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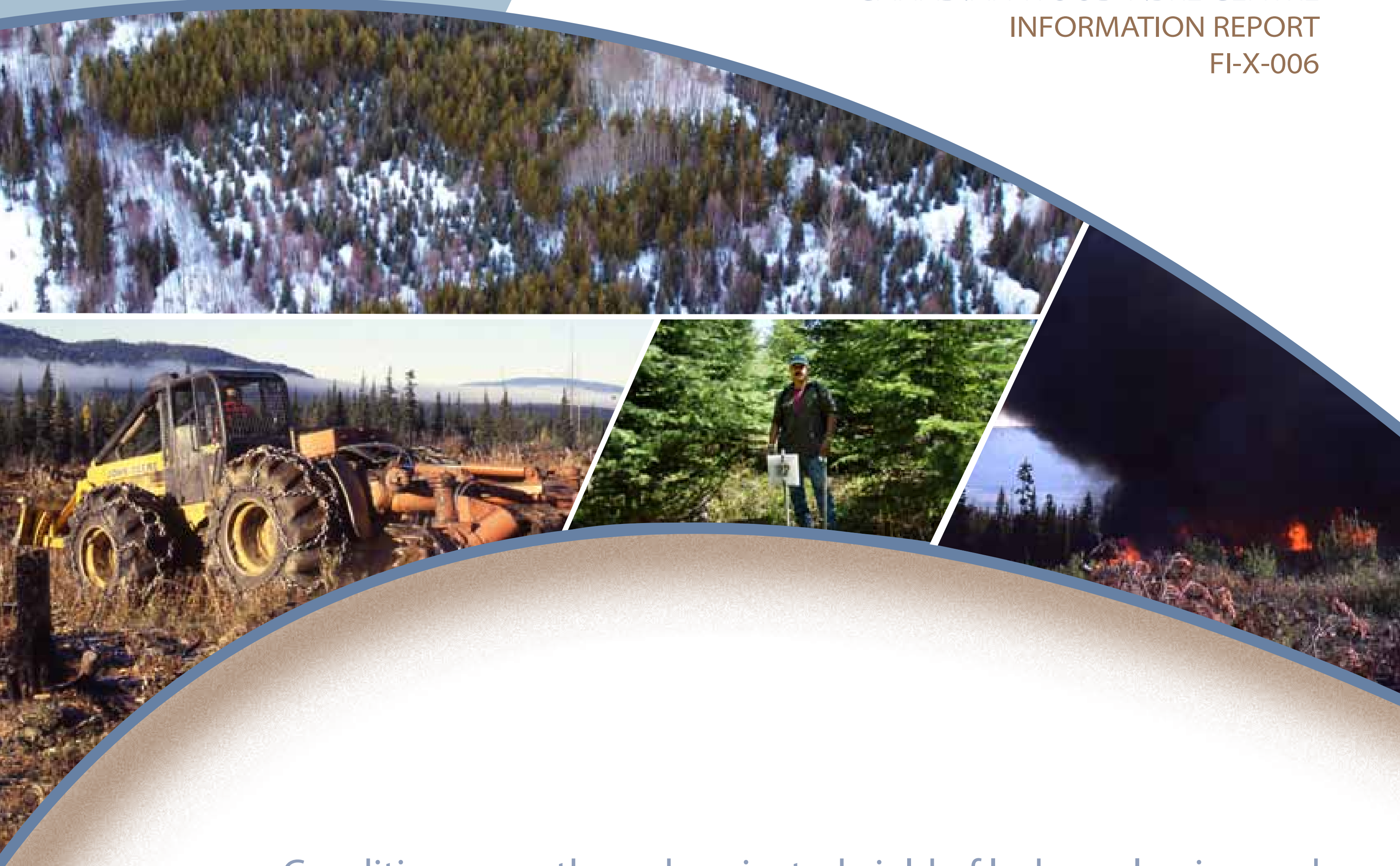

Condition, growth, and projected yield of lodgepole pine and interior spruce 20 years after rehabilitation of an understocked site in north-central British Columbia: The Stony Lake trial

R.J. Whitehead, F. Cortini, S.W. Taylor, A.F. Linnell Nemec, J.W. Goudie, J. Vallentgoed, and K.R. Polsson

Canada

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Condition, growth, and projected yield of lodgepole pine and interior spruce 20 years after rehabilitation of an understocked site in north-central British Columbia: The Stony Lake trial

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Abstract

The Stony Lake trial was established in 1987 to benchmark growth performance of interior spruce (***Picea glauca*** [Moench] Voss x ***engelmannii*** Parry ex Engelm.) and lodgepole pine (***Pinus contorta*** Dougl. Ex Loud. Var. ***latifolia*** Engelm.) planted into 12 treatment regimes for rehabilitating an understocked sub-boreal spruce site (SBSwk1). All combinations of three options for primary site clearing treatments (burn, spray and burn, or windrow), two options for secondary site preparation treatments (disc-trenching or no disc-trenching), and two options for tertiary weeding treatments (broadcast application of herbicide three years after planting or no treatment) were tested. Twenty years after planting, both species had high survival (> 90%), but pine showed much less evidence of damage that could affect future survival or sawlog form than interior spruce. Pine saplings were 57–82% taller and 28–58% larger in diameter than the spruce. Mean total stand volume ranged from 61 to 112 m^3/ha for lodgepole pine, with 10 out of 12 treatments yielding > 95 m^3/ha at 20 years. Total volume for interior spruce ranged from 28 to 52 m^3/ha. High levels of leader weevil damage made it inappropriate to use the Tree and Stand Simulator (TASS) to project future growth for spruce, but simulations for pine predicted yields of at least 300 m^3/ha (merchantable volume) between 40 and 50 years after planting for all but one treatment combination. In addition, growth advantages observed in the first 20 years were associated with a yield of higher stand volume and larger logs with potential for a higher recovery of value at harvest. Our results suggest that establishing plantations of lodgepole pine during rehabilitation of similar sites will require fewer entries than interior spruce and produce larger trees and higher stand-level volumes much earlier.

Résumé

L'établissement d'une parcelle expérimentale au lac Stony, en 1987, visait à évaluer les caractères de croissance d'épinettes de l'intérieur (***Picea glauca*** [Moench] Voss × ***engelmannii*** Parry ex Engelm.) et de pins tordus latifoliés (***Pinus contorta*** Dougl. ex Loud. var. ***latifolia*** Engelm.) plantés selon 12 régimes de traitement, pour la remise en état d'une station insuffisamment régénérée de la zone sub-boréale à épinette (sous-zone SBSwk). Les 12 régimes correspondaient aux diverses combinaisons possibles de trois traitements primaires de déblaiement (brûlage; pulvérisation et brûlage; andainage), de deux traitements secondaires de préparation du terrain (scarifiage par sillons; absence de scarifiage) et de deux traitements tertiaires de désherbage (épandage d'un herbicide à la volée, trois ans après la plantation; absence de désherbage). Vingt ans après la plantation, le taux de survie demeurait supérieur à 90 % chez les deux espèces. Cependant, par rapport aux épinettes, les pins présentaient beaucoup moins de dommages pouvant affecter plus tard leur taux de survie ou la qualité de leur forme pour le sciage. Les gaules de pins dépassaient celles d'épinettes de 57 à 82 % en hauteur et de 28 à 58 % en diamètre. Dans le cas du pin tordu latifolié, le volume ligneux moyen était de 61 à 112 m^3/ha, et 10 des 12 régimes ont produit plus de 95 m^3/ha au bout de 20 ans. Dans le cas de l'épinette de l'intérieur, le volume moyen était de 28 à 52 m^3/ha. Par ailleurs, à cause du taux élevé de pousses apicales endommagées par les charançons, le modèle TASS (Tree and Stand Simulator) ne permettait pas de prédire la croissance future des épinettes; dans le cas des pins, les simulations obtenues au moyen de ce modèle permettaient de prédire un rendement d'au moins 300 m^3/ha (volume marchand), 40 à 50 ans après la plantation, avec 11 des 12 régimes. De plus, la croissance plus forte observée au cours des 20 premières années était associée à un rendement en volume plus élevé et à de plus grosses billes et laissait entrevoir une meilleure récupération de valeur au moment de la récolte. Nos résultats semblent indiquer que l'établissement du pin tordu latifolié plutôt que de l'épinette de l'intérieur pour la remise en état de telles stations exige moins d'interventions sur le terrain et permet d'obtenir, en moins de temps, des arbres plus gros et des peuplements de plus fort volume.

1. Introduction

By the mid 1980s, 2.9 million hectares of productive forest land in British Columbia were not satisfactorily restocked (NSR) with commercially acceptable species more than 10 years after the previous stand had been removed by harvest or destroyed by natural causes (Bedford and Sutton 2000). The first Canada/British Columbia Forest Resource Development Agreement (FRDA), which focused on returning these "backlog NSR" sites to production, funded several benchmark research trials in north-central British Columbia to evaluate treatment options for replacing the existing vegetation with lodgepole pine (*Pinus contorta* Dougl. Ex Loud. Var. *latifolia* Engelm.) and hybrid interior spruce (*Picea glauca* [Moench] Voss x *engelmannii* Parry ex Engelm.) (Bedford et al. 2000).

In 1986, the Canadian Forest Service established one of these benchmark trials at Stony Lake, BC, on a 30-hectare site that was typical of many spruce–subalpine fir (*Abies lasiocarpa* [Hook.] Nutt.) sites logged to intermediate utilization or other partial-cutting standards before about 1970 and later classified as NSR. Twelve treatment regimes were tested for establishment of hybrid interior spruce or lodgepole pine. These included all combinations of three primary (site clearing) treatments, two secondary (site preparation) treatments, and two tertiary (brushing) treatments 3 years after planting. Planted seedlings have been measured periodically for 20 years and now offer an opportunity to document the early growth of conifer plantations following silvicultural treatments at plantation establishment and to generate longer-term projections of growth and yield necessary for forecasting timber supply using the Tree and Stand Simulator (TASS) (Mitchell 1975; Mitchell et al. 1992). The need for these projections after site rehabilitation in north-central British Columbia is acute, especially in the wake of the most recent outbreak of mountain pine beetle (*Dendroctonus ponderosae* Hopk.), which has resulted in extensive areas of mortality that will not be recovered immediately (BCMoFR 2007).

The objectives of this report are to 1) document the status of interior spruce and lodgepole pine trees planted into 12 treatment regimes at the Stony Lake long-term research trial 20 years earlier; and 2) use these early growth data to customize TASS runs to project potential impact on yield and expected value at rotation.

1.1 Study Site

The study site is located in the Prince George Forest District, 90 km southeast of Prince George near Stony Lake (53° 26' 53" N, 121° 53' 47" W) at an elevation of 960 m. Soils are derived from glacial till of medium texture and are moderately well-drained. The site was classified in the Hybrid spruce–oak fern site series in the Willow variant of the Wet Cool subzone of the Sub-Boreal Spruce Zone (SBSwk1) and has a predominantly mesic moisture regime (DeLong et al. 1993). The study site is part of a larger block that had been selectively logged between 1968 and 1970. By 1986 it was occupied by about 40 m^3/ha of scattered residual subalpine fir in generally poor condition, and a dense layer of shrubs and herbs including black twinberry (*Lonicera involucrata* [Richards.] Banks ex Spring), thimbleberry (*Rubus parviflorus* [Nutt.]), and fireweed (*Epilobium angustifolium* L.) (Taylor et al. 1991).

2. Experimental Design and Treatment

The experimental trial was set up as a split-split plot design with three primary treatment levels (clearing), two secondary treatment levels (mechanical site preparation), two species of planting stock, and two tertiary treatment levels (weeding) yielding 24 (3 × 2 × 2 × 2) treatment–species combinations, replicated three times (Figure 1). The primary clearing treatment (broadcast burn, spray and burn, or windrow) was randomly assigned to the main plots and mechanical site preparation (disc-trenching or no disc-trenching) was applied as the first (subplot) split. Two 30 × 33 m permanent sample plots (PSPs) were then established in each of the six combinations; one was planted to lodgepole pine and the other to interior spruce. Three growing seasons after planting, vegetation control (glyphosate as a broadcast spray) was applied to half of each PSP (sub-subplots).

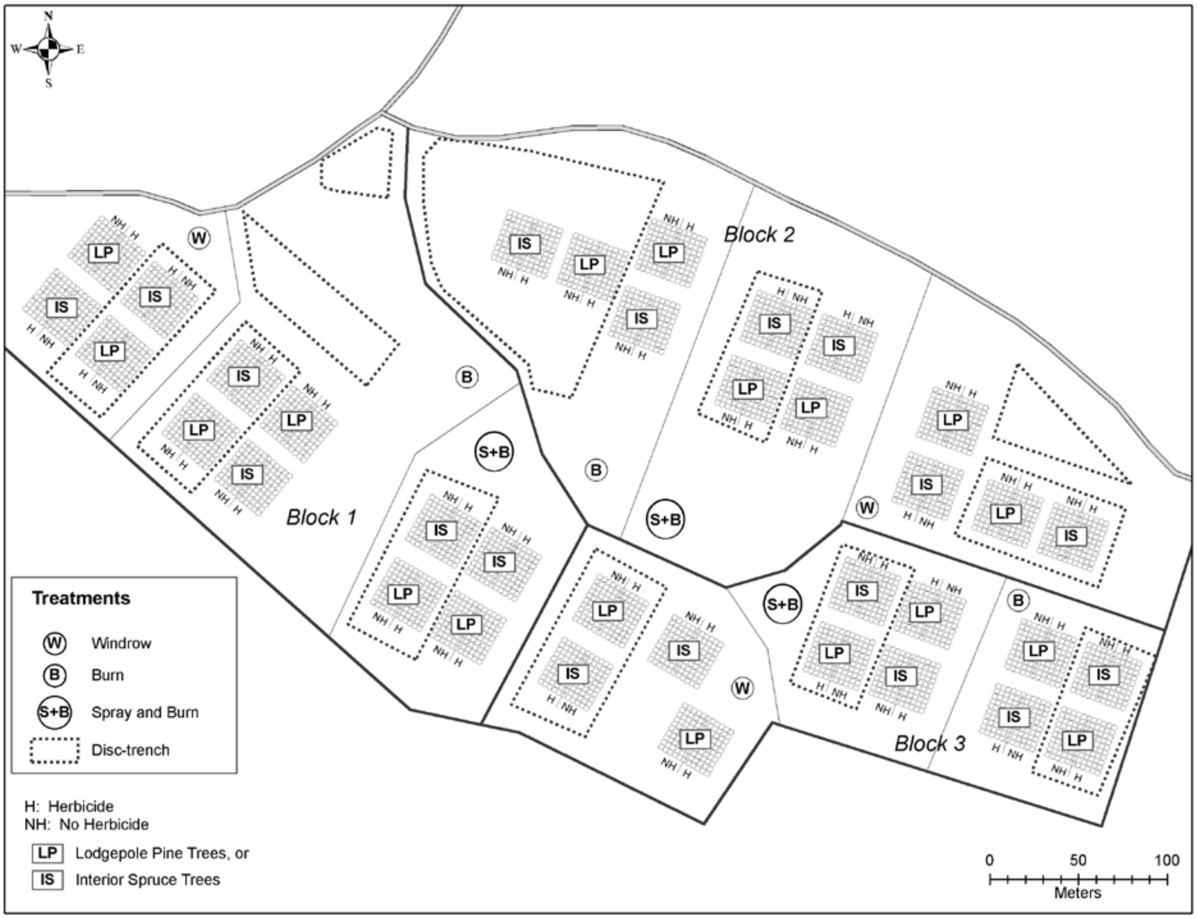

Figure 1. Treatment layout at Stony Lake trial.

In the winter of 1987 residual stems were hand-felled and one of three primary treatments (clearing) was applied to a single plot within each of three replicate blocks (Figure 1):

- Burn—slash was left and broadcast burned in September.
- Spray and burn—glyphosate herbicide (Vision®) was applied in June by backpack sprayer at a nominal rate of 2.1 kg active ingredient per hectare. The area was broadcast burned in September.
- Windrow—slash was piled in windrows (outside the sample plot boundaries) with a brush blade mounted on a crawler tractor and then windrows were burned the following November (1987).

A section of each primary treatment unit was mechanically prepared for planting with a disc-trencher mounted on a rubber-tired skidder in October 1987. Seedlings grown locally in containers were planted in May 1988. Each PSP was planted with 110 hybrid interior spruce or lodgepole pine seedlings in 11 rows of 10 trees at approximately 3 m square spacing (1100 stems per hectare) (Taylor et al. 1991). Glyphosate herbicide (Vision®) was applied by backpack sprayer to rows 1–5 or rows 7–11 at a nominal rate of 1.8 kg active ingredient per hectare in August 1990, leaving row 6 as a buffer between treated and untreated sub-subplots. A detailed description of treatments is found in Taylor et al. (1991).

3. Data Collection and Analyses

Measurements of seedling growth (i.e., height, diameter, and condition) and survival were made at: 1, 2, 3, 4, 5, 12, and 20 years post planting. Survival (number of live trees) and damage incidence (number of new occurrences) were tabulated by species and year for all blocks combined in each of the twelve combinations of primary treatment, disc-trenching, and herbicide application. The total initial sample size for each species and treatment combination was 150 trees (i.e., 3 blocks × 50 trees per sub-subplot, excluding trees in the buffer row).

Analysis of variance (ANOVA) was used to assess the statistical significance of treatment effects on growth and yield. Three response variables were analysed: height, diameter, and volume per hectare. Volume (m^3/ha) was calculated by assuming a conical bole and summing by species over all live trees in the 15 × 30 m (sprayed in 1990 or untreated) sub-subplots. For those years when diameter at breast height (DBH) was measured instead of basal diameter (i.e., 1999 and 2007 for pine, 2007 for spruce), volume was calculated by substituting an estimate of basal diameter derived from the diameter–height relationship for a cone (i.e., we assume basal diameter = DBH × height/[height-1.3 m]).

Univariate (by year) analyses of treatment effects were carried out separately for pine and spruce. The univariate analysis was based on the following split-split plot ANOVA model for the sub-subplot means, which was fitted by maximum likelihood estimation for each year:

$$y_{ijkl} = \mu + \beta_i + \alpha_j + \alpha\beta_{ij} + \gamma_k + \alpha\gamma_{jk} + \alpha\beta\gamma_{ijk} + \theta_l + \alpha\theta_{jl} + \gamma\theta_{kl} + \alpha\gamma\theta_{jkl} + \varepsilon_{ijkl}$$

where y_{ijkl} is the average height, diameter, or volume of live trees in a sub-subplot; μ is the expected overall response; β_i (i = 1, 2, 3) is the random effect of block; α_j (j = 1, 2, 3) is the fixed effect of treatment (burn, burn and spray, or windrow) applied to main plots; $\alpha\beta_{ij}$ is the random interactive effect of block and primary treatment; γ_k (k = 1, 2) is the fixed effect of disc-trenching (or no disc-trenching) applied to subplots; $\alpha\beta\gamma_{ijk}$ is the random interactive effect of block, primary treatment, and disc-trenching treatment; θ_l (l = 1, 2) is the fixed effect of herbicide (or no herbicide) applied to sub-subplots; $\alpha\gamma_{jk}$, $\alpha\theta_{jl}$, $\gamma\theta_{kl}$, $\alpha\gamma\theta_{jkl}$ are the two- and three-way interactive effects of primary treatment, disc-trenching, and herbicide application; and ε_{ijkl} is the random effect of all other sources of variation.

Only trees that survived until the end of the measurement period (1988–2007) were included in the annual (height, diameter) averages while all trees alive at the time of measurement, including those that subsequently died, were included in the annual (volume) totals. Twenty-five live trees that had one or more missing measurements due to damage or competition were omitted from the mean height, diameter, and height/diameter ratio for all years, but were included in volume for those years when the trees were alive and measured. Random effects were assumed to be independent and normally distributed with zero means and homogeneous variances within years. Fixed main and interactive effects were tested by F-tests with denominator degrees of freedom calculated by Satterthwaite's method. Additional contrasts were constructed to assess, for each of the three primary treatments, the statistical significance of the effects of disc-trenching, herbicide, and their interaction. Expected responses were estimated and compared for these and various other treatment combinations of interest.

Estimates of site index (SI) were calculated at age 20 using the growth intercept method described by Nigh (1997) for lodgepole pine and Nigh (2004) for interior spruce. The growth intercept method provides site index estimates for young stands by relating the average height growth rates of trees to site index; accordingly, site index was calculated for each species and treatment by selecting the top height trees—that is, the five largest-diameter trees—within each sub-subplot. The top height cohort was identified as the equivalent of the 100 largest DBH per hectare, which comprises five trees when Garcia and Botho's (2005) correction factor is applied to the 0.045 ha (15 × 30 m) sub-subplots.

Growth of lodgepole pine and interior spruce was modelled by TASS in customized runs. Input parameters were localized by using plot data to describe the spatial tree distribution, initial number of trees per hectare, individual tree vigour, mortality, height–age curves to year 20, and site index. Each plot was randomly replicated 12 times to ensure stable projections to age 100. We then compared values generated by TASS for the quadratic mean DBH at age 20 with the corresponding measured values in order to verify the predictive ability of the model.

TASS also provided estimates of log and lumber volumes based on a sawmill simulator. The sawmill simulator allows for calculation of the economic return of the wood products based on their mean market values between 1976 and 1986. The merchantable volume determined by the sawmill simulator is the volume of boards cut out of the simulated logs while the merchantable volume generated within TASS is the amount of cubic meters in boles of trees minus the top, stump, and all trees less than the merchantability limit (e.g., 12.5 cm DBH outside bark). Thus, small differences in merchantable volume can be observed between the projections generated by TASS and the projected volumes of the sawmill simulator.

4. Results and Discussion

4.1 Lodgepole Pine

4.1.1 Survival and Condition

Early survival (Figure 2) was very high in all treatments (≥ 98% 12 years after planting) and remained above 90% after 20 years in all treatments except the windrow–disc-trenching–herbicide combination, where 10 trees in one sub-subplot were killed by mountain pine beetle during the 3 years preceding the final assessment, which reduced mean survival to 88%. Mortality associated with the 2004 and 2005 flight of mountain pine beetle from an extensive outbreak upwind from the Stony Lake research site severely affected mature pine stands in the surrounding area. However, of the 1782 trees that we monitored at Stony Lake in 2007, only 33 (1.9%) had been attacked by mountain pine beetle, and nine of those attacks (27.2%) did not result in mortality (Figure 3). Only four of the 24 successful attacks occurred in 2007 and there was no attack in 2008, indicating that mountain pine beetle did not establish a viable outbreak population on this site and suggesting that stand susceptibility was very low. All 33 attacks occurred in the eastern third of the site. Twenty-seven attacks occurred in one subplot (windrow–disc-trenching, including three trees in the row of 10 buffer trees that separate the tertiary treatments). These attacks were part of a larger patch outbreak that extended outside the subplot, suggesting that this concentration was more likely a result of local topography and wind patterns than treatment. The remaining six attacks were scattered among other treatments. Pine trees were in good vigour in all treatments. Approximately 9% showed some evidence of stem rust (6.6% western gall rust [*Endocronartium harknessii* (J.P. Moore) Y. Hiratsuka], 2.7% blister rust [probably *Cronartium comandrae* Peck]) and 12% had form problems (9.3% forked top, 1.9% multiple tops) (Table 1). In contrast with our results, Mather et al. (2010) report evidence of poor vigour and high levels of pathogens and insect damage in lodgepole pine plantations of similar age in the Southern Interior of British Columbia. Heineman et al. (2010) report that incidence of damage in young pine plantations increases with warmer and drier climatic conditions. It is important to remember that the Stony Lake trial is in the Wet Cool subzone in the Sub-Boreal Spruce Zone (SBSwk1) with a predominantly mesic moisture regime (DeLong et al. 1993), and hence may be less susceptible to warming-related issues.

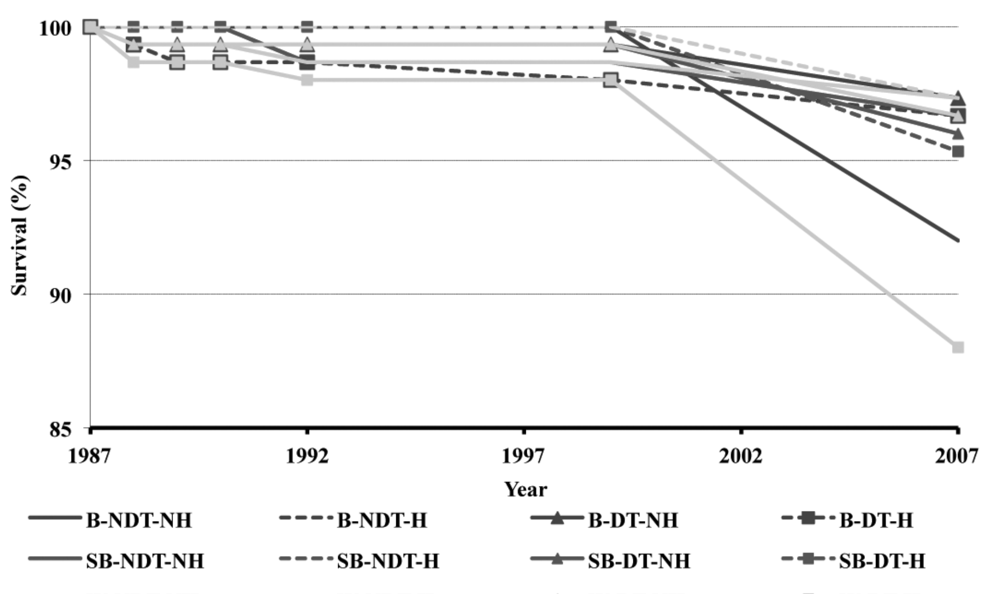

Figure 2. Lodgepole pine percent survival for each combination of primary treatment (windrow [W], burn [B], or spray and burn [SB]), secondary treatment (disc-trenching [DT] or no disc-trenching [NDT]), and tertiary treatment (herbicide [H] or no herbicide [NH]).

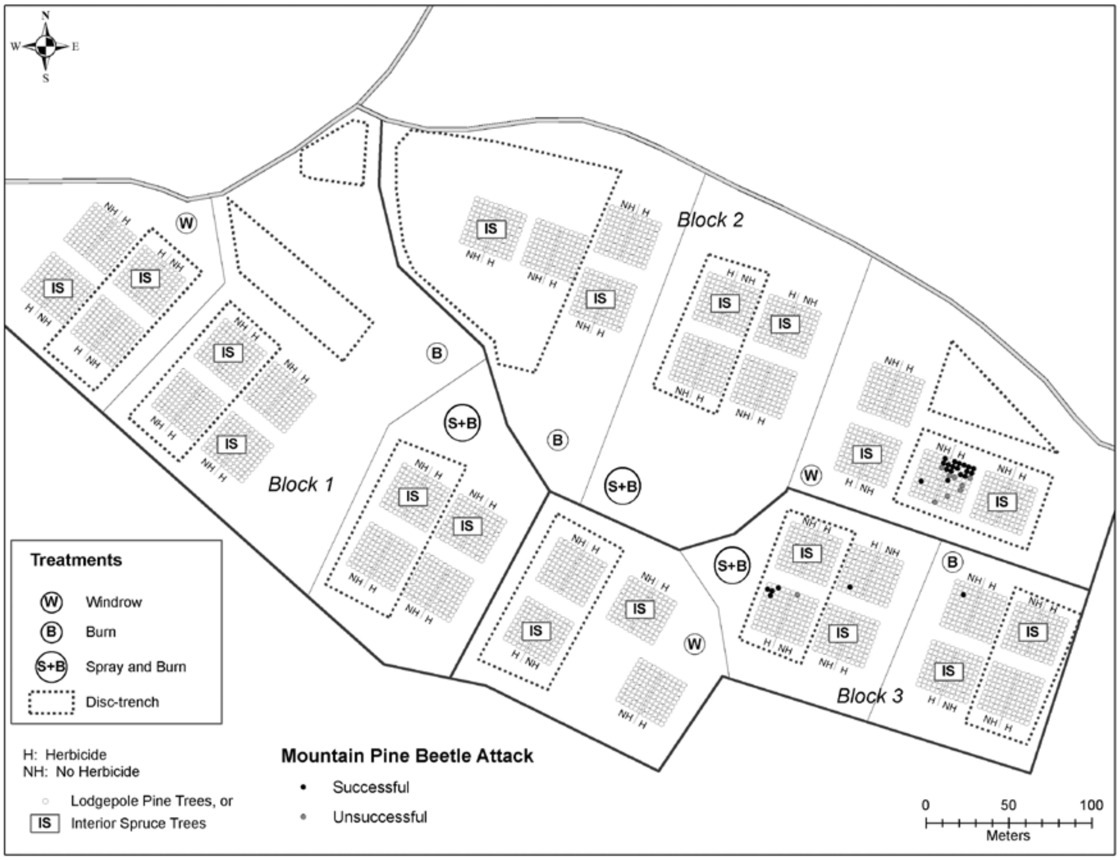

Figure 3. Stem map of planted lodgepole pine indicating which trees have been attacked (successfully or not) by mountain pine beetle based on a survey carried out at age 20.

Table 1. Lodgepole pine assessment, at age 20, of stem rust incidence (gall rust and blister rust) and representative damage characteristics by number of occurrences (#) and percentage (%) for each treatment combination.

			Live Trees	Gall Rust		Blister Rust		Forked Top		Multiple Tops	
Treatment	**Disc-trenching**	**Herbicide**	**#**	**#**	**%**	**#**	**%**	**#**	**%**	**#**	**%**
Burn	No	No	138	6	4.3	0	0	5	3.6	2	1.4
		Yes	145	6	4.1	5	3.4	7	4.8	4	2.8
	Yes	No	146	5	3.4	1	0.7	12	8.2	2	1.4
		Yes	145	6	4.1	0	0	10	6.9	5	3.4
Spray and Burn	No	No	145	22	15.2	4	2.8	17	11.7	4	2.8
		Yes	143	6	4.2	4	2.8	18	12.6	5	3.5
	Yes	No	144	13	9.0	4	2.8	23	16.0	0	0
		Yes	143	15	10.5	6	4.2	23	16.1	10	7.0
Windrow	No	No	146	10	6.8	3	2.1	8	5.5	0	0
		Yes	146	10	6.8	7	4.8	11	7.5	1	0.7
	Yes	No	145	9	6.2	9	6.2	18	12.4	0	0
		Yes	132	5	3.8	4	3.0	8	6.1	0	0
Total			**1718**	**113**	**6.6**	**47**	**2.7**	**160**	**9.3**	**33**	**1.9**

4.1.2 Tree Size and Stand Volume

Mean height, DBH, and stand volume for lodgepole pine at age 20 are presented in Table 2 and results of the statistical analyses are presented in Table 3. Primary (site clearing) treatment had a significant overall effect on seedling height ($p = 0.01$), diameter ($p < 0.0001$) and volume ($p < 0.0001$). Although there was no significant height difference (after averaging over secondary and tertiary treatments) between the burn and windrow treatments, the spray and burn treatment produced taller trees with larger diameter and higher total volume than either of the other treatments.

Table 2. Least-square means (LS Mean) and estimated standard errors (Std. Err.) for lodgepole pine at stand age 20 (2007).

	Height (m)		DBH (cm)		Volume (m^3 /ha)	
Treatments	**LS Mean**	**Std. Err**	**LS Mean**	**Std. Err**	**LS Mean**	**Std. Err**
Burn (B)	9.87	0.112	15.0	0.15	88.6	2.16
Spray and Burn (SB)	10.33	0.112	16.2	0.15	104.0	2.16
Windrow (W)	10.03	0.112	15.6	0.15	96.3	2.16
No Disc-trenching (NDT)	9.73	0.098	15.1	0.13	89.2	1.77
Disc-trenching (DT)	10.42	0.098	16.1	0.13	103.4	1.77
No Herbicide (H)	10.10	0.096	15.3	0.13	94.3	1.77
Herbicide (NH)	10.06	0.096	15.9	0.13	98.3	1.77
B–NDT	9.46	0.146	14.2	0.22	79.1	3.06
B–DT	10.28	0.146	15.7	0.22	98.1	3.06
SB–NDT	9.91	0.146	16.1	0.22	99.6	3.06
SB–DT	10.76	0.146	16.4	0.22	108.5	3.06
W–NDT	9.83	0.146	15.0	0.22	89.1	3.06
W–DT	10.24	0.146	16.2	0.22	103.6	3.06
B–NDT–NH	8.87	0.192	12.5	0.31	61.1	4.32
B–NDT–H	10.05	0.192	15.9	0.31	97.0	4.32
B–DT–NH	10.40	0.192	15.6	0.31	97.4	4.32
B–DT–H	10.15	0.192	15.9	0.31	98.7	4.32
SB–NDT–NH	10.08	0.192	15.8	0.31	100.0	4.32
SB–NDT–H	9.75	0.192	16.3	0.31	99.2	4.32
SB–DT–NH	10.86	0.192	16.1	0.31	105.4	4.32
SB–DT–H	10.65	0.192	16.7	0.31	111.5	4.32
W–NDT–NH	10.03	0.192	15.5	0.31	95.8	4.32
W–NDT–H	9.63	0.192	14.5	0.31	82.4	4.32
W–DT–NH	10.36	0.192	16.2	0.31	106.1	4.32
W–DT–H	10.13	0.192	16.1	0.31	101.1	4.32

Table 3. Univariate ANOVA results and least-square means contrasts for lodgepole pine at age 20. Primary treatments are burn (B), spray and burn (SB), and windrow (W); secondary treatment is either disc-trenching (DT) or no disc-trenching (NDT); and tertiary treatment is either herbicide (H) or no herbicide (NH). Probability values ≤ 0.05 are in bold.

Univariate ANOVA		**Height**			**Diameter**			**Volume**		
Effect	Num DF	Den DF	F Value	Pr > F	Den DF	F Value	Pr > F	Den DF	F Value	Pr > F
Primary Treatment	2	15	6.20	**0.011**	36	16.54	**<.0001**	36	12.79	**<.0001**
Disc-trenching	1	15	39.95	**<.0001**	36	31.98	**<.0001**	36	32.13	**<.0001**
Herbicide	1	18	0.17	0.684	36	12.00	**0.001**	36	2.60	0.116
Burn: DT	1	15	18.49	**0.0006**	36	24.23	**<.0001**	36	19.38	**<.0001**
Burn: H	1	18	7.01	**0.0164**	36	37.58	**<.0001**	36	18.47	**0.0001**
Burn: DT x H	1	18	16.68	**0.0007**	36	24.15	**<.0001**	36	15.95	**0.0003**
Spray and Burn: DT	1	15	19.90	**0.0005**	36	1.30	0.2618	36	4.20	**0.0477**
Spray and Burn: H	1	18	2.42	0.1373	36	3.15	0.0844	36	0.38	0.5422
Spray and Burn: DT x H	1	18	0.11	0.7479	36	0.16	0.6920	36	0.61	0.4396
Windrow: DT	1	15	4.79	**0.0449**	36	13.93	**0.0007**	36	11.32	**0.0018**
Windrow: H	1	18	3.27	0.0871	36	3.63	0.0647	36	4.50	0.0409
Windrow: DT x H	1	18	0.25	0.6260	36	2.67	0.1108	36	0.95	0.3372

Least-square Means	**Height**			**Diameter**			**Volume**		
Mean (difference)	Estimate	Std. Err	Pr > |t|	Estimate	Std. Err	Pr > |t|	Estimate	Std. Err	Pr > |t|
B vs. SB	-0.46	0.134	**0.003**	-1.3	0.22	**<.0001**	-15.5	3.06	**<.0001**
B vs. W	-0.16	0.134	0.240	-0.6	0.22	**0.009**	-7.8	3.06	**0.016**
SB vs. W	0.30	0.134	**0.040**	0.7	0.22	**0.005**	7.7	3.06	**0.016**
NDT vs. DT	-0.69	0.109	**<.0001**	-1.0	0.18	**<.0001**	-14.2	2.50	**<.0001**
NH vs. H	0.04	0.101	0.684	-0.6	0.18	**0.001**	-4.0	2.50	0.116
B–NDT vs. B–DT	-0.81	0.189	**0.001**	-1.5	0.31	**<.0001**	-19.0	4.32	**<.0001**
SB–NDT vs. SB–DT	-0.84	0.189	**0.001**	-0.4	0.31	0.262	-8.9	4.32	**0.048**
W–NDT vs. W–DT	-0.41	0.189	**0.045**	-1.2	0.31	**0.001**	-14.6	4.32	**0.002**
B–NDT–NH vs. B–NDT–H	-1.18	0.248	**0.001**	-3.4	0.44	**<.0001**	-35.9	6.12	**<.0001**
B–DT–NH vs. B–DT–H	0.25	0.248	0.323	-0.4	0.44	0.396	-1.3	6.12	0.831
SB–NDT–NH vs. SB–NDT–H	0.33	0.248	0.200	-0.4	0.44	0.337	0.7	6.12	0.907
SB–DT–NH vs. SB–DT–H	0.22	0.248	0.396	-0.7	0.44	0.133	-6.0	6.12	0.330
W–NDT–NH vs. W–NDT–H	0.40	0.248	0.121	1.1	0.44	**0.017**	13.4	6.12	**0.035**
W–DT–NH vs. W–DT–H	0.23	0.248	0.365	0.1	0.44	0.849	5.0	6.12	0.422

Secondary (site preparation) treatment significantly increased mean height, diameter, and volume ($p < 0.0001$) in lodgepole pine. The increase in height was larger in the burn and spray and burn treatments than in the windrow treatment (0.81, 0.84, and 0.41 m respectively), while the increase in diameter was larger in burn and windrow plots than in the spray and burn (1.5, 1.2, and 0.4 cm respectively). The increase in volume after disc-trenching (which reflects the combined effects on height and diameter) was much higher in the burn treatment than in either the spray and burn or windrow treatments (19, 8.9, and 14.6 m^3/ha respectively).

While the ANOVA indicated a significant difference due to tertiary treatment (brushing and weeding) for diameter only ($p = 0.001$), contrast analyses showed that in all treatment combinations except the burn without disc-trenching treatment, differences between brushed and untreated plots were small in magnitude and inconsistent in direction (-1.1 to +0.7 cm). However, in the burn without disc-trenching treatment, brushing 3 years after planting increased height by 13% ($p = 0.001$), diameter by 27% ($p < 0.0001$), and volume by 59% ($p < 0.0001$), which suggests that burning without secondary site preparation was the only treatment regime that did not provide adequate control of vegetation competition at 3 years after planting. This is consistent with initial results reported by Taylor et al. (1991) and other earlier assessments (unpublished data and analyses).

4.1.3 Growth Projections

Early estimates (age 20) of site index (SI_{50}) for lodgepole pine indicated an average value of 23.8 m. The burn–no disc-trenching–herbicide treatment combination had the highest SI_{50} value with 24.5 m and the windrow–disc-trenching–no herbicide treatment combination had the lowest SI_{50} value with 23.1 m (Table 4). Custom TASS projections based on SI_{50} estimates, observed mortality, and establishment densities predicted quadratic mean diameter at age 20 that only slightly underestimated observed values, suggesting the growth projections are accurate (or may be slightly conservative) and can be used with confidence (Figure 4).

Table 4. Lodgepole pine site index (SI_{50}) values calculated at age 20 by treatment. Minimum, maximum, and average values are in bold.

Primary Treatment	Disc-trenching	Herbicide	SI_{50} (m)
Burn	No	No	23.8
		Yes	**24.5**
	Yes	No	23.9
		Yes	23.8
Spray and Burn	No	No	23.9
		Yes	24.1
	Yes	No	23.2
		Yes	24.0
Windrow	No	No	23.7
		Yes	24.2
	Yes	No	**23.1**
		Yes	23.8
		Average	**23.8**

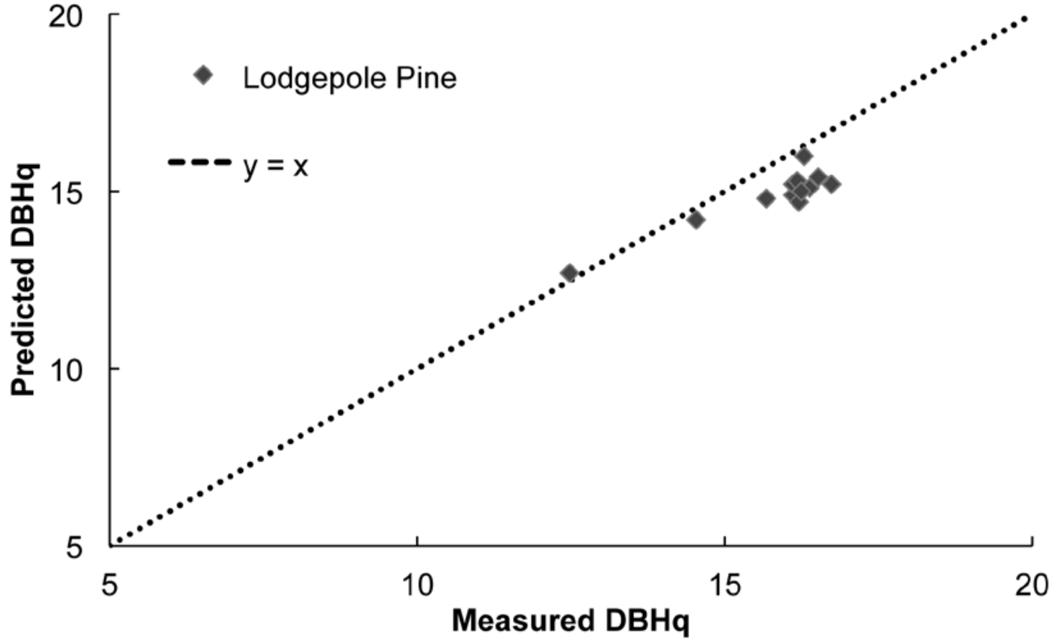

Figure 4. Lodgepole pine comparison between observed values of quadratic mean diameter at breast height (DBHq) and values of DBHq predicted by TASS.

Projections of merchantable volume up to 100 years after planting indicated considerable differences between the treatments (Figure 5), which could have a profound effect on timber supply. For example, the spray and burn–disc-trenching–no herbicide regime was predicted to yield 300 m^3/ha approximately 10 to 20 years earlier than less effective treatment combinations (e.g., windrow–no disc-trenching–herbicide or burn–no disc-trenching–no herbicide). Cortini et al. (2010) reported similar volume gains between treated and untreated plots on a slightly less productive site (SI_{50} = 21.7 m, estimated at age 20) west of Prince George, British Columbia.

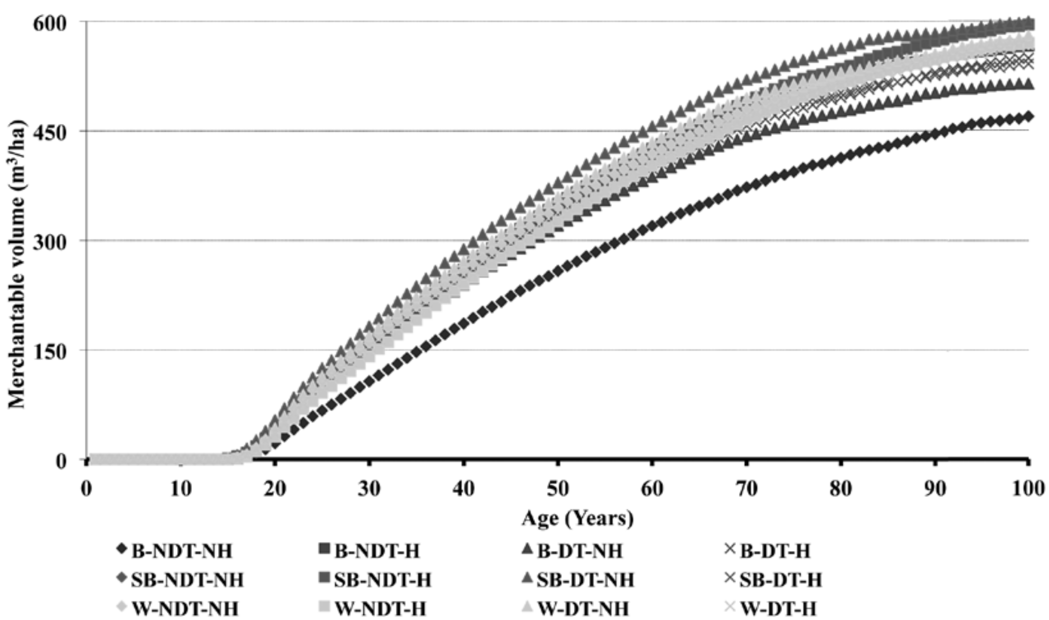

Figure 5. Merchantable volume estimates (predicted by TASS) for lodgepole pine for each combination of primary treatment (burn [B], spray and burn [SB], and windrow [W]), secondary treatment (disc-trenching [DT] or no disc-trenching [NDT]), and tertiary treatment (herbicide [H] or no herbicide [NH]).

Projected stand and stock tables (Tables 5 and 6) at age 60 indicated that for the best treatment (i.e., spray and burn–disc-trenching–no herbicide) the diameter classes between 20 and 35 cm accounted for 95% of the total number of trees per hectare. The same diameter classes represented 87% of the total trees per hectare for the average treatment (i.e., windrow–no disc-trenching–herbicide), and only 76% for the least effective treatment (i.e., burn–no disc-trenching–no herbicide). This outcome suggests that a narrower diameter distribution can be achieved by applying an effective site preparation treatment combination to lodgepole pine seedlings. The stand and stock tables also showed that the treatment combinations predicted to produce the highest volumes at 40 years have larger mean diameters (piece size)

Table 5. Lodgepole pine stand table: Diameter distribution for three representative treatment combinations at ages 20, 40, 50, and 60. Highlighted in gray are the diameter classes that account for 95% of the total number of trees per hectare at age 60.

		Trees	Number of Trees by Diameter Class (DBH in cm)												
Treatment	**Age**	**per ha**	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**
Spray and Burn–	20	1080		14	181	711	172	3							
Disc-trenching–	40	1069			32	89	374	441	122	10	1				
No Herbicide	50	1062			22	68	254	441	231	44	3				
	60	1036			13	41	198	401	287	82	13	1			
Windrow–No Disc	20	1079	27	89	336	553	73	2							
Trenching–Herbicide	40	1062	10	38	48	165	347	323	114	15	2				
	50	1037	6	18	41	119	272	309	214	50	6	2			
	60	1004	3	6	31	94	247	256	256	86	23	3	1		
Burn–No Disc	20	1003	162	137	283	354	66	2							
Trenching	40	964	69	76	71	130	264	225	86	35	5	1	1		
No Herbicide	50	917	35	66	55	103	192	261	141	33	25	5	1	1	
	60	876	20	44	45	90	158	236	169	66	25	15	5	1	1

Table 6. Lodgepole pine stock table: Diameter distribution of merchantable (Merch.) volume (DBH > 12.5 cm) for three representative treatment combinations at ages 20, 40, 50, and 60.

		Merch. Volume	Total Volume by Diameter Class (DBH in cm)												
Treatment	**Age**	**(m^3/ha)**	**0**	**5**	**10**	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**
Spray and Burn–	20	53.9				36.6	16.8	0.5							
Disc-trenching–	40	298.1				7.7	75	147.3	60.4	6.7	0.9				
No Herbicide	50	394.4				5.5	55.8	164.8	128.9	36	3.4				
	60	475.6				3.5	45.2	161.6	177.1	71.8	14.7	1.6			
Windrow–No Disc-	20	31.2				24.2	6.7								
Trenching–Herbicide	40	244.9				12.5	62.6	103.0	54.9	10.2	1.7				
	50	335.5				9.1	51.9	109.8	116.6	39.7	5.9	2.5			
	60	413.3				7.3	50.4	97.5	153.1	73.2	25.8	4.4	1.6		
Burn–No Disc-	20	22.3				15.4	6.5								
Trenching–	40	190.3				8.2	45.5	67.4	38.4	24.1	4.1	1.1	1.3		
No Herbicide	50	265.2				6.6	35.6	88.0	74.6	25.2	25.8	5.9	1.6	1.9	
	60	330.8				5.9	30.7	85.0	95.9	51.9	28.3	21	7.6	2.1	2.4

Table 7. Lodgepole pine sawmill simulations for three representative treatment combinations at ages 40, 50, and 60. The total value column represents the sum of the lumber value plus the chips value.

		Merch.	Log Volume by Grade												
		Volume	Saw Logs				Pulp		Chips	Lumber Volume (bd ft/ha)**				Lumber Value	Total Value
Treatment	Age	m^3/ha	H	I	J	U	X	Y	BDU/ha*	2 X 4	2 X 6	2 X 8	2 X 10	Total	$/ha	$/ha
Spray and	40	296.1	-	-	190.0	86.4	18.7	1.0	54	52 273	13 862	586	248	66 969	12 227	17 127
Burn–Disc-	50	390.1	-	-	286.2	79.2	23.0	1.6	68	65 979	22 299	2492	2189	92 960	17 070	23 215
trenching–																
NoHerbicide	60	472.3	-	0.6	359.5	90.6	17.4	4.2	80	74 939	31 667	3704	6350	116 659	21 484	28 653
Windrow–	40	242.7	-	-	147.4	75.0	18.8	1.5	45	42 617	10 648	496	354	54 115	9 867	13 942
No Disc-	50	332.9	-	-	232.1	76.6	21.3	3.0	59	55 291	18 422	1978	2977	78 668	14 420	19 690
trenching–																
Herbicide	60	410.1	-	2.1	296.9	85.5	20.1	5.5	69	64 072	26 343	2341	8218	100 973	18 569	24 816
Burn–No	40	188.5	-	0.6	99.7	67.5	17.1	3.6	35	32 204	8 111	445	1350	42 111	7 664	10 818
Disc-trenching	50	263.4	-	2.0	166.8	72.1	16.8	5.7	46	40 555	15 104	1525	5392	62 576	11 468	15 618
–No Herbicide	60	329.0	-	7.7	216.0	82.5	15.4	7.4	55	48 220	20 934	2443	9976	81 573	14 998	19 953

*BDU/ha = Bone-dry units per hectare; ** bd ft/ha = Board feet per hectare and narrower diameter distributions, which implies lower harvesting costs, increased productivity at the sawmill, and options to saw higher-value (wider and/or longer) boards.

TASS also provided estimates of log and lumber volumes, together with their economic return based on the mean market values, between 1976 and 1986 (Table 7). Although out of date, these values can still provide guidance regarding the relative economic return of different treatments. At age 60, the total merchantable volume for the best treatment (i.e., spray and burn–disc-trenching–no herbicide) might be expected to produce 76% of that volume in saw logs and 24% in lower-grade logs (chip and saw or pulp logs). A less effective treatment (i.e., windrow–no disc-trenching–herbicide) might produce 73% of the total in saw logs and 27% in pulp, and the worst treatment (i.e., burn–no disc-trenching–no herbicide) might produce 68% of the total merchantable volume in saw logs and 32% in pulp. The total value (i.e., lumber value plus chips value) at age 60 for the best treatment was higher by 13% and 30%, respectively, than the less effective treatment combinations.

These simulations suggest that early growth advantages following effective site rehabilitation treatments should yield higher volume and larger logs with potential for a higher recovery of value when harvested. Although piece size is an important determinant of log and lumber grade, it is not the only factor. Long-term research sites such as Stony Lake provide an opportunity to look at the effect of rapid growth in managed stands on wood quality and fibre attributes (e.g., density, ring width, knot size, stiffness, and mature fibre length) that may confer higher (or lower) value. We recommend that such questions should be a high priority for further study at long-term research sites such as Stony Lake.

4.2 Interior Spruce

4.2.1 Survival and Condition

Survival of interior spruce (Figure 6) was very high for the first 10 years (> 95%) and remained above 90% in all treatment regimes 20 years after planting. Height growth, however, was adversely affected by repeated leader attacks by white pine weevil (*Pissodes strobi* [Peck]) in all treatments (Table 8 and Figure 7). At age 20 approximately 52% of the total number of live trees were showing evidence of weevil attack, which led to 41% of the live trees having poor form (28% terminal damage, 8% forked tops, and 5% multiple tops) (Table 8). Damage caused by the weevil includes destruction of the tree's leader, which results in the growth of one or more branches competing for apical dominance and a consequent reduction in height growth (Alfaro 1994). Taylor et al. (1996) found that trunk deformation caused by the weevil is more severe on trees growing in open conditions than on trees growing under a canopy or in densely planted areas.

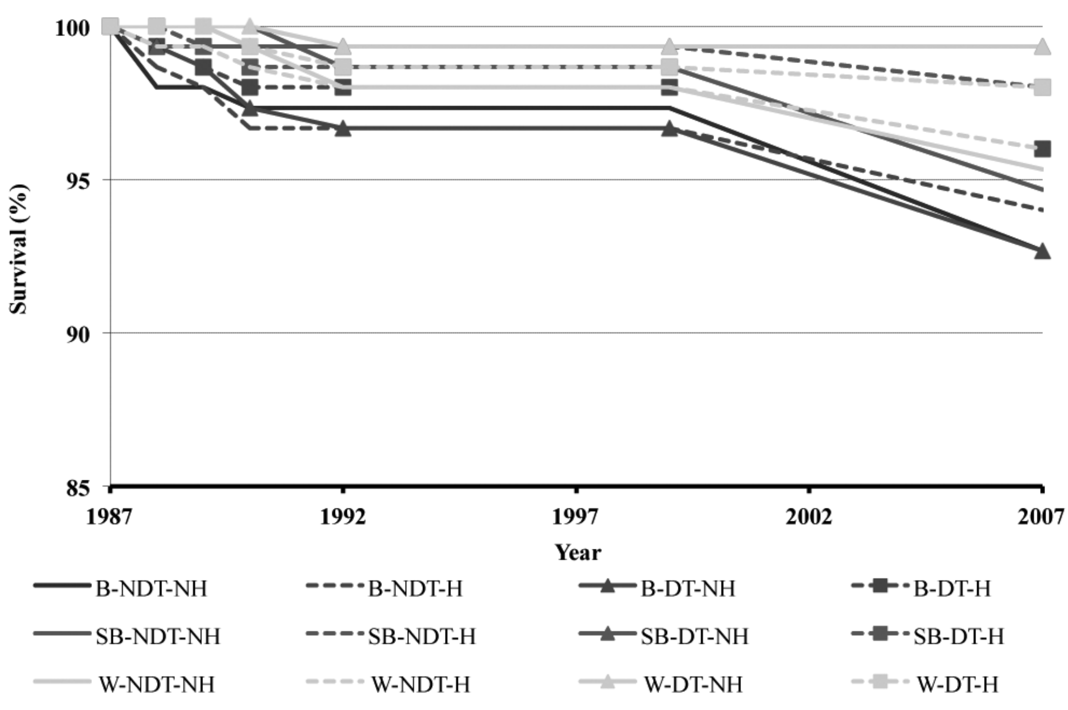

Figure 6. Interior spruce percent survival for each combination of primary treatment (burn [B], spray and burn [SB], and windrow [W]), secondary treatment (disc-trenching [DT] or no disc-trenching [NDT]), and tertiary treatment (herbicide [H] or no herbicide [NH]).

Table 8. Interior spruce assessment at age 20 of white pine weevil attacks and representative damage characteristics by number of occurrences (#) and percentage (%) for each treatment combination.

Treatment	Disc-trenching	Herbicide	Live Trees #	Weevil Attacks #	Weevil Attacks %	Terminal Damage #	Terminal Damage %	Forked Top #	Forked Top %	Multiple Tops #	Multiple Tops %
Burn	No	No	139	50	36.0	24	17.3	7	5.0	7	5.0
		Yes	141	67	47.5	33	23.4	6	4.3	12	8.5
	Yes	No	139	68	48.9	39	28.1	3	2.2	0	0
		Yes	144	91	63.2	59	41.0	6	4.2	1	0.7
Spray and Burn	No	No	142	81	57.0	48	33.8	7	4.9	10	7.0
		Yes	147	69	46.9	38	25.9	11	7.5	1	0.7
	Yes	No	149	72	48.3	35	23.5	13	8.7	4	2.7
		Yes	147	79	53.7	54	36.7	24	16.3	2	1.4
Windrow	No	No	143	55	38.5	7	4.9	8	5.6	19	13.3
		Yes	144	83	57.6	25	17.4	14	9.7	18	12.5
	Yes	No	149	81	54.4	57	38.3	8	5.4	8	5.4
		Yes	147	101	68.7	71	48.3	27	18.4	3	2.0
Total			1731	897	51.8	490	28.3	134	7.7	85	4.9

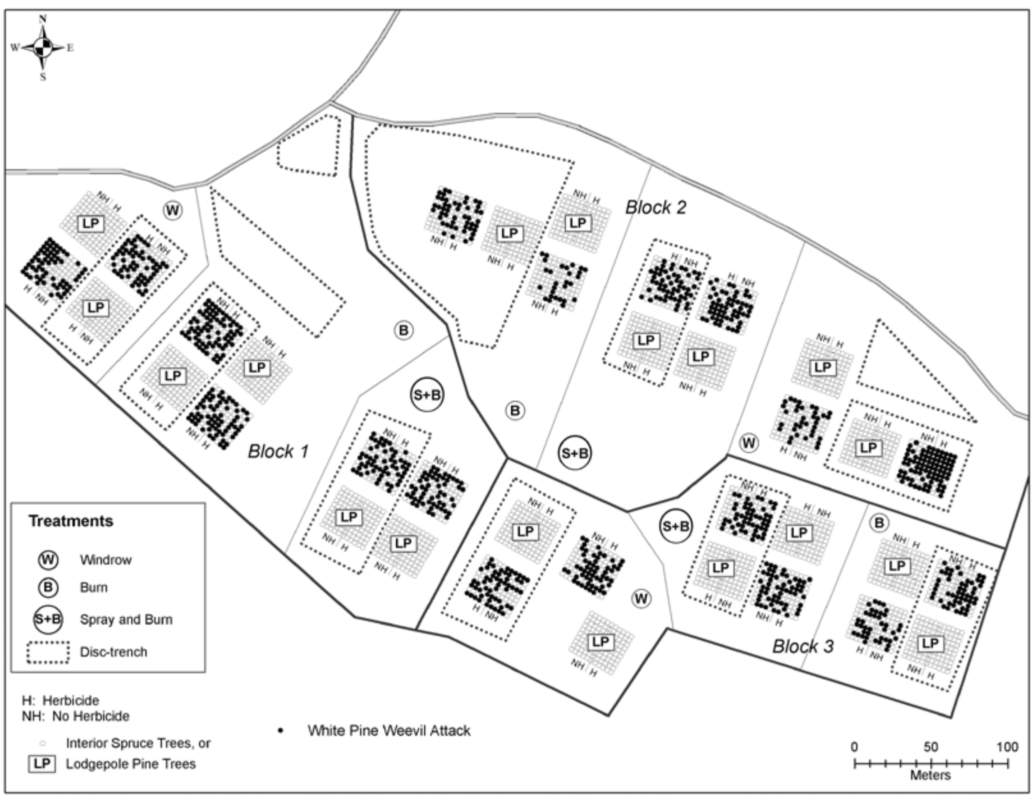

Figure 7. Stem map of planted interior spruce indicating which trees have been attacked by white pine weevil based on a survey carried out at age 20.

For sites with high SI_{50} similar to Stony Lake, single species spruce plantations are not recommended in areas with significant weevil hazard (Alfaro 1994), and our observations support this caution. The data collection protocol used in this study was not designed to quantify the degradation of log quality that resulted from spruce weevil damage. We recommend that such a survey be undertaken, as our data suggest a high risk of failure when the objective is to return the site to optimal saw timber production.

4.2.2 Tree Size and Stand Volume

Means for DBH, height, and volume (total) at stand age 20 for interior spruce and the univariate ANOVA analysis are presented in Tables 9 and 10 respectively. Overall, the spray and burn treatment resulted in significantly ($p < 0.05$) larger trees (volume = 42.7 m^3/ha) than either the windrow (volume = 35.8 m^3/ha) or the burn (volume = 31.1 m^3/ha) treatments, which did not differ significantly. The secondary treatment (disc-trenching) resulted in significantly larger trees

Table 9. Least-square means (LS Mean) and estimated standard errors (Std. Err.) for interior spruce at stand age 20 (2007).

	Height (m)		**DBH (cm)**		**Volume (m^3/ha)**	
Treatments	**LS Mean**	**Std. Err**	**LS Mean**	**Std. Err**	**LS Mean**	**Std. Err**
Burn (B)	5.70	0.089	10.2	0.35	31.1	2.28
Spray and Burn (SB)	6.27	0.089	11.7	0.35	42.7	2.28
Windrow (W)	6.04	0.089	10.7	0.35	35.8	2.28
No Disc-trenching (NDT)	5.82	0.077	10.5	0.30	33.4	2.07
Disc-trenching (DT)	6.18	0.077	11.2	0.30	39.6	2.07
No Herbicide (H)	5.92	0.071	10.4	0.26	33.1	1.93
Herbicide (NH)	6.09	0.071	11.3	0.26	40.0	1.93
B–NDT	5.62	0.117	10.2	0.45	30.3	2.84
B–DT	5.78	0.117	10.3	0.45	31.9	2.84
SB–NDT	6.05	0.117	11.5	0.45	40.0	2.84
SB–DT	6.48	0.117	11.9	0.45	45.4	2.84
W–NDT	5.79	0.117	9.9	0.45	30.0	2.84
W–DT	6.30	0.117	11.4	0.45	41.7	2.84
B–NDT–NH	5.51	0.143	9.8	0.50	27.5	3.25
B–NDT–H	5.73	0.143	10.7	0.50	33.1	3.25
B–DT–NH	5.71	0.143	9.9	0.50	29.2	3.25
B–DT–H	5.84	0.143	10.6	0.50	34.5	3.25
SB–NDT–NH	5.85	0.143	11.3	0.50	37.7	3.25
SB–NDT–H	6.26	0.143	11.6	0.50	42.4	3.25
SB–DT–NH	6.46	0.143	11.1	0.50	39.1	3.25
SB–DT–H	6.49	0.143	12.7	0.50	51.6	3.25
W–NDT–NH	5.80	0.143	9.9	0.50	29.9	3.25
W–NDT–H	5.78	0.143	10.0	0.50	30.1	3.25
W–DT–NH	6.16	0.143	10.5	0.50	35.0	3.25
W–DT–H	6.44	0.143	12.4	0.50	48.4	3.25

Table 10. Univariate ANOVA results and least-square means contrasts for interior spruce at age 20. Primary treatments are burn (B), spray and burn (SB), or windrow (W); secondary treatment is either disc-trenching (DT) or no disc-trenching (NDT); and tertiary treatment is either herbicide (H) or no herbicide (NH). Probability values ≤ 0.05 are in bold.

Univariate ANOVA		**Height**			**Diameter**			**Volume**		
Effect	Num DF	Den DF	F Value	Pr > F	Den DF	F Value	Pr > F	Den DF	F Value	Pr > F
Primary Treatment	2	15	13.78	**0.001**	6	6.30	**0.034**	15	11.91	**0.001**
Disc-trenching	1	15	16.62	**0.001**	9	3.82	0.083	15	10.04	**0.006**
Herbicide	1	18	6.84	**0.018**	18	26.59	**< 0.0001**	18	29.11	**<.0001**
Burn: DT	1	15	1.01	0.3302	9	0.01	0.9452	15	0.21	0.6533
Burn: H	1	18	2.32	0.1453	18	6.82	**0.0177**	18	5.89	**0.0259**
Burn: DT x H	1	18	0.14	0.7098	18	0.06	0.8172	18	0.01	0.9435
Spray and Burn: DT	1	15	7.49	**0.0153**	9	0.50	0.4954	15	2.47	0.1365
Spray and Burn: H	1	18	3.69	0.0706	18	9.62	**0.0062**	18	14.95	**0.0011**
Spray and Burn: DT x H	1	18	2.78	0.1125	18	4.54	**0.0472**	18	3.11	0.0949
Windrow: DT	1	15	11.00	**0.0047**	9	6.77	**0.0286**	15	11.95	**0.0035**
Windrow: H	1	18	1.18	0.2926	18	10.36	**0.0048**	18	9.31	**0.0069**
Windrow: DT x H	1	18	1.69	0.2103	18	8.40	**0.0096**	18	8.76	**0.0084**

Least-square Means	**Height**			**Diameter**			**Volume**		
Mean (difference)	Estimate	Std. Err	Pr > |t|	Estimate	Std. Err	Pr > |t|	Estimate	Std. Err	Pr > |t|
B vs. SB	-0.57	0.109	**0.001**	-1.5	0.42	**0.013**	-11.6	2.39	**0.001**
B vs. W	-0.35	0.109	**0.006**	-0.4	0.42	0.332	-4.7	2.39	0.066
SB vs. W	0.22	0.109	0.059	1.0	0.42	0.053	6.9	2.39	**0.012**
NDT vs. DT	-0.36	0.089	**0.001**	-0.6	0.33	0.083	-6.2	1.95	**0.006**
NH vs. H	-0.17	0.067	**0.018**	-0.9	0.18	**< 0.0001**	-7.0	1.29	**<.0001**
B–NDT vs. B–DT	-0.16	0.154	0.330	0.0	0.57	0.945	-1.5	3.38	0.653
SB–NDT vs. SB–DT	-0.42	0.154	**0.015**	-0.4	0.57	0.495	-5.3	3.38	0.137
W–NDT vs. W–DT	-0.51	0.154	**0.005**	-1.5	0.57	**0.029**	-11.7	3.38	**0.004**
B–NDT–NH vs. B–NDT–H	-0.22	0.163	0.196	-0.9	0.44	0.059	-5.6	3.16	0.094
B–DT–NH vs. B–DT–H	-0.13	0.163	0.429	-0.7	0.44	0.110	-5.3	3.16	0.113
SB–NDT–NH vs. SB–NDT–H	-0.41	0.163	**0.021**	-0.3	0.44	0.501	-4.7	3.16	0.154
SB–DT–NH vs. SB–DT–H	-0.03	0.163	0.860	-1.6	0.44	**0.002**	-12.6	3.16	**0.001**
W–NDT–NH vs. W–NDT–H	0.02	0.163	0.881	-0.1	0.44	0.823	-0.2	3.16	0.949
W–DT–NH vs. W–DT–H	-0.28	0.163	0.109	-1.9	0.44	**0.001**	-13.4	3.16	**0.001**

in the windrow treatment (39% increase in volume), but differences were not significant in either the spray and burn (except for height) or the burn treatments.

The tertiary treatment (weeding) had significant effects on tree growth in more instances than observed for lodgepole pine, suggesting that competition with other vegetation at 3 years after planting was still a factor affecting growth. The treatments with significant responses to weeding were: the spray and burn–disc-trenching and the windrow–disc-trenching (for diameter and volume), and spray and burn–no disc-trenching (for height). These treatments showed average increases of 35% in volume, 16% in diameter, and 7% in height compared to the corresponding treatment combinations without herbicide. Other studies indicate that competing vegetation affects diameter growth of interior spruce more than height growth (e.g., Wagner et al. 1999; Macadam and Kabzems 2006).

4.2.3 Growth Projections

Site indices (SI_{50}) estimated for spruce ranged from a low of 21.0 to a high of 23.3 (average = 22.2) (Table 11), but mean heights within treatments averaged 2.1 m less than the top heights used to estimate SI_{50}, primarily due to the frequency of repetitive leader attacks by white pine weevil (Figure 7). The low mean height/diameter ratio (0.6) observed at 20 years also suggests a problem with spruce development. Custom TASS projections based on SI_{50} estimates, observed mortality, and establishment densities generated estimates of quadratic mean diameter at age 20 that grossly underestimated the measured values and consequently we chose not to use TASS to project spruce growth beyond 20 years (Figure 8).

Table 11. White spruce site index (SI_{50}) values calculated at age 20 by treatment. Minimum, maximum, and average values are in bold.

Primary Treatment	Disc-trenching	Herbicide	SI_{50} (m)
Burn	No	No	21.7
		Yes	21.5
	Yes	No	22.0
		Yes	22.1
Spray and Burn	No	No	**21.0**
		Yes	23.2
	Yes	No	22.3
		Yes	22.9
Windrow	No	No	21.8
		Yes	22.8
	Yes	No	22.2
		Yes	**23.3**
Average			**22.2**

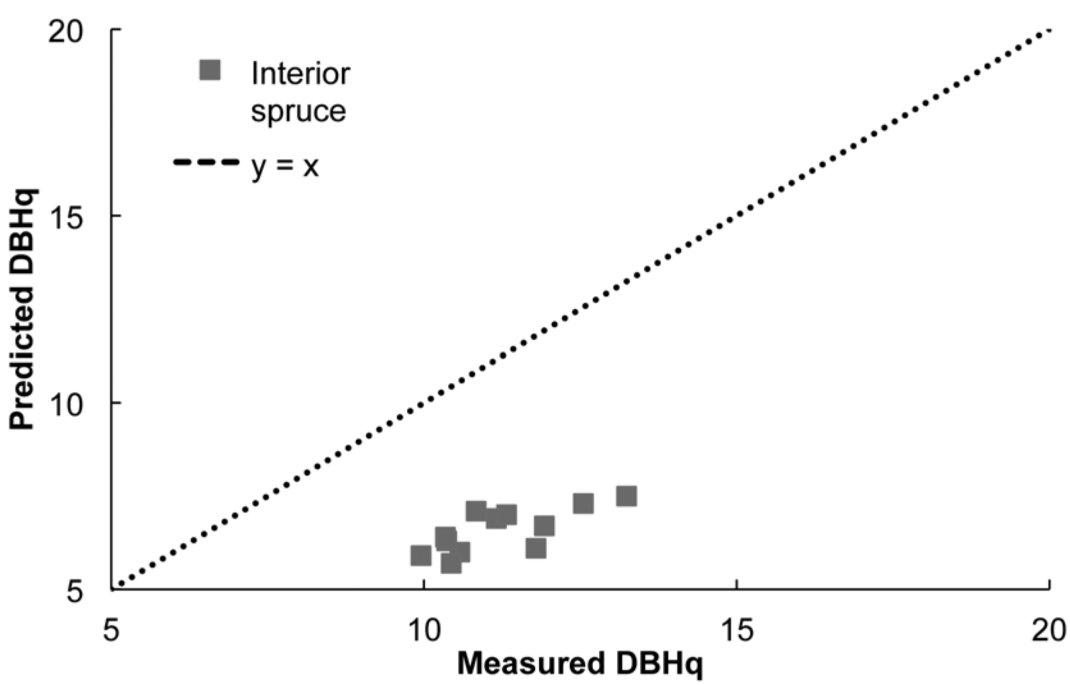

Figure 8. Comparison between observed values of quadratic mean diameter at breast height (DBHq) and DBHq values predicted by TASS for interior spruce.

5. Summary and Recommendations

The Stony Lake trial was established in 1987 to evaluate the growth of interior spruce and lodgepole pine trees planted into 12 treatment regimes for rehabilitating an understocked sub-boreal spruce site (SBSwk1). All combinations of three options for primary site clearing (burn, spray and burn, or windrow), two options for secondary site preparation (disc-trenching or no disc-trenching), and two options for tertiary weeding treatment (broadcast application of herbicide 3 years after planting or no treatment) were tested. This report documents the status of planted seedlings 20 years after planting, and uses growth data from the first 20 years to project potential yield, harvest date, and expected value at rotation. Key findings and recommendations are summarized below.

5.1 Survival

Twenty years after planting, both species had excellent vigour and very high survival rates (88–97% for lodgepole pine; 93–99% for interior spruce). In spite of high mountain-pine-beetle pressure 2–3 years preceding the final assessment, < 2% of pine saplings were attacked and no viable outbreak developed on the site.

5.2 Condition

Lodgepole pine had much less evidence of damage that could affect future survival or sawlog form than did interior spruce. Nine percent of pine had stem rusts and 12% had potential stem form problems, while 52% of the spruce had white pine weevil damage and 41% had potential stem form problems. These data raise some concern for the likelihood of reaching saw timber objectives with interior spruce on this site and we recommend further study to quantify the extent and impact of weevil damage on sawlog form and value.

5.3 Tree Size and Stand Volume

Twenty years after planting, lodgepole pine saplings were much larger than interior spruce. Within treatment regimes, they were 57–82% taller, 28–58% larger in diameter, and produced 2.1 to 3.3 times as much total volume per hectare at 20 years total stand age. Mean total stand volume ranged from 61 to 112 m^3/ha for lodgepole pine, but all treatment regimes produced > 95 m^3/ha at 20 years, except the burn-only treatment (61 m^3/ha) and one windrow treatment (82 m^3/ha), which suffered significant mountain pine beetle mortality apparently unrelated to treatment. In contrast, total volume for interior spruce ranged from 28 to 52 m^3/ha (always less than half the corresponding volumes for lodgepole pine).

Site-clearing treatments significantly affected total stand volume for both species. For interior spruce, stand-level volume in the four combinations that included spray and burn was 37% higher on average than those in the combinations that included the burn, and 19% higher than those with windrowing. Similarly, for lodgepole pine, regimes initiated with the spray and burn produced 17% more volume than those with burn-only and 8% more than those with windrowing.

Subsequent treatments interacted significantly with the primary treatment and the two species responded somewhat differently. In the burn-only combinations, where the primary treatment did not provide effective control of competing vegetation over the first several years, any follow-up treatment (disc-trenching, herbicide application in the third growing season, or both) increased stand volume at 20 years by about 60% for lodgepole pine. In contrast, disc-trenching or herbicide application increased volume by only 6% and 20% respectively for spruce, while combining both treatments produced 25% more volume than burning alone.

In the spray and burn treatment, which was more effective at controlling early competition with seedlings, individual follow-up treatments had much less effect on lodgepole pine volume at 20 years (a 5% increase with disc-trenching, no apparent benefit from herbicide application 3 years after planting, and only a 12% increase from combining both treatments). For spruce, disc-trenching, herbicide application, and the combination treatment increased volume by 4, 12, and 37% respectively.

Similarly, in regimes initiated with the windrow treatment, lodgepole pine volume increased 11% with disc-trenching, but only 6% after combining disc-trenching and herbicide application. Any effects of herbicide application alone were obscured by mortality from mountain pine beetle attack just prior to the last assessment. In contrast, disc-trenching resulted in a 17% increase in spruce volume and there was no apparent benefit from herbicide application, but the combination of both treatments resulted in a 62% increase over windrowing alone.

These results suggest that good lodgepole pine growth on sites like the Stony Lake research area requires fewer entries at establishment than would be needed for interior spruce, and will produce larger trees and much higher stand-level volumes much earlier.

5.4 Growth Projections

Repeated attack by leader weevils reduced height growth of interior spruce saplings too much to allow the use of customized TASS runs to project future growth. However, custom TASS projections based on SI_{50} estimates for lodgepole pine predicted quadratic mean diameter at age 20 that agreed quite closely with observed values, suggesting the growth projections for that species can be used with confidence.

Pine simulations predicted that an intensive combination of clearing and site preparation (i.e., spray and burn–disc-trenching–no herbicide) could potentially yield 300 m^3/ha within 40 years of planting, which is 10–20 years earlier than less effective treatments (e.g., burn–no disc-trenching–no herbicide). This suggests that early growth advantages observed at 20 years should yield higher stand volume and larger logs with potential for a higher-value recovery when harvested in the future. Although high stand-level volume is desirable, and larger piece size is an important determinant of log and lumber grade, these are not the only factors affecting value of the future harvest. Long-term research sites such as Stony Lake provide an opportunity to look at the effect of rapid growth in managed stands on wood quality and fibre attributes (e.g., ring width, knot size, stiffness, mature fibre length) that may confer higher (or lower) value. The authors strongly believe in the importance of monitoring long-term studies such as the Stony Lake trial, and recommend further investigation of the impacts of pests, diseases, and rapid growth rates on future log quality, fibre attributes, and value return.

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