Soil properties and tree growth on rehabilitated forest landings in the interior cedar hemlock biogeoclimatic one: British Columbia

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Abstract

We studied operational landing rehabilitation programs in three forest districts of interior British Columbia (BC). Winged subsoiling and grass/legume seeding, followed b planting of lodgepole pine ([illegible] var. [illegible]) generall resulted in successful re-establishment of forest cover on landings. In the Boundar district, fth ear tree heights on landings were not signi cantl different from those in adjacent plantations, and fth ear growth increments were also similar despite evidence of dela ed seedling establishment caused b cattle gra ing damage. Trees on landings in the Kalum district were shorter than those in plantations, but fth ear increments were similar. Landings in the Kalum with >20% cla had lower stocking densities, tree heights, and probe depths compared to landings with <20% cla content. In the Kispio district, average fth ear tree heights and fth ear increments were lower on landings than those on plantations. In the Kispio district, landings with >20% cla content had shorter trees growing on them when compared to tree heights on landings with <20% cla . Landings in the Kispio had the least probe depth of the three districts, and the greatest difference in height and increments between landings and plantations, supporting eld reports of poor decompaction effectiveness there. In all districts, there was

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Soil rehabilitation is an important component of forest management strategies aimed at reducing the effect of soil degradation on forest productivit (Froehlich and McNabb, 1984; Forest Practices Code of British Columbia, 1995a). The success of such strategies depends on the establishment and favourable growth of commercial tree species on rehabilitated soils.

Forest soil degradation can result from the passage of heav logging equipment over unprotected soils, and from construction of trails, access roads and log landing areas (Froehlich, 1988). Log landings are constructed b removing surface soils and levelling the site, and the landing area e periences intensive use b heav equipment and loaded log trucks during loading operations. Degraded soils on landings are often characteri ed b compaction and displacement of surface soils rich in organic matter and nutrients (Greacen and Sands, 1980; Krag et al., 1986). Soil rehabilitation usuall involves techniques that alleviate soil compaction, and ma include steps to restore organic matter and nutrients (Bulmer, 1998).

A variet of equipment options is available for rehabilitation of forest soil. The winged subsoiler was shown to be effective for decompaction in Oregon (Andrus and Froehlich, 1983), and was previousl used successfull in BC (Carr, 1989). However, the winged subsoiler was not effective on medium- and ne-te tured soils in Alberta because of adverse soil moisture conditions during treatment (McNabb, 1994).

The objective of our stud was to compare soil properties and tree growth on rehabilitated sites with those on adjacent forest plantations. We used the retrospective stud approach (Powers, 1989a; Smith, 1998) to evaluate the productivit of a group of landings that were rehabilitated b operational forestr staff in the earl 1990s. Long-term treatment effects in forests are often hard to evaluate because of the long maturation time of forest trees, so retrospective studies of e isting sites have a role in providing interim information before results from designed e periments are available.

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Stud sites were randoml selected from a complete list of 368 rehabilitated forest landings in the Boundar , Kalum and Kispio forest districts of interior BC (Table 1). Landing soils were decompacted with a winged subsoiler in 1991 and a mi ture of grass and legume seed was applied. In the Kalum district, additional treatments involved spreading an ash piles over the landing area, and adding 200 kg ha^{-1} of 19 23 15 fertili er. Landings in all districts were planted with lodgepole pine seedlings in 1992. Plantations in all districts were clear-cut harvested between 1987 and 1990, and replanted with lodgepole pine seedlings. A total of 88 landing sites and adjacent plantations were sampled between Ma and August 1998. All sites were within the interior cedar hemlock (ICH) biogeoclimatic one.

Three circular, 0.005 ha subplots were randoml located on each sampled landing, ensuring that all portions of a landing had an equal probabilit of being selected. Three subplots were randoml located in the adjacent plantation along a transect that best resembled the slope, aspect, and landscape position of the landing. Plantation plots were onl established in areas where more than three lodgepole pine seedlings were growing, and where there was no evidence of detrimental soil disturbance caused b logging equipment. We assumed that the tree heights determined for adjacent plantation sites re ected the growth potential, or "e pected" growth for lodgepole pine at each site.

In the Boundar district, harvested areas are often used for cattle gra ing, which can affect both the landing areas and the adjacent plantations. Because gra ing is widel practiced in the Boundar district, we considered cattle to be part of the ecos stem there, and simpl recorded the gra ing intensit on each plot as indicated b signs of cattle. No gra ing occurred in the Kispio and Kalum districts.

[illegible]

For each subplot, we recorded percent slope, aspect, presence of standing water, evidence of post-subsoiling soil disturbance, evidence of cattle gra ing,

Table 1

Characteristics of the stud sites in Boundar , Kalum and Kispio , forest districts

Forest district, major town: latitude/longitude	Ecological classification[a]	No. of sites	Elevation range (m.a.s.l.)	Mean annual temperature[b]	Mean annual precipitation[b] (mm)	Parent material[c]	Soil classification[d]
Boundar , Grand Forks:	ICHdw	2	1200 1275	7.6	471	Colluvium	Humo-ferric
49.0°N latitude/118.5°W longitude	ICHmw	15	1275 1540			Moraine	Pod ols
	ICHmk	14	720 1500				Eutric Brunisols
Kalum, Terrace:	ICHmc	25	400 620	6.1	1136	Alluvium	Humo-ferric
54.5°N latitude/128.5°W longitude						Colluvium	Pod ols
						Morainal	D stric Brunisols
Kispio , Ha elton:	ICHmc	32	340 500	4.3	625	Morainal	Humo-ferric
55.3°N latitude/127.7°W longitude						Colluvium	Pod ols

[a] Braumandl and Curran (1992), Banner et al. (1993). d, dr ; m, moist; w, warm; k, cool, c, cold.

[b] Boundar : Grand Forks (Environment Canada, 1993); Kalum: Terrace (Environment Canada, 1993); Kispio : Temlahan (Environment Canada, 1982) and Date Creek (Coates et al., 1997).

[c] Holland (1976), Banner et al. (1993) and Coates et al. (1997).

[d] Luttmerding (1992), Luttmerding (1994) and Banner et al. (1993).

characteristics of non-coniferous vegetation, presence of coarse wood debris (CWD) and forest oor depth. All undamaged and unsuppressed lodgepole pine trees taller than 0.15 m were counted to determine the stocking densit , and height increments for each ear of growth were recorded.

Soil temperature was recorded at each subplot at the 0.10 m depth. Soil temperature measurements on paired landing and plantation plots usuall occurred within 1 h, and never e ceeded 1.5 h. Soil water content of surface soil was determined at each subplot, either using a theta probe (Delta T devices) or b gravimetric anal sis.

A hand-pushed 0.013 m diameter steel probe was used to determine depth to a restricting or compacted la er. An estimated force of 68 kg was applied to the probe, representing a cone inde value of appro i-matel 5000 kPa. Probe measurements were taken at a minimum of 15 locations within each subplot. Ma imum, minimum, and average probe depth was recorded, along with a description of obstructions such as bedrock, buried CWD, or large coarse fragments that ma have halted the probe. Probe depths as determined with this method were considered to represent depth of loose soil available for rooting.

Composite soil samples were collected throughout the top 0.25 m of mineral soil at three locations within each subplot (Petersen and Calvin, 1986). Samples were air dried and passed through a 0.002 m sieve to separate coarse and ne soil fractions. Total C and N were determined b dr combustion using a Fisons NA-1500 elemental anal ser (Tiessen and Moir, 1993; McGill and Figueirdo, 1993). Min-N was determined from ammonium-N in a KCl e tract of soil following a 2 week anaerobic incubation at 30 °C (Bremner, 1996). Particle si e distribution was determined for all samples using a variation of the h drometer method (Gee and Bauder, 1986). Soil pH in 0.01 M calcium chloride ($CaCl_2$) solution was also determined (Hendershot et al., 1993).

On a randoml selected subset of 10 landings and adjacent plantation sites within each district, bulk densit samples were collected to 0.15 m depth using an e cavation method (modi ed from Blake and Hartge, 1986). Bulk densit samples were dried and sieved through 0.002 m to remove coarse mineral and organic fragments, and ne fraction bulk densit was calculated (Culle , 1993; Federer et al., 1993).

Foliage samples were collected (Ballard and Carter, 1985) during the dormant season from the same sites where bulk densit was determined. Foliage samples were oven-dried at 70 °C for 16 h, and ground. Total C and N were determined using a Fisons NA-1500 elemental anal ser. Total Ca, K, Mg, P, S, B, Cu, Fe, Mn and Zn were determined b ICP-AES following a microwave assisted, strong acid digestion (Kalra and Ma nard, 1991).

Paired -tests were used to test for signi cant differences ($\alpha = 0.05$) between landing and plantation sites within each district. Landing and plantation values used in paired comparisons (-tests) were comprised of averages generated from the three subplots on each site. Where no signi cant differences were found, power $(1 - \beta)$ was calculated using software developed b Borenstein and Cohen (1988).

Pearson correlations were applied to selected variables describing growth, soil factors and foliage nutrient concentrations, and although some correlations were chosen a priori, Bonferroni adjusted probabilities were used throughout since the are appropriate when scanning a data matri for signi cant correlations (Wilkinson et al., 1997). Simple correlations were calculated using all subplots (landing and plantation) within each district, both separatel and in combination. Variables that did not meet underl ing statistical assumptions (Norcliffe, 1987), especiall concerning normalit , were either square root or log transformed.

To evaluate the effect of cla content on establishment, growth and other soil variables, -tests were used to compare subplots with >20% cla and those with <20% cla . The 20% value was chosen because it separates the sand loam te ture class from sand cla loam (Gee and Bauder, 1986), and also appro imates the level of 15% cla , above which soils can e hibit plastic behaviour (Brad , 1996).

3. R

Landing construction resulted in complete removal of forest oor (L + FH), and CWD coverage of the ground surface was substantiall lower for landings than plantations (Table 2). Seven ears after subsoiling, no forest oor development was observed. The CWD we observed on landings was either buried in the soil surface during landing construction and unearthed b the subsoiler, or it was debris that had remained on the surface after logging and loading operations.

Kalum, and 1289 stems ha^{-1} for Kispio . The Forest Practices Code of British Columbia (1995b,c) de nes target densities of well-spaced lodgepole pine, for the ICH sub ones studied here, as a range between 1000 stems ha^{-1} and 1200 stems ha^{-1}, with minimum stocking levels of 500 700 stems ha^{-1}. These results indicate that most of the subsoiled landings supported acceptable forest cover.

In the Boundar , 8 of 31 landings had no established trees with at least 5 ears growth compared with 1 of 25 landings in the Kalum, and 1 of 32 landings in the Kispio . Evidence of gra ing cattle was observed on 6 of 31 landings (19%) in the Boundar . Planting records showed that 5 of the 6 gra ed landings required ll-planting to replace dead trees, compared with 5 of the remaining 25 landings. Seedlings are most at risk to trampling and browsing damage b cattle in the rst 2 ears after planting (Newman and Powell, 1997). Our results support the conclusion that cattle gra ing damage contributed to low survival on some sites in the Boundar .

Five ears after establishment, trees on landings were shorter than plantation trees in both Kalum (= 0.00) and Kispio (= 0.00). Tree heights were not signi cantl different between landings and plantations in the Boundar (power = 0.014). Five ears after establishment, the growth rate of trees on landings and plantations appeared equal in the Boundar district (Fig. 2) and in the Kalum district (Fig. 3). For the Kispio district (Fig. 4), fth ear growth rate was lower on landings than on LT.n

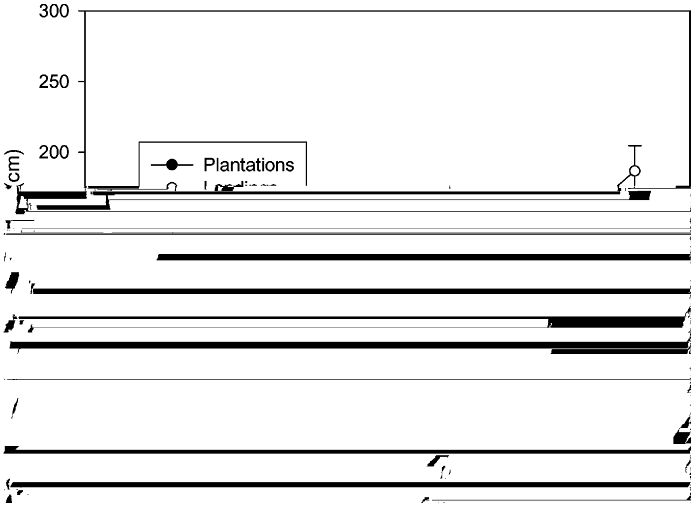

Fig. 2. Growth of lodgepole pine on landings and plantations in the Boundar forest district. Trees on landings and plantations had similar height after 5 ears. Error bars represent point-wise 95% con dence intervals.

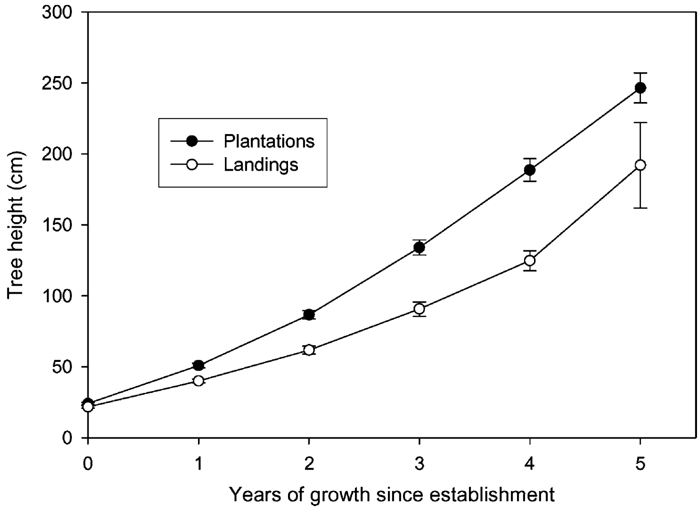

Fig. 3. Growth of lodgepole pine on landings and plantations in the Kalum forest district. Trees on landings were shorter than those on plantations. Error bars represent point-wise 95% con dence intervals.

Table 3
Comparison of average height of established trees (m) after 5 ears growth[a]

	Boundar			Kalum			Kispio		
	Height	S.D.		Height	S.D.		Height	S.D.	
Landing	1.29	(0.29)	23	1.25 a	(0.26)	24	1.07 a	(0.34)	31
Plantation	1.24 bc	(0.18)	31	1.89 abd	(0.29)	25	2.11 acd	(0.31)	32

[a] Values with the same letter represent signi cant differences at < 0.05.

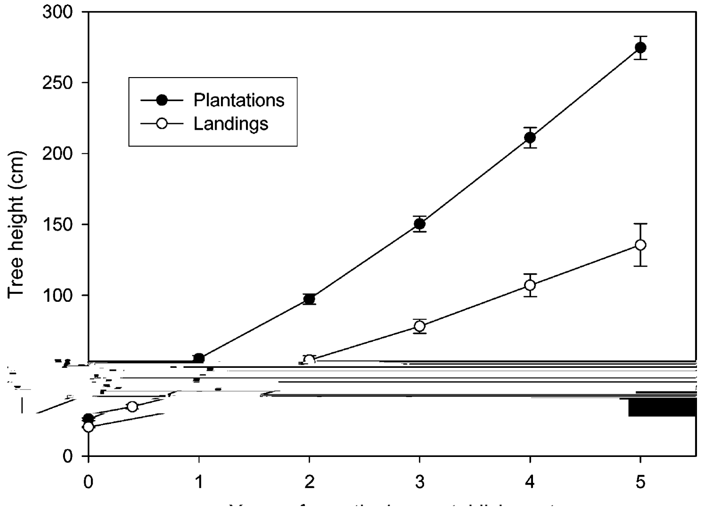

Fig. 4. Growth of lodgepole pine on landings and plantations in the Kispio forest district. Trees on landings were generall shorter than those on plantations. Error bars represent point-wise 95% con dence intervals.

[illegible]

The most common surface soil te tures for all sites were sand loam, loam and loam sand (Table 4). In the Boundar district, 100% of landings and 81% of plantations had te tures of sand loam or coarser. In the Kalum district, 44% of landings and 12% of plantations had soil te ture of sand cla loam or ner. Cla content was similar for landings and plantations in the Boundar district, while Kalum and Kispio landings had higher cla content than plantations (Table 5). Te ture affects response to soil disturbance (Powers, 1989b), and the subsequent effects on root growth through processes such as water retention, aeration, and soil strength development (Jones, 1983; Kramer and Bo er, 1995).

Differences in te ture and coarse fragment content between landings and plantations in Kalum and Kispio (Table 5) ma re ect differences between surface soils and subsoils that were uncovered b removal of the upper la ers during landing construction. Man of the landings had debris and surface soil piled at the perimeter.

Table 4
Number of sites b average te ture class, b district

	Sand	Loam sand	Sand loam	Loam	Silt loam	Sand cla loam cla loam	Silt cla loam silt cla	Cla	Total
[illegible]									
Landing	1	5	25	0	0	0	0	0	31
Plantation	0	3	22	1	5	0	0	0	31
[illegible]									
Landing	0	3	10	1	0	5	2	4	25
Plantation	0	3	13	6	0	3	0	0	25
[illegible]									
Landing	0	4	17	9	1	1	0	0	32
Plantation	0	2	21	9	0	0	0	0	32
Total	1	20	108	26	6	9	2	4	176

plant moisture stress on dr sites (Brad , 1996; Nambiar and Sands, 1993). Summer moisture de cits in the ICH are not so severe as in other biogeoclimatic ones, however, so drought stress ma be less of a concern than in other areas.

Surface soil bulk densities were higher for landings than plantations onl in the Boundar (Table 5). For all landings in the Kispio was too shallow to allow tress to achieve their e pected growth.

Probe depth was strongl and inversel correlated with cla content for landings in the Kalum district (Table 7). Landing subplots with >20% cla in the Kalum also had lower stocking (= 0.00), height (= 0.02) and probe depth (= 0.00) than subplots with <20% cla (Fig. 6). Grass cover was higher for ne-te tured soils leading to reduced establishment success and earl growth of planted trees.

Other studies have also shown that subsoiling and deep tillage treatments were more successful on coarse te tured soils (Andrus and Froehlich, 1983; Froehlich and McNabb, 1984). The amount of soil loosening achieved b subsoiling depends on soil te ture and water content because these factors in uence soil strength, and the ef cienc with which energ is transferred from the subsoiler up through the soil pro le (Bulmer, 1998). Soil strength is particularl dependent on moisture in ne-te tured soils (Greacen and Sands, 1980), so effective decompaction of ne te tured soils strongl depends on water content at the time of treatment (Fewer, 1992; McNabb, 1994).

Foliar N concentrations and tree height on Kalum plantations (Table 8) showed a negative correlation, suggesting dilution of N (Timmer and Stone, 1978; Ballard and Carter, 1985). Average foliar P concentrations for both Kalum and Kispio plantations were also negativel correlated with tree height (Table 8) also suggesting dilution. Average foliar P and K concentrations showed positive correlations with tree heights and/or 1998 height increments for Boundar plantations, Wh(I <Weif(Hth)TaW.aT*ILcrem(IKT Wents(I>

these sites. In general, relations between foliar and soil variables could not be described b simple linear correlations.

the importance of prescribing reclamation equipment that is appropriate to the soil conditions, and ensuring that it is working as intended during the operational phase of the work.

Seven ears after subsoiling, restored soils on landings in all districts had no forest   oor, and cover of non-coniferous vegetation was substantiall below that of adjacent plantations, which ma have contributed to favourable establishment and earl growth of trees on some sites through bene cial effects on soil temperature and moisture. Landing soils had lower concentrations of total C, N and min-N than plantations in the Boundar and Kispio . Such differences were not observed in the Kalum, which supports recommendations that replacing topsoil and associated ash piles is effective for replenishing organic matter and nutrients that were lost from degraded soils.

Despite differences in soil nutrient levels, foliar nutrient concentrations on all sites were generall adequate or onl slightl de cient, with the e ception of S. Differences in foliar nutrient concentrations for trees on landings relative to plantations were likel a enhance growth rates. However, correlations suggest some growth response could be reali ed with increased availabilit of P and K on Boundar plan-

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