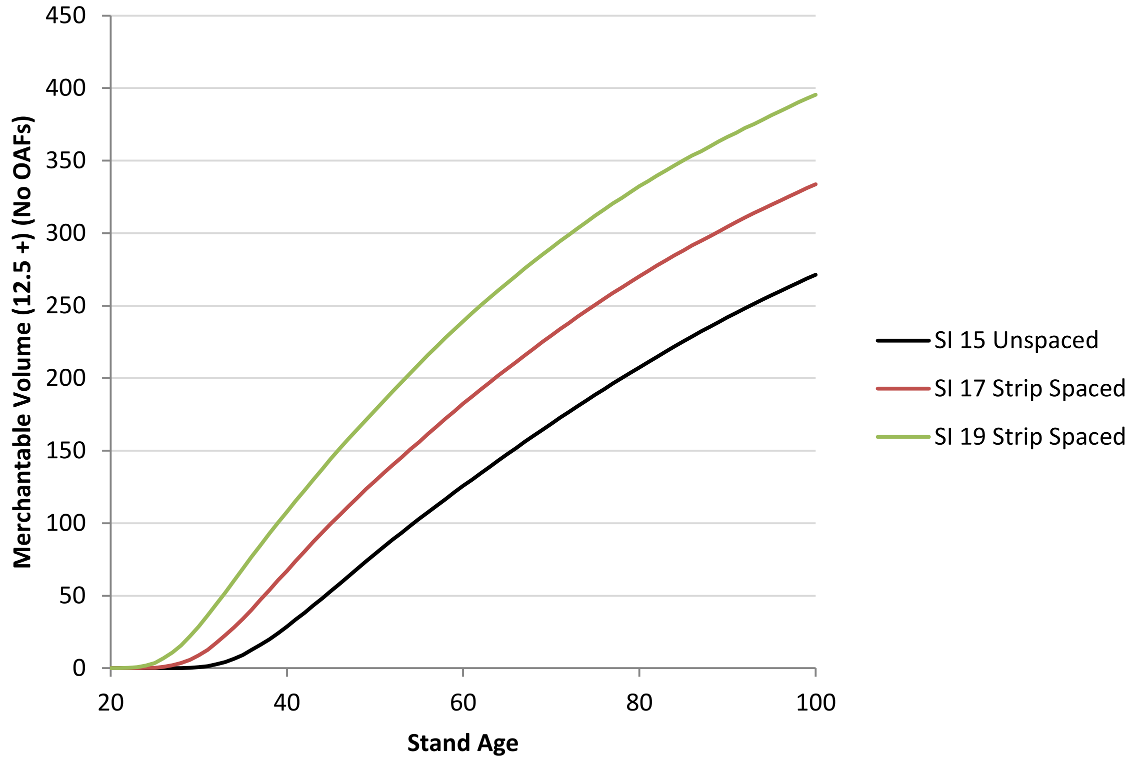
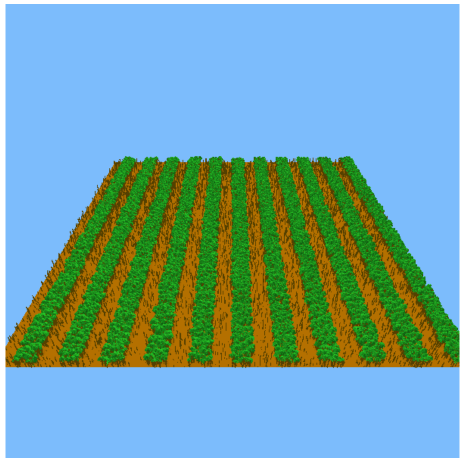


Figure 7. Merchantable volumes (12.5+, no OAFs) versus age for site index 15 unspaced compared to site index 17 and 19 strip spaced.

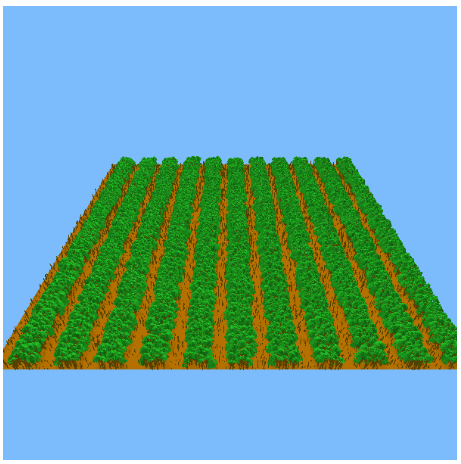
4.1.2 Pl – Lw Mixture

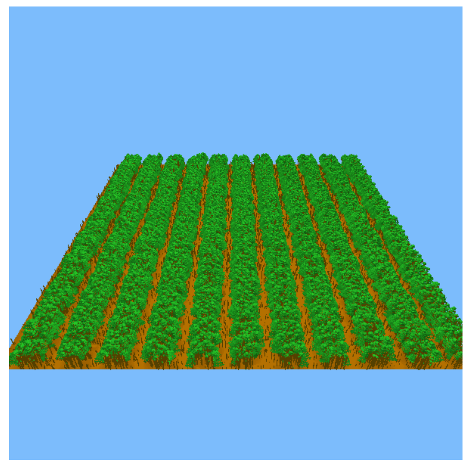
An example of TASS II output from a simulated Pl – Lw mixture is shown in Figure 9. Despite initial densities of 50,000 Pl and 4,000 Lw (93% Pl, 7% Lw), the Lw takes over the site. This results from the faster height growth of Lw and the shade intolerance of Pl. This simulation is used to illustrate the expected outcome of a stand with a small percentage Lw in a high density Pl.



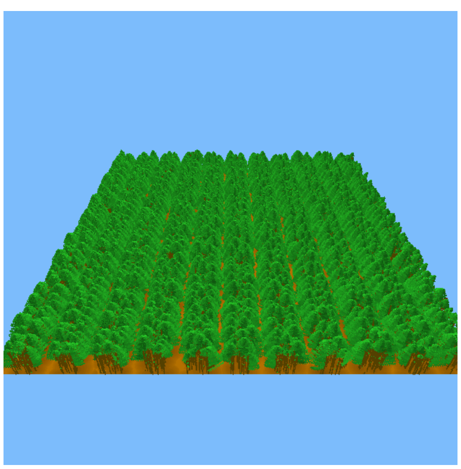
Stand Growing at site index 10 m strip spaced at 2 m top height

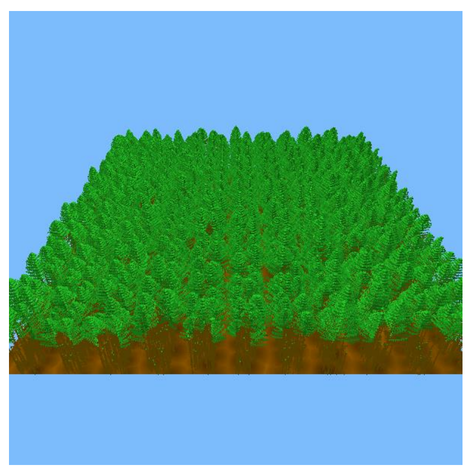
Continues growing at site index 10 Is Released and grows at site index 20





4 years after spacing





20 years after spacing

Figure 8. Growth of a 100,000 stems/ha Pl stand strip spaced at 2 m top height. Initially growing at site index 10 m. Images on the left show how the stand would grow if it continued at site index 10. Images on the right show if repression is removed and stand grows at site index 20.

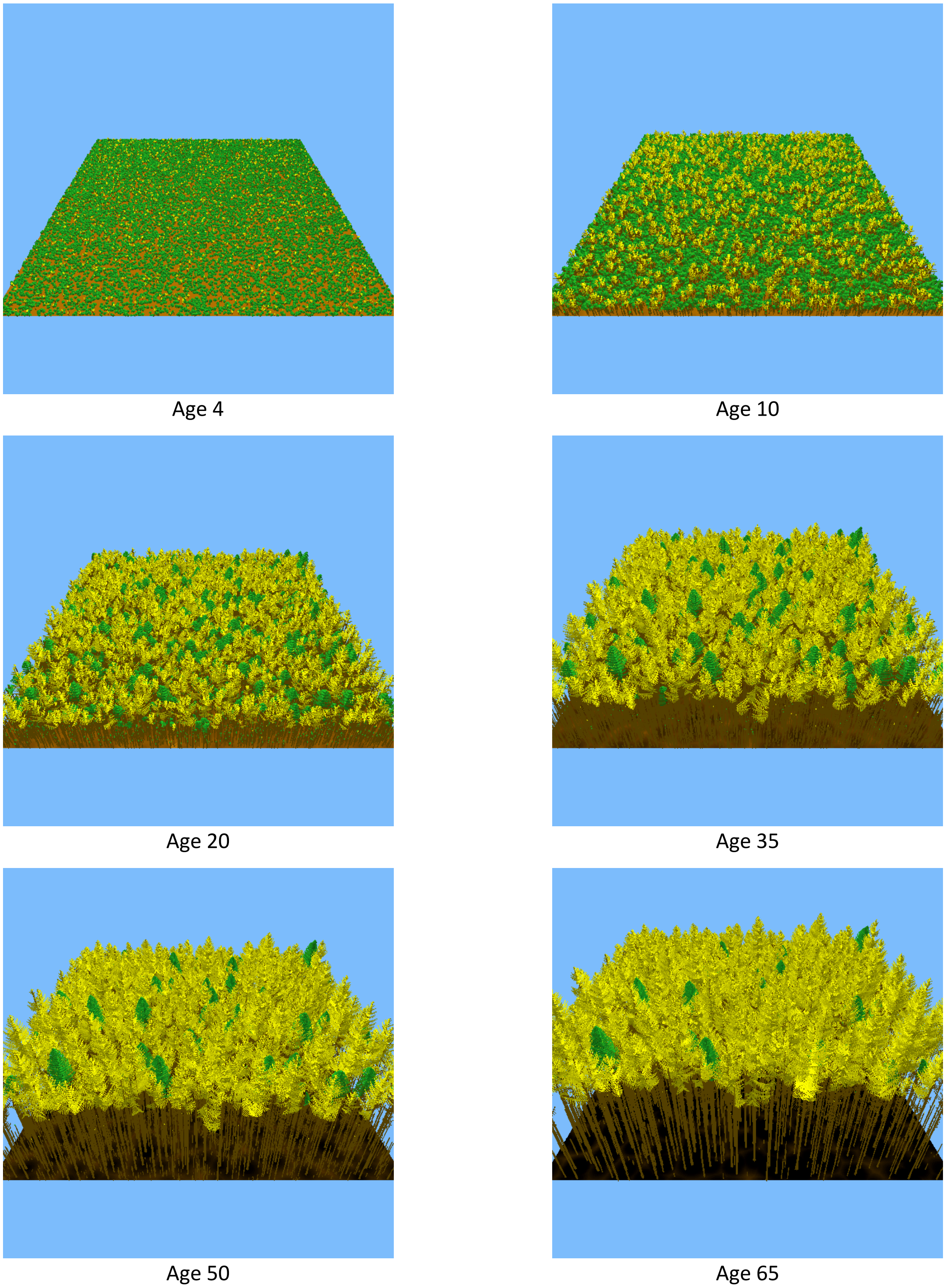


Figure 9. TASS II projection of a Pl – Lw stand. Initial densities of 50,000 Pl and 4,000 Lw (random spatial distributions, all regenerating in year 1). Pl site index 20 and Lw site index 21.1 (from Nigh's conversion equation).

4.2 Breakeven Treatment Costs

Breakeven costs are a function of the realized site index after treatment, and the site index lost due to repression if the stand is not treated. Breakeven costs represent the maximum amount that can be spent on a treatment to provide a positive return at 2%.

Breakeven treatment costs are provided for the seven spacing treatments simulated. There are two tables for each treatment (Table 12 - Table 25). Both tables have the same information; it is presented in a different format to allow for ease of use depending on the interpretation required. The first table presented for each treatment shows the breakeven costs by the site index after treatment and the site index loss if the stand is not treated. This allows for a quick review of how much repression is required to justify different treatment costs. In these first tables, the column headed by a site index loss of zero shows what could be spent on the treatment if no site index gain was expected. These values are predominantly negative. This indicates that treating a stand without realizing any subsequent gain in site index will actually devalue the stand. This must be recognized as a risk when making treatment decisions. In the second table for each treatment the breakeven costs are presented by site index before and after treatment. This allows for a quick assessment of how much can be invested if the current (pre-treatment) and expected (potential) site index after treatment are known.

The following is an example of how to interpret the values in the Tables.

- Assume the potential site index is 19 m.
- Assume the current stand is growing at a rate which indicates a site index of 14 m.
- If a strip 2.7 m at 2 m treatment is believed to move the stand to a site index 17 (alleviate a loss of 3 m) then one can afford to spend $600/ha. This value is found in Table 22 by finding the row for 17 in the first column and going to the column labeled 3. Alternatively it can be found in Table 23 by going to the row labelled 17 and the column labelled 14.
- Note the fact that the potential site index is 19 m does not factor into the decision[4]. The key information is where the stand is starting and what the treatment will move it to.
- Now consider the Patch 2 treatment moving the stand from site index 14 to 16. One can only afford to spend up to $100 on this treatment if that is the gain expected (Table 12, Table 13). However, if the Patch 2 + brushsaw treatment is expected to move the stand from 14 to 19 then one can afford to spend a total of $1,200/ha (Table 14, Table 15).

A comparison of Table 12 and Table 14 (Patch 2 treatment and Patch 2 + Brushsaw treatment) shows that for the same site index gain (loss alleviated) one can afford to spend less money on the Patch 2 + Brushsaw treatment than the Patch 2 treatment alone. Assume the site index after treatment will be 19 and the site index before treatment is 14 (loss of 5 m). For the Patch 2 treatment one can spend $1,500/ha and for the Patch 2 + Brushsaw treatment one can spend $1,200/ha. The reason for this is

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[4] The potential site index will be included in future analyses. Preliminary results show that one can afford to spend more money on more productive sites to move a stand from site index "X" to site index "Y". This results in the values in the tables being conservative. For example, one could spend more money to move a stand from SI 12 to SI 18 if the potential SI was 22 as compared to 18. The reason for this is the higher value of the future stand that can be obtained on the more productive site.

the Patch 2 + Brushsaw treatment results in a lower merchantable volume that the Patch 2 treatment (Figure 6, Figure 7), so there is less “pay back” from the Patch 2 + Brushsaw treatment for stands growing on the same site index. The reason one would do the Patch 2 + Brushsaw treatment over the Patch 2 treatment alone is to further alleviate site index losses, and therefore gain additional merchantable volume and stand value.

Table 12. Breakeven costs for Patch 2 treatment – by site index loss if not treated and site index after treatment.

Site Index	**Site Index Loss (m) due to repression if not treated**																
After Trtmt	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
15	-$500	-$200	$100	$400	$700	$900	$1,100	$1,200									
16	-$600	-$200	$100	$500	$800	$1,000	$1,300	$1,400	$1,600								
17	-$700	-$200	$200	$500	$900	$1,200	$1,500	$1,700	$1,900	$2,100							
18	-$700	-$200	$200	$600	$1,000	$1,300	$1,700	$2,000	$2,200	$2,400	$2,600						
19	-$700	-$200	$200	$600	$1,100	$1,500	$1,800	$2,200	$2,500	$2,800	$3,000	$3,200					
20	-$800	-$300	$200	$700	$1,100	$1,600	$2,000	$2,400	$2,700	$3,000	$3,300	$3,600	$3,800				
21	-$900	-$300	$200	$700	$1,200	$1,600	$2,100	$2,600	$3,000	$3,300	$3,700	$4,000	$4,300	$4,500			
22	-$900	-$300	$200	$800	$1,300	$1,800	$2,200	$2,700	$3,200	$3,600	$4,000	$4,300	$4,700	$5,000	$5,200		
23	-$900	-$300	$300	$800	$1,400	$1,900	$2,400	$2,800	$3,400	$3,800	$4,200	$4,700	$5,000	$5,400	$5,800	$6,000	
24	-$1,000	-$400	$200	$800	$1,400	$1,900	$2,400	$2,900	$3,400	$3,900	$4,400	$4,900	$5,300	$5,700	$6,100	$6,500	$6,800

Table 13. Breakeven costs for Patch 2 treatment – by site index before and after treatment.

Site Index	**Site Index Before Treatment**																
After Trtmt	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
15	$1,200	$1,100	$900	$700	$400	$100	-$200	-$500									
16	$1,600	$1,400	$1,300	$1,000	$800	$500	$100	-$200	-$600								
17	$2,100	$1,900	$1,700	$1,500	$1,200	$900	$500	$200	-$200	-$700							
18	$2,600	$2,400	$2,200	$2,000	$1,700	$1,300	$1,000	$600	$200	-$200	-$700						
19	$3,200	$3,000	$2,800	$2,500	$2,200	$1,800	$1,500	$1,100	$600	$200	-$200	-$700					
20	$3,800	$3,600	$3,300	$3,000	$2,700	$2,400	$2,000	$1,600	$1,100	$700	$200	-$300	-$800				
21	$4,500	$4,300	$4,000	$3,700	$3,300	$3,000	$2,600	$2,100	$1,600	$1,200	$700	$200	-$300	-$900			
22	$5,200	$5,000	$4,700	$4,300	$4,000	$3,600	$3,200	$2,700	$2,200	$1,800	$1,300	$800	$200	-$300	-$900		
23	$6,000	$5,800	$5,400	$5,000	$4,700	$4,200	$3,800	$3,400	$2,800	$2,400	$1,900	$1,400	$800	$300	-$300	-$900	
24	$6,800	$6,500	$6,100	$5,700	$5,300	$4,900	$4,400	$3,900	$3,400	$2,900	$2,400	$1,900	$1,400	$800	$200	-$400	-$1,000

Table 14. Breakeven costs for the Patch 2 + brushsaw treatment – by site index loss if not treated and site index after treatment.

Site Index	**Site Index Loss (m) due to repression if not treated**																
After Trtmt	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
15	-$600	-$300	$100	$300	$600	$800	$1,000	$1,100									
16	-$700	-$300	$0	$400	$700	$900	$1,100	$1,300	$1,400								
17	-$800	-$300	$0	$400	$700	$1,000	$1,300	$1,500	$1,700	$1,800							
18	-$800	-$400	$0	$400	$800	$1,200	$1,500	$1,800	$2,000	$2,200	$2,300						
19	-$900	-$400	$100	$500	$900	$1,200	$1,600	$1,900	$2,300	$2,500	$2,700	$2,800					
20	-$1,000	-$400	$100	$600	$1,000	$1,400	$1,800	$2,100	$2,500	$2,800	$3,000	$3,300	$3,400				
21	-$1,100	-$500	$0	$600	$1,000	$1,500	$1,900	$2,300	$2,700	$3,100	$3,400	$3,600	$3,900	$4,100			
22	-$1,100	-$500	$0	$600	$1,100	$1,600	$2,000	$2,400	$2,800	$3,300	$3,700	$4,000	$4,300	$4,600	$4,700		
23	-$1,200	-$600	$0	$600	$1,100	$1,600	$2,100	$2,600	$3,000	$3,400	$3,900	$4,300	$4,700	$4,900	$5,300	$5,400	
24	-$1,200	-$600	$0	$600	$1,200	$1,700	$2,200	$2,700	$3,200	$3,600	$4,100	$4,500	$5,000	$5,400	$5,700	$6,000	$6,200

Table 15. Breakeven costs for the Patch 2 + brushsaw treatment – by site index before and after treatment.

Site Index	**Site Index Before Treatment**																
After Trtmt	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
15	$1,100	$1,000	$800	$600	$300	$100	-$300	-$600									
16	$1,400	$1,300	$1,100	$900	$700	$400	$0	-$300	-$700								
17	$1,800	$1,700	$1,500	$1,300	$1,000	$700	$400	$0	-$300	-$800							
18	$2,300	$2,200	$2,000	$1,800	$1,500	$1,200	$800	$400	$0	-$400	-$800						
19	$2,800	$2,700	$2,500	$2,300	$1,900	$1,600	$1,200	$900	$500	$100	-$400	-$900					
20	$3,400	$3,300	$3,000	$2,800	$2,500	$2,100	$1,800	$1,400	$1,000	$600	$100	-$400	-$1,000				
21	$4,100	$3,900	$3,600	$3,400	$3,100	$2,700	$2,300	$1,900	$1,500	$1,000	$600	$0	-$500	-$1,100			
22	$4,700	$4,600	$4,300	$4,000	$3,700	$3,300	$2,800	$2,400	$2,000	$1,600	$1,100	$600	$0	-$500	-$1,100		
23	$5,400	$5,300	$4,900	$4,700	$4,300	$3,900	$3,400	$3,000	$2,600	$2,100	$1,600	$1,100	$600	$0	-$600	-$1,200	
24	$6,200	$6,000	$5,700	$5,400	$5,000	$4,500	$4,100	$3,600	$3,200	$2,700	$2,200	$1,700	$1,200	$600	$0	-$600	-$1,200

Table 16. Breakeven costs for the Patch 2.7 treatment – by site index loss if not treated and site index after treatment.

Site Index	**Site Index Loss (m) due to repression if not treated**																
After Trtmt	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
15	-$500	-$200	$100	$400	$700	$900	$1,100	$1,200									
16	-$600	-$200	$100	$500	$800	$1,000	$1,300	$1,400	$1,600								
17	-$700	-$300	$200	$500	$800	$1,100	$1,400	$1,700	$1,900	$2,000							
18	-$700	-$300	$200	$600	$1,000	$1,300	$1,600	$1,900	$2,200	$2,400	$2,500						
19	-$800	-$200	$200	$600	$1,100	$1,400	$1,800	$2,100	$2,400	$2,700	$2,900	$3,100					
20	-$800	-$300	$200	$700	$1,100	$1,600	$2,000	$2,300	$2,700	$3,000	$3,300	$3,500	$3,700				
21	-$900	-$300	$200	$800	$1,200	$1,700	$2,100	$2,600	$2,900	$3,300	$3,700	$4,000	$4,200	$4,500			
22	-$900	-$300	$200	$800	$1,300	$1,800	$2,200	$2,700	$3,200	$3,600	$3,900	$4,300	$4,600	$4,900	$5,200		
23	-$900	-$300	$300	$900	$1,400	$1,900	$2,400	$2,900	$3,400	$3,800	$4,300	$4,700	$5,000	$5,400	$5,800	$6,000	
24	-$1,000	-$400	$200	$800	$1,400	$2,000	$2,500	$3,000	$3,500	$4,000	$4,500	$4,900	$5,300	$5,800	$6,200	$6,500	$6,900

Table 17. Breakeven costs for the Patch 2.7 treatment – by site index before and after treatment.

Site Index	**Site Index Before Treatment**																
After Trtmt	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
15	$1,200	$1,100	$900	$700	$400	$100	-$200	-$500									
16	$1,600	$1,400	$1,300	$1,000	$800	$500	$100	-$200	-$600								
17	$2,000	$1,900	$1,700	$1,400	$1,100	$800	$500	$200	-$300	-$700							
18	$2,500	$2,400	$2,200	$1,900	$1,600	$1,300	$1,000	$600	$200	-$300	-$700						
19	$3,100	$2,900	$2,700	$2,400	$2,100	$1,800	$1,400	$1,100	$600	$200	-$200	-$800					
20	$3,700	$3,500	$3,300	$3,000	$2,700	$2,300	$2,000	$1,600	$1,100	$700	$200	-$300	-$800				
21	$4,500	$4,200	$4,000	$3,700	$3,300	$2,900	$2,600	$2,100	$1,700	$1,200	$800	$200	-$300	-$900			
22	$5,200	$4,900	$4,600	$4,300	$3,900	$3,600	$3,200	$2,700	$2,200	$1,800	$1,300	$800	$200	-$300	-$900		
23	$6,000	$5,800	$5,400	$5,000	$4,700	$4,300	$3,800	$3,400	$2,900	$2,400	$1,900	$1,400	$900	$300	-$300	-$900	
24	$6,900	$6,500	$6,200	$5,800	$5,300	$4,900	$4,500	$4,000	$3,500	$3,000	$2,500	$2,000	$1,400	$800	$200	-$400	-$1,000

Table 18. Breakeven costs for the Patch 2.7 + Brushsaw treatment – by site index loss if not treated and site index after treatment.

Site Index After Trtmt	**Site Index Loss (m) due to repression if not treated**																
	0	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
15	-$600	-$200	$100	$300	$600	$800	$1,000	$1,100									
16	-$700	-$300	$0	$300	$600	$900	$1,100	$1,300	$1,400								
17	-$800	-$400	$0	$300	$700	$1,000	$1,300	$1,500	$1,700	$1,800							
18	-$800	-$400	$0	$400	$800	$1,100	$1,400	$1,700	$1,900	$2,100	$2,300						
19	-$900	-$400	$0	$500	$900	$1,200	$1,600	$1,900	$2,200	$2,400	$2,700	$2,800					
20	-$1,000	-$500	$100	$500	$900	$1,300	$1,700	$2,100	$2,400	$2,700	$3,000	$3,200	$3,300				
21	-$1,000	-$500	$100	$600	$1,000	$1,500	$1,900	$2,300	$2,700	$3,000	$3,400	$3,600	$3,900	$4,000			
22	-$1,100	-$500	$0	$600	$1,100	$1,600	$2,000	$2,400	$2,800	$3,200	$3,600	$4,000	$4,200	$4,500	$4,700		
23	-$1,200	-$600	$0	$600	$1,200	$1,700	$2,200	$2,600	$3,000	$3,500	$3,900	$4,300	$4,700	$4,900	$5,300	$5,500	
24	-$1,200	-$600	$0	$600	$1,200	$1,800	$2,300	$2,800	$3,300	$3,700	$4,100	$4,600	$5,000	$5,400	$5,700	$6,100	$6,200

Table 19. Breakeven costs for the Patch 2.7 + Brushsaw treatment – by site index before and after treatment.

Site Index After Trtmt	**Site Index Before Treatment**																
	8	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
15	$1,100	$1,000	$800	$600	$300	$100	-$200	-$600									
16	$1,400	$1,300	$1,100	$900	$600	$300	$0	-$300	-$700								
17	$1,800	$1,700	$1,500	$1,300	$1,000	$700	$300	$0	-$400	-$800							
18	$2,300	$2,100	$1,900	$1,700	$1,400	$1,100	$800	$400	$0	-$400	-$800						
19	$2,800	$2,700	$2,400	$2,200	$1,900	$1,600	$1,200	$900	$500	$0	-$400	-$900					
20	$3,300	$3,200	$3,000	$2,700	$2,400	$2,100	$1,700	$1,300	$900	$500	$100	-$500	-$1,000				
21	$4,000	$3,900	$3,600	$3,400	$3,000	$2,700	$2,300	$1,900	$1,500	$1,000	$600	$100	-$500	-$1,000			
22	$4,700	$4,500	$4,200	$4,000	$3,600	$3,200	$2,800	$2,400	$2,000	$1,600	$1,100	$600	$0	-$500	-$1,100		
23	$5,500	$5,300	$4,900	$4,700	$4,300	$3,900	$3,500	$3,000	$2,600	$2,200	$1,700	$1,200	$600	$0	-$600	-$1,200	
24	$6,200	$6,100	$5,700	$5,400	$5,000	$4,600	$4,100	$3,700	$3,300	$2,800	$2,300	$1,800	$1,200	$600	$0	-$600	-$1,200

Table 20. Breakeven costs for the Strip 2.7 30 cm treatment – by site index loss if not treated and site index after treatment.

Site Index	**Site Index Loss (m) due to repression if not treated**																
After Trtmt	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
15	-$400	-$100	$200	$500	$700	$1,000	$1,100	$1,300									
16	-$500	-$100	$300	$600	$900	$1,100	$1,400	$1,600	$1,700								
17	-$500	-$100	$300	$700	$1,000	$1,300	$1,600	$1,800	$2,000	$2,200							
18	-$500	-$100	$300	$800	$1,100	$1,500	$1,800	$2,100	$2,300	$2,500	$2,700						
19	-$600	$0	$400	$800	$1,300	$1,700	$2,000	$2,300	$2,600	$2,900	$3,100	$3,300					
20	-$600	-$100	$500	$900	$1,300	$1,800	$2,200	$2,600	$2,900	$3,200	$3,500	$3,800	$4,000				
21	-$600	$0	$500	$1,000	$1,500	$1,900	$2,400	$2,800	$3,200	$3,500	$3,900	$4,200	$4,500	$4,700			
22	-$600	$0	$600	$1,100	$1,600	$2,100	$2,500	$3,100	$3,500	$3,900	$4,300	$4,600	$5,000	$5,300	$5,500		
23	-$700	$0	$600	$1,100	$1,700	$2,200	$2,700	$3,100	$3,700	$4,100	$4,500	$4,900	$5,300	$5,700	$6,000	$6,300	
24	-$700	$0	$600	$1,200	$1,800	$2,400	$2,900	$3,300	$3,800	$4,400	$4,900	$5,300	$5,700	$6,100	$6,500	$6,900	$7,200

Table 21. Breakeven costs for the Strip 2.7 30 cm treatment – by site index before and after treatment.

Site Index	**Site Index Before Treatment**																
After Trtmt	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
15	$1,300	$1,100	$1,000	$700	$500	$200	-$100	-$400									
16	$1,700	$1,600	$1,400	$1,100	$900	$600	$300	-$100	-$500								
17	$2,200	$2,000	$1,800	$1,600	$1,300	$1,000	$700	$300	-$100	-$500							
18	$2,700	$2,500	$2,300	$2,100	$1,800	$1,500	$1,100	$800	$300	-$100	-$500						
19	$3,300	$3,100	$2,900	$2,600	$2,300	$2,000	$1,700	$1,300	$800	$400	$0	-$600					
20	$4,000	$3,800	$3,500	$3,200	$2,900	$2,600	$2,200	$1,800	$1,300	$900	$500	-$100	-$600				
21	$4,700	$4,500	$4,200	$3,900	$3,500	$3,200	$2,800	$2,400	$1,900	$1,500	$1,000	$500	$0	-$600			
22	$5,500	$5,300	$5,000	$4,600	$4,300	$3,900	$3,500	$3,100	$2,500	$2,100	$1,600	$1,100	$600	$0	-$600		
23	$6,300	$6,000	$5,700	$5,300	$4,900	$4,500	$4,100	$3,700	$3,100	$2,700	$2,200	$1,700	$1,100	$600	$0	-$700	
24	$7,200	$6,900	$6,500	$6,100	$5,700	$5,300	$4,900	$4,400	$3,800	$3,300	$2,900	$2,400	$1,800	$1,200	$600	$0	-$700

Table 22. Breakeven costs for the Strip 2.7 2 m treatment – by site index loss if not treated and site index after treatment.

Site Index After Trtmt	Site Index Loss (m) due to repression if not treated																
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
15	-$600	-$200	$200	$500	$800	$1,100	$1,300	$1,400									
16	-$600	-$200	$200	$600	$900	$1,300	$1,500	$1,700	$1,900								
17	-$700	-$200	$200	$600	$1,000	$1,300	$1,700	$2,000	$2,200	$2,400							
18	-$700	-$100	$300	$700	$1,100	$1,600	$1,900	$2,300	$2,500	$2,800	$3,000						
19	-$700	-$100	$400	$800	$1,300	$1,700	$2,100	$2,500	$2,900	$3,200	$3,400	$3,700					
20	-$700	-$100	$500	$1,000	$1,400	$1,900	$2,300	$2,800	$3,200	$3,500	$3,900	$4,200	$4,400				
21	-$800	-$100	$500	$1,000	$1,600	$2,000	$2,500	$3,000	$3,400	$3,800	$4,200	$4,600	$4,900	$5,200			
22	-$800	-$200	$500	$1,100	$1,700	$2,200	$2,600	$3,200	$3,700	$4,200	$4,600	$5,000	$5,400	$5,700	$6,100		
23	-$900	-$200	$500	$1,100	$1,700	$2,300	$2,900	$3,300	$3,800	$4,300	$4,900	$5,300	$5,800	$6,200	$6,600	$6,900	
24	-$800	-$200	$400	$1,100	$1,700	$2,400	$2,900	$3,500	$3,900	$4,500	$5,100	$5,600	$6,100	$6,600	$7,000	$7,400	$7,800

Table 23. Breakeven costs for the Strip 2.7 2 m treatment – by site index before and after treatment.

Site Index After Trtmt	Site Index Before Treatment																
	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
15	$1,400	$1,300	$1,100	$800	$500	$200	-$200	-$600									
16	$1,900	$1,700	$1,500	$1,300	$900	$600	$200	-$200	-$600								
17	$2,400	$2,200	$2,000	$1,700	$1,300	$1,000	$600	$200	-$200	-$700							
18	$3,000	$2,800	$2,500	$2,300	$1,900	$1,600	$1,100	$700	$300	-$100	-$700						
19	$3,700	$3,400	$3,200	$2,900	$2,500	$2,100	$1,700	$1,300	$800	$400	-$100	-$700					
20	$4,400	$4,200	$3,900	$3,500	$3,200	$2,800	$2,300	$1,900	$1,400	$1,000	$500	-$100	-$700				
21	$5,200	$4,900	$4,600	$4,200	$3,800	$3,400	$3,000	$2,500	$2,000	$1,600	$1,000	$500	-$100	-$800			
22	$6,100	$5,700	$5,400	$5,000	$4,600	$4,200	$3,700	$3,200	$2,600	$2,200	$1,700	$1,100	$500	-$200	-$800		
23	$6,900	$6,600	$6,200	$5,800	$5,300	$4,900	$4,300	$3,800	$3,300	$2,900	$2,300	$1,700	$1,100	$500	-$200	-$900	
24	$7,800	$7,400	$7,000	$6,600	$6,100	$5,600	$5,100	$4,500	$3,900	$3,500	$2,900	$2,400	$1,700	$1,100	$400	-$200	-$800

Table 24. Breakeven costs for traditional spacing to 4,000 trees/ha at 2m - by site index loss if not treated and site index after treatment.

Site Index	**Site Index Loss (m) due to repression if not treated**																
After Trtmt	**0**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**
15	-$500	-$100	$300	$600	$900	$1,100	$1,300	$1,500									
16	-$600	-$100	$300	$700	$1,000	$1,300	$1,600	$1,800	$2,000								
17	-$600	-$200	$300	$700	$1,100	$1,400	$1,800	$2,000	$2,300	$2,500							
18	-$600	-$100	$300	$800	$1,200	$1,600	$2,000	$2,300	$2,600	$2,800	$3,100						
19	-$700	-$100	$500	$800	$1,300	$1,800	$2,200	$2,600	$2,900	$3,200	$3,500	$3,700					
20	-$700	-$100	$400	$1,000	$1,400	$1,900	$2,300	$2,800	$3,200	$3,500	$3,800	$4,200	$4,400				
21	-$800	-$100	$500	$1,100	$1,600	$2,000	$2,500	$3,000	$3,500	$3,900	$4,300	$4,600	$5,000	$5,200			
22	-$800	-$100	$500	$1,100	$1,700	$2,200	$2,600	$3,200	$3,700	$4,200	$4,600	$5,000	$5,400	$5,800	$6,100		
23	-$800	-$200	$500	$1,100	$1,800	$2,300	$2,900	$3,300	$3,900	$4,400	$4,900	$5,400	$5,800	$6,200	$6,600	$7,000	
24	-$800	-$300	$400	$1,100	$1,700	$2,300	$2,900	$3,500	$3,900	$4,500	$5,000	$5,600	$6,000	$6,500	$6,900	$7,400	$7,800

Table 25. Breakeven costs for traditional spacing to 4,000 trees/ha at 2m – by site index before and after treatment.

Site Index	**Site Index Before Treatment**																
After Trtmt	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**	**19**	**20**	**21**	**22**	**23**	**24**
15	$1,500	$1,300	$1,100	$900	$600	$300	-$100	-$500									
16	$2,000	$1,800	$1,600	$1,300	$1,000	$700	$300	-$100	-$600								
17	$2,500	$2,300	$2,000	$1,800	$1,400	$1,100	$700	$300	-$200	-$600							
18	$3,100	$2,800	$2,600	$2,300	$2,000	$1,600	$1,200	$800	$300	-$100	-$600						
19	$3,700	$3,500	$3,200	$2,900	$2,600	$2,200	$1,800	$1,300	$800	$500	-$100	-$700					
20	$4,400	$4,200	$3,800	$3,500	$3,200	$2,800	$2,300	$1,900	$1,400	$1,000	$400	-$100	-$700				
21	$5,200	$5,000	$4,600	$4,300	$3,900	$3,500	$3,000	$2,500	$2,000	$1,600	$1,100	$500	-$100	-$800			
22	$6,100	$5,800	$5,400	$5,000	$4,600	$4,200	$3,700	$3,200	$2,600	$2,200	$1,700	$1,100	$500	-$100	-$800		
23	$7,000	$6,600	$6,200	$5,800	$5,400	$4,900	$4,400	$3,900	$3,300	$2,900	$2,300	$1,800	$1,100	$500	-$200	-$800	
24	$7,800	$7,400	$6,900	$6,500	$6,000	$5,600	$5,000	$4,500	$3,900	$3,500	$2,900	$2,300	$1,700	$1,100	$400	-$300	-$800

5. DECISION KEY AND PROPOSED REVISED FFT FUNDING CRITERIA

5.1 SUPPORTING INFORMATION

5.1.1 Guiding Concepts

The following concepts were used to guide the development of the decision key and proposed revised FFT criteria.

- Repression can be quantified by a loss of site index.
- Repressed stands grow and develop (differentiate into crown classes) in a similar manner to unrepressed stands but at a much slower rate.
- Repression has been commonly observed in high density fire-origin Pl stands and much less commonly in high density fire-origin Lw stands.
- Repression has not been observed in PHR stands of any species.
- The temporal ingress pattern of fire-origin stands is significantly different (shorter) than PHR stands.
- Financial analyses[5] suggest that a minimum of 2-3 m site index loss is required to warrant treatment of stands (the lower the potential site index, the higher the loss required to warrant treatment).
- For the two case studies with data that allows us to predict site index loss as a function of initial density (Farnden and Herring 2002, Carlson and Johnstone 1983) the initial total stems/ha that resulted in a 2 m loss were 87,500 and 110,000 stems/ha. Minor amounts of repression start at lower densities.
- The value of treating repressed stands comes from releasing them from repression to grow at a faster rate (higher site index).
- Spacing stands that are not in repression decreases stand value. All recent financial analyses that include wood quality indicate that spacing Pl stands will decrease stand value, and also increase the risk of unacceptable losses to forest health agents. This means there is a significant risk associated with simply assuming all stands above a certain density will go into repression and therefore need spacing.
- On any given site, the exact density at which fire-origin Pl stands enter repression is not known. We do know that the probability of repression occurring increases with:
    - Increasing initial stand density
    - Decreasing site quality

  Furthermore for a given initial stand density and site quality (e.g., 100,000 stems/ha and site index 18) there is not a single expected level of repression (e.g., 3 m loss in site index) but rather

[5] Using a 2% discount rate.

an unknown probabilistic level of repression (e.g.[6], a 10%, 10%, 20%, 20%, 20%, 10%, 10% chance of 0, 1, 2, 3, 4, 5 and 6 m loss respectively).

For example, it is possible (though unlikely) to have fire-origin Pl stands that regenerated with less than 50,000 stems/ha go into repression, but it is also possible for stands that regenerate with more than 150,000 stems/ha not to go into repression (e.g., TFL 59 study – Thrower 2013).

- The probabilistic nature of the occurrence and magnitude of repression does not fit well within regulatory rule-based stocking standards.

The decision key and proposed funding criteria are kept as simple as possible and are augmented with the information presented below to aid informed decision making by forest professionals who are familiar with the sites.

[6] These numbers are made up strictly for demonstration purposes.

5.1.2 Western Larch in Fire-origin Stands

There is sufficient evidence to suggest that if Lw establishes immediately after a fire on non-dry sites it will often outcompete Pl and take over the site. On dry sites, there is a higher likelihood that the Pl will outcompete the Lw. Additionally, Lw regenerating a few years after Pl may not be able to catch up and outcompete the Pl.

The question then becomes how to assess whether there are sufficient numbers and distribution of Lw growing fast enough to outcompete Pl and take over the site. As the currently available survey systems are not designed to answer this question, ideally we would test and experiment with different survey systems to obtain the information necessary. In the interim, one may choose to use the existing survey methodologies. These will provide:

- Total trees by species
    - Use smaller plots (1 – 10 m^2) or quadrants of 3.99 m plots if densities are very high to ensure accurate counts. With smaller plots, the number of plots should be increased to a minimum of 10 per stratum.
    - Do not use ocular estimates of densities as these have been shown to be biased in high density stands.
- Top height tree heights, ages and height increments by species.
    - Select the tallest healthy trees of each species in a minimum of 10 - 100 m^2 plots (5.64) per stratum.
    - Estimate total age (use knowledge of fire year).
    - Total height and previous year's (as many as can be obtained) height growth.
    - Alternatively, given time constraints often faced in surveying high density stands, a quick assessment of the height of the dominant trees (see definition in Section 5.1.5) in the plot can be used to approximate top height. However, it must be recognized that the dominant height will under-estimate top height and therefore under-estimate site index.
- Ocular estimates of the distribution pattern of Lw.

If the above information indicates at least 2,000 well distributed Lw growing as fast or faster in height than the Pl, then it is likely that the Lw will take over the site. Stands like this should be monitored over time to provide information on stand development that will help guide and refine future decision making[7].

[7] Ideally a subset of stands would have permanent plots established in them so that the stand dynamics could be fully documented and this information would then contribute to our knowledge base.

5.1.3 Lodgepole Pine Early Height Growth

The key factor in determining whether or not stands are going into repression and the severity of the repression is the height growth of the top height trees in the stand relative to what is expected for the site. This requires two pieces of information, both of which will have uncertainty; the potential site index (from SIBEC, or adjacent stands on similar sites), and the growth of the top height trees in the stand. The information in Table 2 and Table 3 can be used to guide expectations for expected early top height growth for a given potential site index. These values can be compared to measured top height growth. (As described above – Section 5.1.2 – this can be approximated by dominant tree height as long as it is recognized this will under-estimate top height and site index). The ability to detect significant differences will be hampered by the variability in the potential site indices (SIBEC includes variability information for sites that have measurements) and the variability in the measured top heights. If initial assessments are uncertain, the best course of action is to defer treatment and prescribe a follow-up assessment.

5.1.4 Treatment Decisions

The breakeven treatment costs provided in Table 12 - Table 25 can be used with the best estimates of potential site index and the current site index being expressed. Note that while the treatments simulated in TASS were all spacing treatments, fertilizer treatments could also be incorporated (as they can be approximated by site index gains). For example, consider a stand with a potential site index of 20 m currently growing at 14 m (a loss of 6 m). If one believed a strip 2.7 m at 2 m treatment would move the stand from site index 14 to 16 m then the maximum expenditure is $200/ha (Table 23). However, if a strip 2.7 m plus fertilization treatment would move the stand from 14 to 20, then the maximum expenditure would be $2,300/ha (Table 23).

The obvious information missing for making treatment decisions is the actual responses to the various treatments. With current information we can only make educated guesses on the responses. In general it is expected that the earlier a stand is treated, the higher the probability of achieving full site potential. As stands get older the research suggests that spacing and fertilization or fertilization alone are needed to move stands out of repression (e.g., Blevins et al. 2005, Farnden and Herring 2002).

One way of addressing the uncertainty of the treatment response and therefore the amount of money that can be invested is to use a risk analysis similar to the following example:

- Assume we are starting with a stand growing at site index 15 that we believe has a potential of 20.
- Based on the best available information we assume that a 2.7 m strip thinning at 2 m height has the following probabilities of increasing site index:

Site Index Gain	Probability
0	0.1
1	0.1
2	0.2
3	0.3
4	0.2
5	0.1
Total	**1.0**

- Multiplying the maximum expenditures (from Table 23) by the probabilities and summing them gives us with a probability weighted maximum expenditure of $620/ha.

Site Index Gain	Probability	Breakeven	Prob X Breakeven
0	0.1	-$600	-$60
1	0.1	-$200	-$20
2	0.2	$200	$40
3	0.3	$700	$210
4	0.2	$1,300	$260
5	0.1	$1,900	$190
Total	**1.0**		**$620**

5.1.5 Countable Conifers

In order to assess stand densities the subset of trees to be included in the density count must be defined. We recommend that the current process for counting conifers is reviewed and revised, and are proposing the following in the interim:

- Determine the total stems in the dominant and co-dominant layer.
- Use this total to assess whether density treatments are needed.

Dominants and co-dominants are defined as follows[8]: (For complete reference the definitions of intermediate and suppressed trees are also provided.)

Dominants: Trees with crowns that extend above the general level of the trees immediately around the measured trees. They are somewhat taller than the codominant trees, and have well-developed crowns, which may be somewhat crowded on the sides, receiving full light from above and partly from the side.

Co-dominants: Trees with crowns forming the general level of the trees immediately around the measured trees. The crown is generally smaller than those of the dominant trees and is usually more crowded on the sides, receiving full light from above and little from the sides.

Intermediate: Trees with crowns below, but extending into, the general level of the trees immediately around the measured trees. The crowns are usually small and quite crowded on the sides, receiving little direct light from above but none from the sides.

Suppressed: Trees with crowns entirely below the general level of the trees around the measured trees, receiving no direct light either from above or from the sides.

The density numbers included in the decision key are based on the dominant-codominant definitions above. The expectation is that as stands develop the proportion of total trees being considered dominant and codominant will decrease. Since the rates of the key developmental processes—self-thinning and height-differentiation—are correlated with the height growth of dominant trees, the rate of development is inversely proportional to the amount of repression so that highly repressed stands develop more slowly than stands with little or no repression. This means that the proportion of countable trees will remain high in heavily repressed stands for a longer period of time than in stands with little or no repression.

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[8] Definitions are from the Vegetation Resource Inventory ground sampling procedures appendices version 5.1 March 2015.

https://www.for.gov.bc.ca/hts/vri/standards/RISC/2015/vri_ground_sampling_appendices_2015.pdf

Current silviculture survey procedures for countable conifers are to determine the median height of the well-spaced trees and then use the following countable height rules:

1. Where the median height is:
    a. ≤2 m
        i. the countable height is 30% times the median height.
    b. >2 m
        i. the countable height is 50% times the median height.

These rules result in the following minimum absolute countable heights across a range of median heights (Table 26). When the current definition is applied to late free growing stands the countable height can be 3 or more metres less than the median height. This can result in trees in the intermediate or suppressed layer being counted.

Table 26. Current countable heights (m).

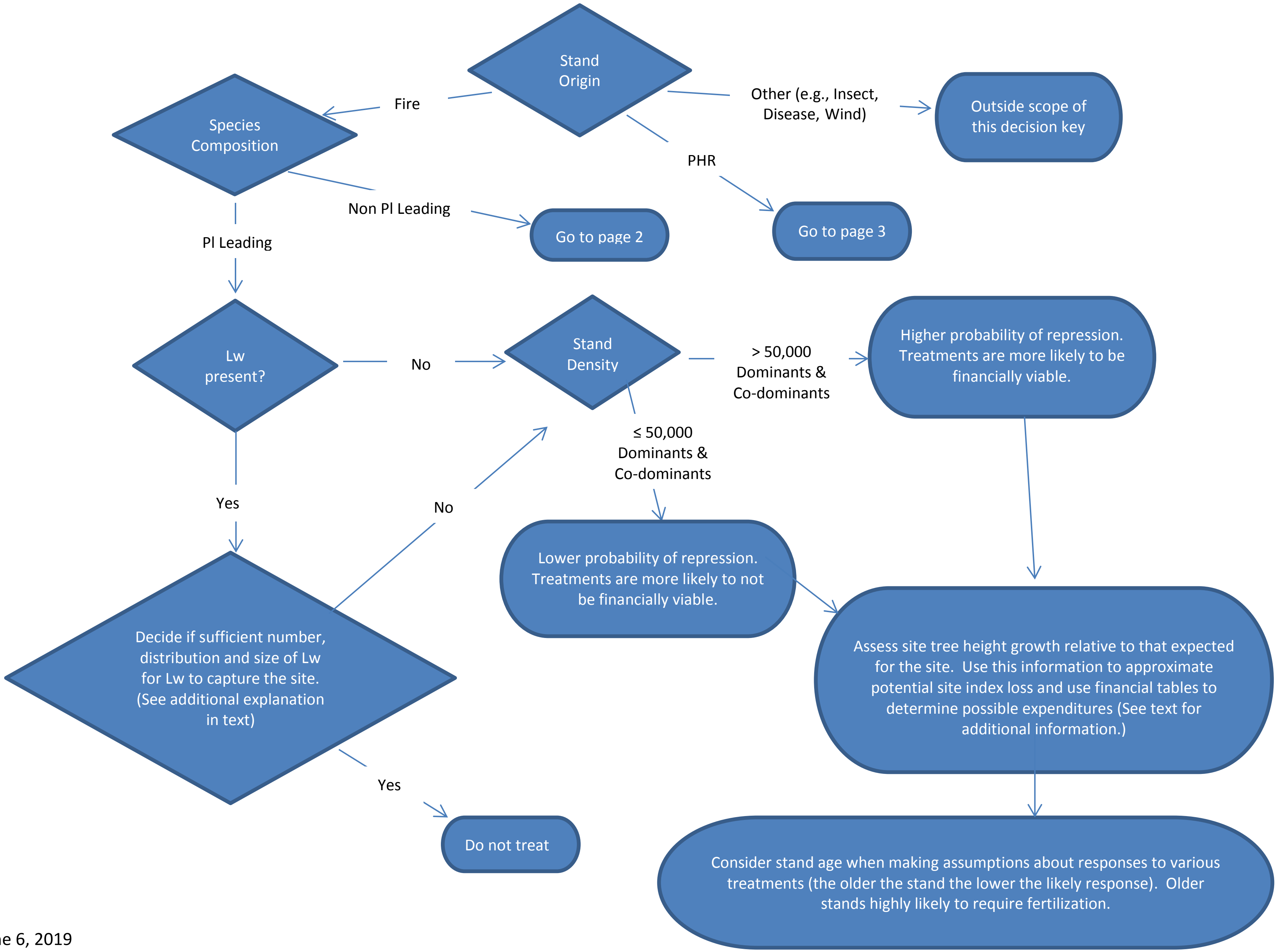
Median Ht	Countable Ht	Difference	% of Median
0.50	0.15	0.35	30%
1.00	0.30	0.70	30%
1.50	0.45	1.05	30%
2.00	0.60	1.40	30%
2.10	1.05	1.05	50%
2.50	1.25	1.25	50%
3.00	1.50	1.50	50%
3.50	1.75	1.75	50%
4.00	2.00	2.00	50%
4.50	2.25	2.25	50%
5.00	2.50	2.50	50%
5.50	2.75	2.75	50%
6.00	3.00	3.00	50%
6.50	3.25	3.25	50%
7.00	3.50	3.50	50%
7.50	3.75	3.75	50%
8.00	4.00	4.00	50%

5.2 DECISION KEY

A simple decision key and proposed revised FFT funding criteria are provided that incorporate our current understanding of repression. There are limited defined numbers for densities included in decision points because the available evidence suggests that threshold densities can vary considerably across sites, stand ages, and species mixtures. The past rule-based approach of setting a single maximum density above which stands must be treated is no longer justifiable given our current knowledge of the probabilistic nature of, and the degree to which repression occurs. We must move towards a science-based, professional decision making approach when deciding which stands need treatment. The decision making must include risk analysis that considers not only the risk of the stand going into repression if not treated, but also the risk of de-valuing stands that did not need to be treated and the associated loss of treatment funds that could have been put to better use.

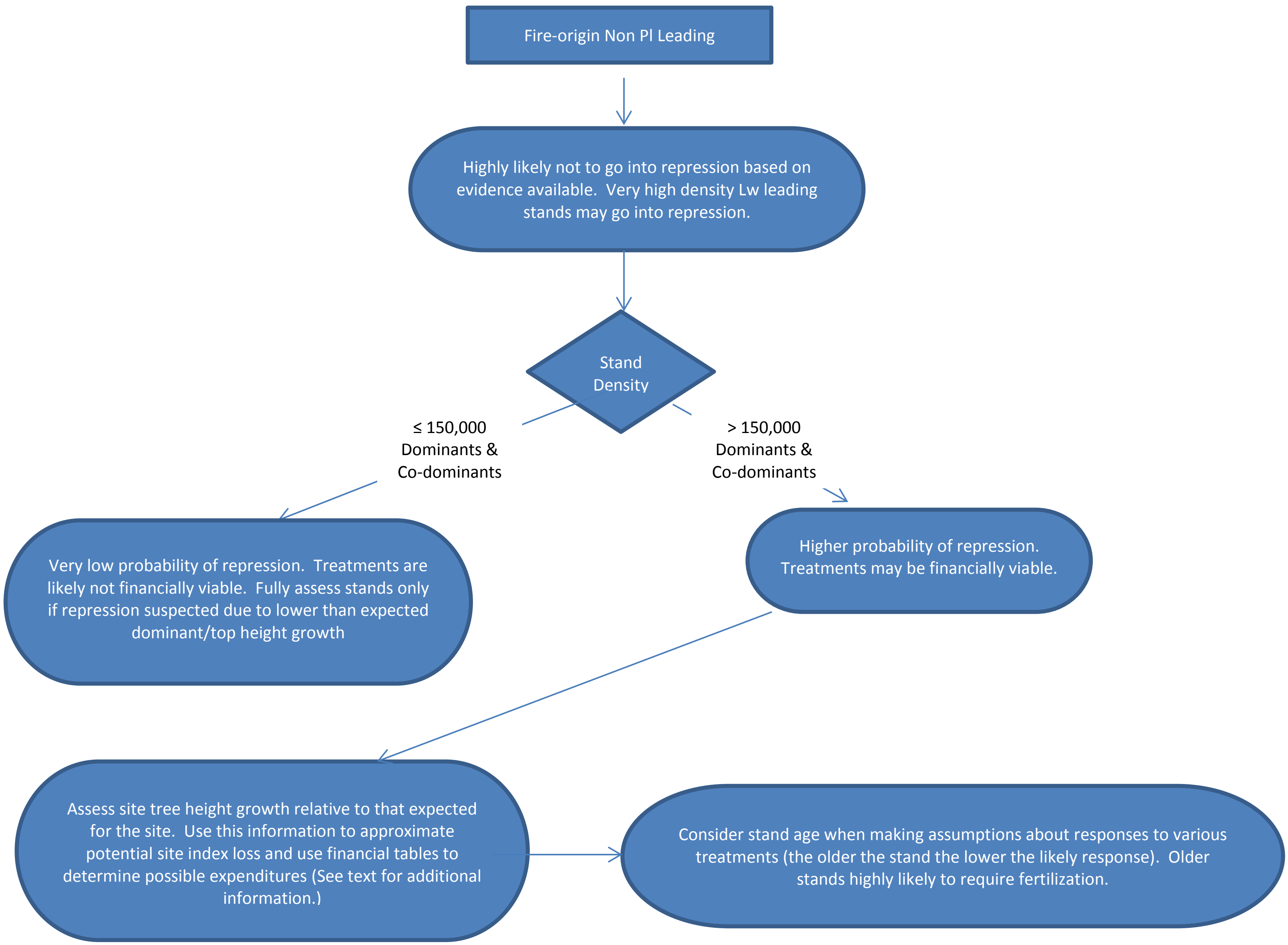
In the interim, the thresholds we have proposed are based on our experience, our interpretation of the current science, and a risk analysis approach that considers both the potential yield losses to repression and the potential value losses from unnecessary spacing. The current science does not provide us with definitive methods for identifying which stands will go into repression or quantifying how such stands will respond to treatments, and accordingly we've adopted a probabilistic approach to both. Our financial analyses suggests that it takes a substantial loss of site index to warrant any treatment and at 2% discount that benchmark is 2m; using a higher discount rate would raise that bar significantly. In summation, it is our consideration of all these factors that has resulted in the proposed density thresholds being raised.

DECISION KEY PAGE 1

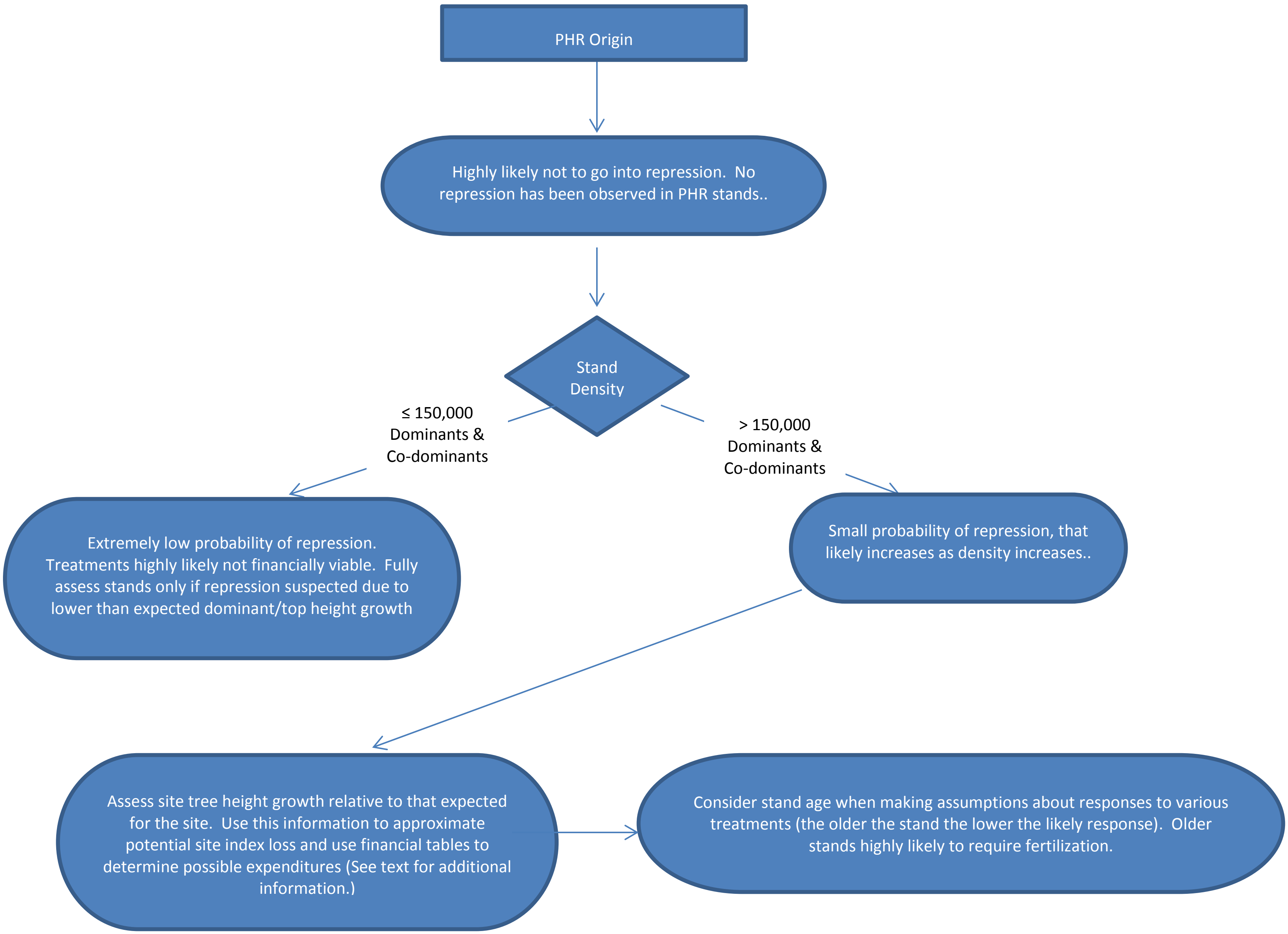


June 6, 2019

DECISION KEY PAGE 2



DECISION KEY PAGE 3



June 6, 2019

5.3 PROPOSED REVISED FFT FUNDING CRITERIA

The following are the proposed revisions to the FFT funding criteria for repression density treatments (spacing and fertilization).

Repression Density Treatments

Due to the significantly higher cost of repression density treatments as compared to planting un-stocked areas, repression density treatments should only be undertaken where the future timber supply improvements are strongly weighted in favour of repression density spacing as compared to the benefit of planting un-stocked areas.

Repression Density Treatments - All areas

Review the background information and decision key (Section 5) to fully understand the rationale behind the following priority rankings within each category. All categories listed below must be considered together to determine an overall ranking and eligibility.

Leading species to be released through repression density spacing:

1. Pli with no expectation of Lw capturing the site.
2. Pli with a low probability of Lw capturing the site.
3. Lw (fire origin) > 150,000 stems/ha with observed repression.

Stand Origin and Stem density[9]

1. Fire origin > 500,000 stems/ha.
2. Fire origin 150,000 – 500,000 stems/ha.
3. Fire origin 50,000[10] - 150,000 stems /ha
4. PHR > 150,000 stems/ha.

Site Index

The site index estimate should be based on the potential of the site in absence of repression density impacts on height. Note that there is a low probability of repression on higher productivity sites (site index greater than 20) and that if it does occur, it is likely below a 2 m loss – but if repression of 2 m or greater does occur on the higher productivity sites then these are the top priority areas.

1. Potential SI > 20
2. Potential SI 15 - 20
3. No treatment for areas < Potential SI 15

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[9] Based on a count of dominant and co-dominant trees in the stand.

[10] Stands with less than 50,000 dominants and co-dominants have a small probability of going into repression significant enough (2 m loss or more) to possibly warrant treatment. These stands can be treated if significant repression is demonstrated via observed top height growth compared to expected top height growth, and the potential site index is high enough to result in sufficient breakeven treatment costs.

<u>Forest Health</u>

1. Minimal forest health hazard[11]

<u>Magnitude of Repression</u>

The magnitude of repression is estimated by a loss in site index. The higher the expected loss the higher the priority.

1. > 5 m
2. 3 – 5 m
3. 2 m
4. No treatment for less than 2 m SI loss.

Combining Site Index and the magnitude of repression (site index loss) the general priorities are:

<table>
<tr><th rowspan="2">Potential SI</th><th colspan="9">Expected site index loss if not treated</th></tr>
<tr><td>2</td><td>3</td><td>4</td><td>5</td><td>6</td><td>7</td><td>8</td><td>9</td><td>10 +</td></tr>
<tr><td>15
16
17
18
19
20</td><td>Priority 4</td><td colspan="3">Priority 3</td><td colspan="5">Priority 2</td></tr>
<tr><td>21
22
23
24</td><td>Priority 3</td><td colspan="3">Priority 2</td><td colspan="5">Priority 1</td></tr>
</table>

Within each of the cells above, the highest priority is given to the stands with the highest potential SI and highest potential loss of SI.

<u>Stand height</u>

The magnitudes of the response to spacing treatments generally decline as stands age and have been in repression longer.

1. < 50 cm
2. >50 cm - <300 cm
3. >300 cm (It is highly recommended that stands > 3 m in height include a high dosage of fertilization (400 kg N/ha +) as part of the prescription.)

[11] A forest health specialist should be consulted in situations where insect, disease, or animal factors may affect the priority rating of candidate stands.

<u>Stand age</u> (years post fire)

The magnitudes of the response to spacing treatments generally decline as stands age and have been in repression longer.

1. < 5 years
2. 5-10 years
3. 10-15 years
4. > 15 (It is highly recommended that more than 15 years post fire include a high dosage of fertilization (400 kg N/ha +) as part of the prescription.)

6. RECOMMENDATIONS

This project highlights well-known significant gaps in knowledge about the biology and treatment of height growth repression in Pl. Some of these information gaps include:

- At what density does repression occur?
- Is there an interaction with site quality?
- At what stage of stand development will a repressed stand not respond to a reduction in stand density?
- Can fertilizer be used to reduce or eliminate the effects of repression?

And although there has been considerable research on the issue for many years in BC and elsewhere, there has not been a coordinated effort focusing specifically on repression.

Therefore, our primary recommendation from this project is to:

> *Develop and implement a coordinated program to address some of the key knowledge gaps about the biology and treatment of height growth repression.*

Some elements of such a program could include:

1. Funding key existing studies that will contribute to better understanding. Examples include the Weyerhaeuser Grant Creek spacing trial in a PHR stand, and the Weyerhaeuser TFL 59 post-fire ingress study.
2. A combined analysis of data from existing or abandoned trials that could contribute to the program. For example, the Ministry's EP922 trials.
3. Documenting cases of repression observed in the field. This could provide potential case study areas.
4. Reviewing abandoned trials that could be resurrected to provide additional information.
5. Establish new trials or enhance existing ones to examine specific components of repression responses to various types of treatments. One example is to enhance the Barnes Creek trial to include a larger area planting of the high density treatment.
6. Review and revise survey methodologies for determining stand densities and top height in high density stands. This includes examining which subset of trees should be counted, plot sizes, and numbers of plots required.
7. Obtaining additional data on early height growth in unrepressed stands across a range of sites for comparison to repressed stands.

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APPENDIX I – DETAILS OF SITE VALUE CALCULATIONS

ROTATION LENGTHS

The FFT return on investment calculations guidance document (MFLNRO 2013) defines maximum merchantable volume mean annual increment (MAI) (also referred to as biological rotation) as the rotation age used in FFT return on investment calculations. Initial site value calculations were determined using biological rotations but this resulted in very long rotation ages for the unspaced repressed stands. Based on discussions with project team members it was decided that operationally these repressed unspaced stands would be harvested at or soon after it became economically viable to do so as there would be an incentive to return the site to a more productive stand sooner rather than later. We therefore did a comparison with between biological and financial rotation ages (using a 2% discount rate) to look at the difference between them. The results for Pl naturally regenerated at 100,000 stems/ha all in year 1 (to mimic fire origin) are shown in Table 27.

Table 27. Comparison of biological and financial rotations for pure Pl regenerated at 100,000 stems/ha all in year 1.

Site	Rotation Lengths (years)	
Index	Biological	Financial (2%)
10	140	130
11	130	115
12	115	105
13	110	95
14	100	85
15	95	85
16	85	80
17	85	75
18	80	75
19	75	70
20	70	70
21	65	65
22	65	65
23	60	60
24	60	60

The results show that at the higher site indices (20 and above) there is no difference between biological and financial rotation lengths. At the lower site indices (used to simulate repressed stands) there can be up to a 15 year difference. Based on the results shown in Table 27 a decision was made to use financial rotation (at 2%) as the basis for all the site value calculations.

NPV OF A SINGLE ROTATION

If the objective is to maximize the returns from a single rotation with no regard for the future use of the land after final harvest then NPV_S (the subscript S is used to denote a single rotation) can be calculated as follows:

$$NPV_S = \sum_{y=0}^{H} \frac{R_y}{(1+i)^y} - \sum_{y=0}^{H} \frac{C_y}{(1+i)^y} = \sum_{y=0}^{H} \frac{(R_y - C_y)}{(1+i)^y}$$

where R_y = revenue received in year y
C_y = cost incurred in year y
i = discount rate
H = final harvest age

and the present is time 0.

What this NPV_S calculation does not include is a term that accounts for the benefits derived from future rotations, and, at the same time, the cost of foregoing the revenues obtained from future rotations. As a result net present values for a single rotation cannot be used to compare management regimes having different harvest ages.

A key difference between unspaced and spaced repressed stands is the rotation length with the unspaced stands typically having much longer rotation lengths. The reduced rotation length of spaced stand is a benefit that needs to be recognized when comparing no spacing to spacing options in repressed stands.

TRADITIONAL SITE VALUE (SV)

Site value is the present value of all cash flows produced by an infinite series of identically managed rotations. It is the value one would be willing to pay for bare ground if the intent was to manage an infinite series of rotations under an assumed management regime. This is why site value is also often referred to as bare land value, soil expectation value, or land expectation value.

When starting with bare ground and comparing alternative management regimes, the regime that has the highest site value is considered the most economically efficient choice.

We have defined the NPV of a single rotation (NPV_S), as the value of the single rotation at time zero (the present). So the value of the same rotation at harvest age (H) would be:

$$= NPV_S (1+i)^H$$

SV is the present value of an infinite series of identical rotations with the first payment being received in H years. In the following two equations the numerator represents the net value of the rotation at harvest age H. So the site value equation assumes that one is starting with bare ground and will manage the land infinitely under identical management regimes, with the first "payment" being received in H years at the time of the first final harvest and then every H years thereafter.

$$SV = \frac{NPV_S (1+i)^H}{(1+i)^H - 1}$$

$$SV = \frac{\sum_{y=0}^{H} \left(R_y - C_y\right)(1+i)^{(H-y)}}{\left(1+i\right)^H - 1}$$

MODIFIED SITE VALUE

For this analysis we did not want to assume an infinite series of fire-origin naturally regenerating stands when determining SV. Instead it is reasonable to assume that regardless of the treatment option chosen (spacing or not), that after harvest the stand would be regenerated the same way. We chose to define the future regenerated stands as 1600 planted plus 1000 naturals. These stands were simulated in TASS across a range of site indices. SVs were determined for these future stands using the formula:

$$SV_F = \frac{NPV_F (1+i)^{H_F}}{(1+i)^{H_F} - 1}$$

Where SV_F is the site value of the future regenerated stand

NPV_F is the NPV of a single rotation of the future regenerated stand

H_F is the rotation length of the future regenerated stand.

It is then assumed that this future stand SV_F (future revenue stream) will be available once the initial stand (spaced or not) is harvested.

If the NPV of the initial stand is defined as:

$$NPV_I = \sum_{y=0}^{H_I} \frac{(R_y - C_y)}{(1+i)^y}$$

where H_I = final harvest age of the initial stand

Then the site value that represents the present value of the initial rotation plus a future series of identically managed rotations is:

$$SV = NPV_I + \frac{SV_F}{(1+i)^{H_I}}$$

This is the SV that is used to compare the spacing versus no spacing option. The SV_F values are equivalent for a given site index and species combination, but when that future revenue stream becomes available is a function of the initial rotation length. Typically unspaced stands have longer rotation lengths making the present value of that future revenue stream smaller as it is more heavily discounted (H_I for the unspaced stand will be equal to or greater than H_I for the spaced stand).

Calculation of Breakeven Spacing Costs

The breakeven spacing cost is defined as the spacing cost that results in the SV of the spaced stand equaling the SV of the unspaced stand. Any spacing costs higher than this value would result in the SV of the spaced stand being lower than that of the unspaced stand.