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British Columbia
Ministry of
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ABSTRACT

The effects of logging, using the feller-buncher/grapple-skidder equipment combination, on cone distribution in lodgepole pine (Pinus contorta Dougl. var. latifolia Engelm.) in the southern Interior of British Columbia are reported. Ingress of regeneration occurred at approximately the same rate as with older, conventional methods of logging. However, it was recommended that additional cone-bearing slash be left on logged areas to ensure, in conjunction with scarification, satisfactory stocking levels within minimum time.

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INTRODUCTION

Conventional harvesting methods, which combined hand felling, shears, or feller-bunchers with line-skidding, normally left sufficient numbers of well-distributed slash-borne, serotinous cones on the logged areas (Clark 1974). During the mid-1970's, however, a change to the feller-buncher/grapple-skidder equipment combination and the removal of stems with complete crowns to central topping and sorting areas, raised questions concerning adequacy of seed supply for natural regeneration.

The amount of seed stored in serotinous cones provides an estimate of potential natural regeneration when stands of lodgepole pine (*Pinus contorta* Dougl. var. *latifolia* Engelm.) are harvested. If the probability of a seedling becoming established from seed is known, then one can estimate the number of cones and seeds required for minimum satisfactory stocking.

Estimates of the number of viable lodgepole pine seed required to produce one established seedling vary considerably. Prochnau (1963) suggested 10, Lotan (1964) estimated 30-50, and Lotan and Perry (1977) calculated fifth year seed/seedling ratios ranging from 29 to 7333 depending upon seedbed treatment and habitat type. These estimates of viable seed requirements may, for more practical purposes, be translated into number of cones required to produce an established seedling or to produce a desired stocking level at a specific time. For example, Glen (1978) estimated that between 10 000 and 25 000 cones per hectare, depending upon the average number of viable seeds per cone, are required to ensure satisfactory stocking. Glen assumed that 100 viable seeds are necessary to produce one five-year-old seedling. He recommended a minimum of three cones on 75% of 5-m^2 sample plots for satisfactory cone distribution. In Alberta it was recommended that, to obtain a minimum stocking of 40%, at least 25 000 cones per hectare be available if scarification takes place one year following logging (Anon. 1971). Clark (1974) examined the relation between number of cones and number of seedlings, or percentage stocking, and suggested that a minimum of 14 000 cones per hectare are required on unscarified areas to achieve satisfactory stocking.

Although minimum cone requirements are based on the assumption that cones will be distributed on favourable seedbeds on scarified or unscarified areas, the absolute number of cones in relation to type of seedbed is unknown. Also, because the quantity of lodgepole pine regeneration occurring on an area is a function of time since harvest (Crossley 1976; Johnstone 1976; Glen and Ackermann 1978), the finite relationship between cones and seedbed becomes somewhat conjectural. Most importantly, the method of tree harvesting and post-harvesting slash treatment affects the quantity and distribution of cones. The present report summarizes a study initiated to investigate these concerns.

The objectives of this study were: 1) to determine whether the number of cones remaining on areas logged by the feller-buncher/grapple-skidder equipment combination are sufficient for adequate natural regeneration; and 2) to determine seedbed distribution after logging and to relate this to seedling stocking in subsequent years.

METHODS AND MATERIALS

General

Areas of lodgepole pine logged using the feller-buncher/grapple-skidder equipment combination were sampled in an approximately systematic pattern. The type of seedbed, the category and number of open and closed cones on the ground and in the slash, and the amount and species of seedlings by age-class were determined. In addition, information was recorded on size of area, date and season of logging, date and method of post-logging site preparation, aspect, ecological description, elevation, stand age, average amount of cone bearing slash for the area as a whole, and a percentage rating for number of serotinous (closed) cone-habit trees in the perimeter stand. Sixteen areas, ranging in size from 9 to 72 ha, were included in the project.

Cone Survey

Lodgepole pine cones on slash and on the ground were recorded within 5-m^2 sample plots of 1.26-m radius, with at least four plots per hectare (0.2%) for each of the 16 areas. The number of cones, up to a maximum of 10, were recorded as open or closed for each of three main categories: Category I - usually brown, bronze, or gold colour on all faces, age approximately 2 years; Category II - usually bronze, brown, or gold on one face and on others grey (weathered), age 3 to 5 years; Category III - generally grey with a weathered appearance on all cone faces, greater age than Category I and II cones (Anon. 1971). Category III cones are normally not recommended for collection (Anon. 1972) and, although recorded in this study, were not considered in the assessment of "acceptable" cone distribution.

Cone distribution in a sample plot was rated as acceptable if there were 1) five or more cones per plot on 70% or more plots, where less than 70% of the plot area had mixed mineral-organic (disturbed) or mineral seedbed; or 2) three or more cones per plot on 70% or more plots, where more than 70% of the area had mixed mineral-organic or mineral seedbed.

Seedbed Survey

Each 5-m^2 sample plot was also classified according to prevalent seedbed condition. Seedbed classes recognized were: mineral (M), if the plot contained a minimum of 225 cm^2 of mineral soil (plots situated on landings, roads, or skidtrails were excluded); disturbed (D), where the organic surface had been disturbed to produce a mineral-organic mixture; undisturbed (U), representing no disturbance at the forest floor; and no seedbed (NS), where rock, water, logs, or stumps predominated.

Regeneration Survey

The 5-m^2 cone-survey sample plots were used to assess quantity of regeneration by species and age-class each year, over a period of five years. The total number of seedlings were recorded for each plot as germinants, one-year-olds, two-year-olds, and three-year-olds and older; or as advanced regeneration if they were established prior to harvesting. The assessment of seedling age was done subjectively by the researchers.

Areas were judged to be satisfactorily regenerated if 40% or more of the 5-m^2 plots were stocked with an acceptable established seedling, i.e., either one 3-year-old or older, two 2-year-old, or three 1-year-old seedlings or germinants.

Descriptive data for areas sampled are shown in Table 1. The analysis is exploratory in nature. Any aspects requiring confirmation should be investigated in subsequent studies.

RESULTS AND DISCUSSION

General

Six of the 16 areas sampled (No. 3, 4, 9, 10, 11, and 14) had stands with a mixed cone habit, with more than 20% but less than 80% of dominants and co-dominants having serotinous cones (Table 1). This is not uncommon (Clark 1974), and is of minor importance if a sufficient number of the serotinous cones are available on the ground or in the slash for seed supply following logging. Area 3 was the only area with a mixed cone habit that met cone distribution requirements relative to quality of seedbed (Table 2). However, with mixed cone habit both Area 3 and 14 attained minimum satisfactory stocking (Table 2).

Although nine of the 10 remaining areas supporting stands with a serotinous cone habit (Table 1) did attain the minimum satisfactory stocking level, only three met the cone distribution requirements according to quality of seedbed (Table 2). Cone habit, cone distribution, and stocking were, apparently, unrelated to such factors as elevation, aspect, slope, and biogeoclimatic zone.

Cone Distribution, Seedbed and Regeneration

The stocking of natural regeneration achieved four to six years after site disturbance on each area can be compared with previously defined standards for acceptable cone distribution. Figure 1 illustrates stocking relative to quality of initial seedbed and cone distribution, and Figure 2 shows the relationship of stocking to time following disturbance. These figures illustrate that stocking levels are generally higher, and minimum satisfactory levels attained earlier, if quality seedbed and cone distribution are within acceptable ranges. In general, the highest rate of stocking is obtained where seedbed and cone distribution are both acceptable and sufficient (e.g. Area 1 and 5), but acceptable stocking may also occur where seedbed quality is

TABLE 1. Descriptive data for sampling areas

Area	(ha)	Elev. (m)	Aspect	Slope (%)	Drainage	Ecological Class-ification[2]	Soil texture[3]	Percent of stand serotinous[4]	Year of logging	Site preparation	
										Year	Method
1.	**24.3**	1525	N	0-10	Poor	MSc	cl lo	90	77-78	78	Drag
2.	**67.0**	1524-1584	SE	15	Good	MSc	gr lo	90	77-78	78	Drag
3.	**72.0**	1447	N-S	0-10	Poor	MSc	sa cl lo	70	77-78	78	Drag
4.	**12.0**	1554	SE	0-10	Poor	MSc	sa cl lo	75	77-78	78	Drag
5.	**14.2**[1]	1296	W	0-15	Variable	IDFb1	sa cl lo	80	75	76	Drag
6.	**55.7**	1430	N	0-30	Mod. well	IDFb1	sa cl lo	90	77	*Nil*	
7.	**21.0**	1370	SE	0-40	Rapid	MSc	sa lo	80	77	*Nil*	
8.	**26.3**	1707-1768	SE	0-30	Well	ESSFe	sa lo	90	76	*Nil*	
9.	**33.2**	1700	SE	0-35	Mod. to poor	MSc	sa cl lo	50	78	*Nil*	
10.	**15.0**	1800	SE	5-20	Mod. well	MSc	cl lo	70	77-78	78	Drag & Blade
11.	**31.0**	1700	S	5-20	Mod. well	MSc	si lo	70	77	*Nil*	
12.	**32.4**	1395	N	0-30	Good	MSc	cl lo	90	77	*Nil*	
13.	**28.7**	1450	Var.	0-10	Poor	MSc	cl lo	90	77	77	Drag
14.	**50.6**	1311	S	0-30	Mod.	MSc	cl lo	60	76-77	78	Part Drag Part Burn
15.	**9.0**	1067	E-N	15-30	Rapid	IDFd1	gr lo	90	77	77	Drag
16.	**41.0**	1433	N	5-35	Good to mod. poor	MSb1	lo	80	77	77	Drag

[1] Area 5 partially hand-felled.

[2] Zonal ecosystem associations are characteristic of broad geographical areas of similar climate, as opposed to finite ecosystems of variable size. In this study, areas were designated by the zonal ecosystem, e.g. MSc, IDFb1, rather than classified into ecosystem associations and phases. MSc = Very Dry Southern Montane Spruce; IDFb1 = Thompson Plateau Very Dry Montane Interior Douglas-fir; ESSFe = Forested Dry Southern Engelmann Spruce - Subalpine fir; IDFd1 = Dry Western Montane Interior Douglas-fir; MSb1 = Thompson Plateau Dry Montane Spruce, according to Mitchell and Green (1981)

[3] cl = clay, lo = loam, gr = gravel, sa = sand(y), si = silt

[4] Serotinous refers to cones that do not open at maturity because of a resin bond between cone scales. When subjected to temperatures of 45 to 50°C, the resin bond breaks and cones are free to open. Seed stored for many years may be released. "Percent of stand serotinous" was assessed on stands bordering cut-over areas.

acceptable and cone distribution is insufficient to meet standards (Area 7 and 14), or vice versa (Area 3). The exception to the general rules is Area 10, where seedbed was acceptable and cone distribution was only slightly below acceptable standards. However, the high elevation (1800 m) of this area, with its short growing season and frosts, may have had some effect on lodgepole pine establishment. Areas with both unsatisfactory seedbeds and cone distributions (Area 2 and 12) may restock to acceptable levels, but will require longer periods of time (Figure 2).

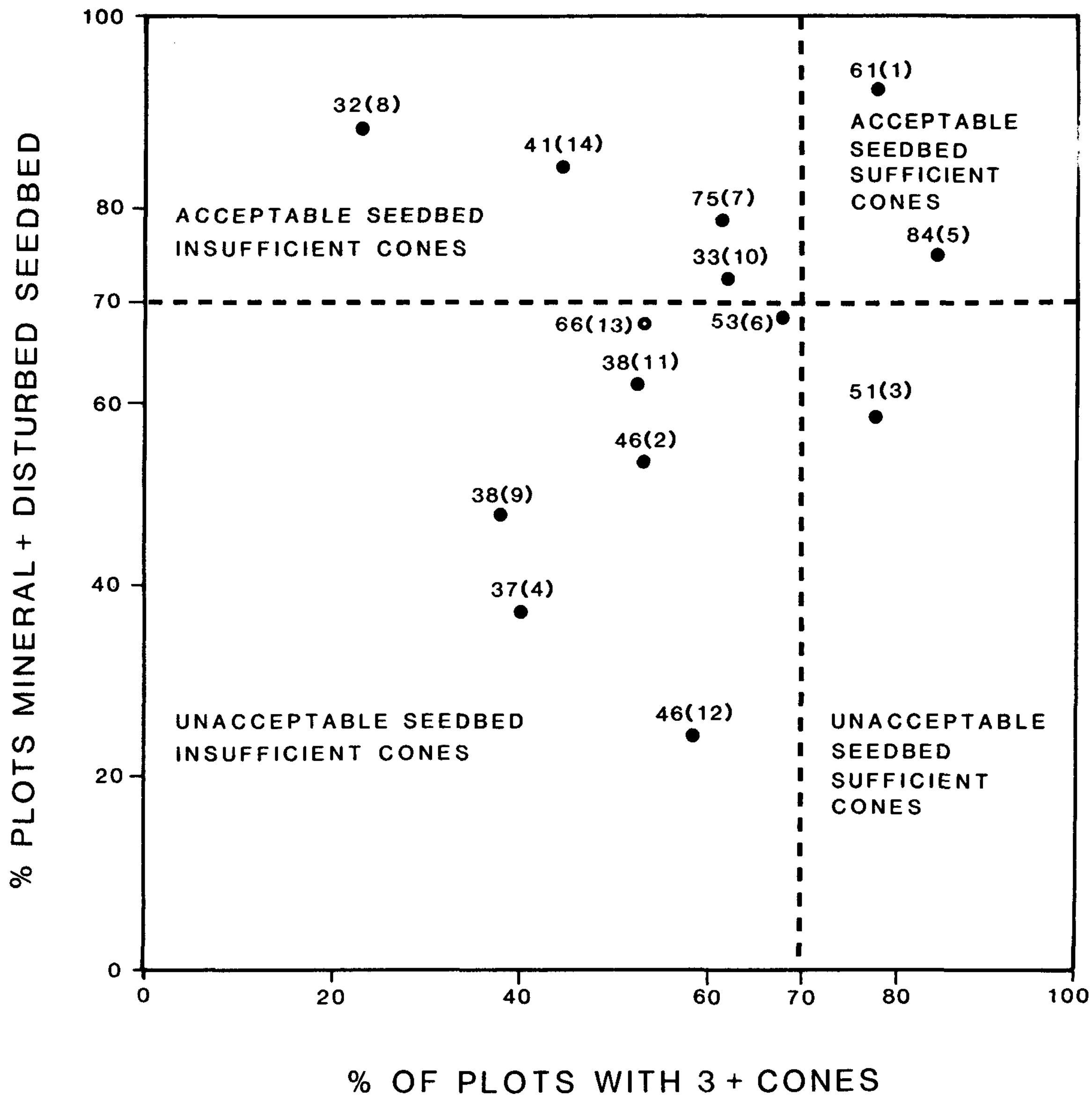
TABLE 2. Cone distribution, seedbed, and regeneration

	Seedbed class (% of area)[1]				No. of acceptable cones (% of sample plots)[2]			Post-logging regeneration (seedlings/ha by years)					Stocked sample plots (%) by years from disturbance							
Area	M	D	U	NS	5	3	1	1978	1979	1980	1981	1982	0	1	2	3	4	5	6	All[5]
1	59	33	1	7	68	80	93	0	2,200	8,080	5,584	6,900	0	11.4	47.9	42.7	60.8			64.9
2	10	44	43	3	48	54	71	0	1,200	2,060	3,624	3,900	0	6.8	21.1	37.0	46.3			53.7
3	14	44	34	8	73	78	82	0	1,800	3,360	3,238	3,720	0	14.2	35.7	42.0	51.0			64.1
4	17	24	55	4	30	38	68	42	1,320	2,480	1,609	565	0	8.5	28.6	28.3	37.0			50.0
5	46	29	20	5	80	86	93	4,435	3,115	3,595	4,036	4,328			75.0	76.8	76.8	83.9		87.5
6	44	25	26	5	58	69	85	2,900	4,340	5,940	7,895	6,088		21.5	30.4	42.4	51.3	52.9		67.0
7	59	20	17	4	54	63	79	786	4,880	9,440	15,211	15,017		5.3	28.9	55.3	71.1	75.0		81.6
8	87	1	4	8	17	24	48	2,260	1,580	2,320	2,909	2,604			11.1	16.1	24.2	27.3	32.3	45.4
9	25	23	36	16	23	38	56	16	1,080	3,620	7,309	—[3]	0	11.3	33.3	38.2	—[3]			
10	45	28	17	10	50	63	83	0	200	1,140	1,466	1,300	0	1.7	13.3	33.3	33.3			50.0
11	42	20	36	2	43	53	64	48	2,220	3,940	7,691	6,714		0	14.6	23.1	35.0	38.2		48.0
12	15	9	64	12	47	58	78	0	1,400	2,340	4,308	3,860		0	12.3	22.2	41.5	46.1		60.8
13	35	33	26	6	45	54	75	88	2,600	2,840	4,597	3,870		0.8	14.9	34.5	47.4	45.6		46.5
14	38	46	15	1	34	46	64	440	2,400	3,240	3,980	3,490		2.0	16.8	25.2	36.6	41.1		44.2
15	—[4]				12	22	44			1,375	2,313	2,180				25.0	40.6	40.6		50.0
16	—[4]				13	22	44			2,570	3,514	3,660				30.8	39.1	47.9		53.9

[1] M = mineral, D = disturbed, U = undisturbed, NS = no seedbed.
[2] 5, 3 and 1 acceptable cones per plot.
[3] Plots destroyed by mining activity.
[4] Areas first examined three years following disturbance; seedbed description not possible.
[5] Advanced regeneration included in column "ALL" only.

Because the number of cones on acceptable seedbeds (mineral or disturbed) can be readily assessed in practice, this factor is likely to have a major bearing on the rate and extent of restocking. Any variation may be attributable to a variety of less easily measured factors, such as buried cones, variation in seed viability, and losses due to pest damage. Also, viable seed may be present in Category III cones, which are not included in judging acceptable cone distribution.

The unknown seed supply factor may be of importance. Three of the areas (2, 3, and 4) seedbed provided pre-scarification as well as post-scarification cone and seedbed distribution data that can be compared to stocking achievement (Table 3). These data suggest that post-scarification cone distribution is not a reliable indication of seed supply. For example, the



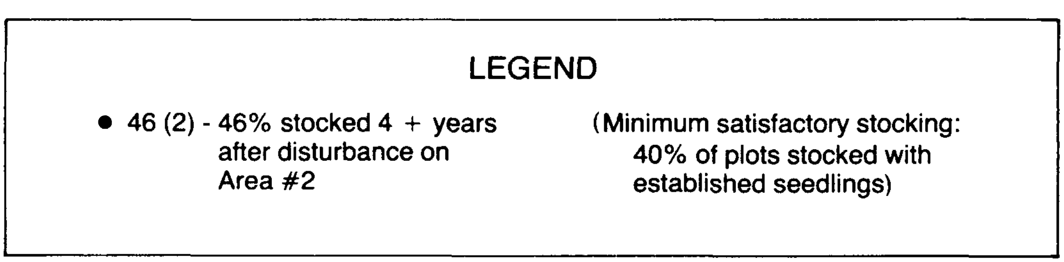


FIGURE 1. Stocking relative to seedbed and cone distribution.

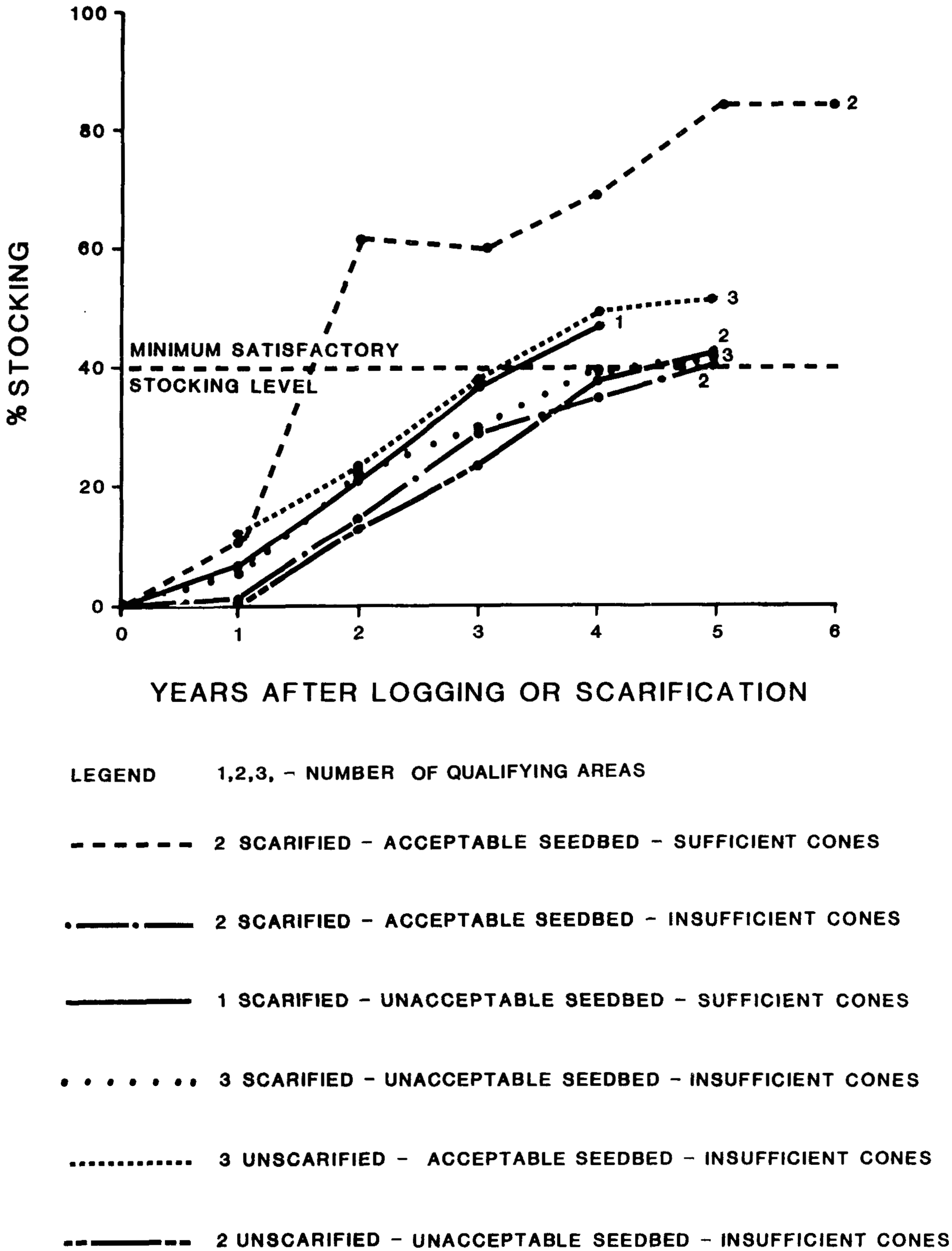


FIGURE 2. Relationship of stocking to time following disturbance.

TABLE 3. Cone and seedbed distribution pre- and post-scarification on three areas

No. cones per plot (Category I and II)	No. of plots all seedbeds[1] Before	After	Total no. plots stocked	Percent stocked 1982
0	7	80	31	38.8
1	3	26	12	46.2
2	10	17	8	47.1
3	5	14	11	78.6
4	5	9	4	44.4
5	14	14	6	42.9
6	8	16	6	37.5
7	16	14	8	57.1
8	5	4	1	25.0
9	6	8	5	62.5
10	262	139	72	51.8
Total	341	341	164	48.0

[1] Before: pre-scarification; After: post-scarification.

pre-scarification survey showed a total of only seven plots with no cones, whereas the post-scarification survey showed a total of 80 plots with no cones. Thirty-one of the plots became stocked with seedlings, indicating that many of the plots contained cones prior to scarification. Unacceptable quality cones (Category III) averaged eight per plot over all areas. These may have contained some viable seed that contributed to stocking, particularly on plots with no visible cones of acceptable quality.

Although a much larger number of plots with seedbeds of acceptable quality became satisfactorily stocked, than did plots with poor quality seedbeds (Table 4), it does not signify that this increase in stocking was due solely to the effect of scarification. However, it does indicate that a side effect of scarification is the distribution of cones over favourable seedbeds, which in turn increases the chance of satisfactory seedling establishment.

Minimum satisfactory stocking levels were attained on 11 of the 16 areas within five years following disturbance. This success was obtained with only 48% of sample plots (Table 4) with seedlings of any age (post-disturbance), size, or number. One of the five areas that did not reach minimum satisfactory stocking was severely disturbed by mining activity and can be discounted, although stocking was progressing favourably at three years following disturbance. The remaining four areas all had unsatisfactory cone distribution. Two of these areas had acceptable quality seedbed distribution and two had that of unacceptable quality. If, however, particularly on the unsatisfactorily stocked areas, seedlings present at the time of logging (advanced regeneration) and surviving scarification are included, then all areas can be considered as having satisfactorily restocked with seedlings within five years of disturbance. The advanced regeneration, in this case mainly subalpine fir (Abies lasiocarpa (Hook) Nutt.), can be very important, particularly on areas that have not received acceptable seedbed disturbance or on which cone distribution is not sufficient to meet requirements.

The data (Table 4) indicate that, for all seedbeds, a minimum of two cones per sample plot are necessary for 40% of plots to contain one or more seedlings four years after disturbance, a minimum satisfactory stocking requirement if seedlings are three or more years old. To obtain a higher

TABLE 4. Cone and seedbed distribution and stocking (all areas)

No. cones per plot	No. plots mineral or disturbed	No. plots with seedlings	No. plots stocked 1982	No. plots other seedbeds	No. plots with seedlings	No. plots stocked 1982	No. plots stocked all seedbeds	Percent stocked 1982	Plots with seedlings avge. no. seedlings/plot (All Ages 1982) min. and disturbed	other	% Plots with seedlings all seedbeds
0	253	90	84	234	74	68	152	31.2	3.3	4.0	33.7
1	98	39	36	68	26	24	60	36.1	4.3	4.2	39.2
2	81	45	40	33	14	12	52	45.6	4.0	3.7	51.8
3	61	31	26	31	12	10	36	39.1	3.4	2.2	46.7
4	50	32	31	24	9	9	40	54.0	5.2	3.4	55.4
5	38	24	23	17	3	3	26	47.2	4.4	6.7	49.1
6	34	24	22	14	5	4	26	54.1	8.8	1.8	60.4
7	35	21	20	19	10	9	29	53.7	7.3	1.9	57.0
8	39	28	25	12	7	7	32	62.7	5.1	4.0	68.6
9	24	14	14	17	9	8	22	53.2	5.2	3.4	56.1
10 +	283	196	187	228	110	95	282	55.2	8.7	4.2	58.1
Total	996	544	508	697	279	249	757	45.3	6.1	3.9	48.0

percentage of plots with seedlings, one would require a greater number of cones per plot (for example, six cones per sample plot is required to ensure that roughly 60% of sample plots contain one or more seedlings four years following disturbance). On acceptable quality seedbeds (mineral and disturbed) this number of cones per plot could be reduced to four.

In Alberta, Johnstone (1976) and Crossley (1976) each graphically illustrated the ingress of regeneration over time following harvest and/or scarification. Johnstone found that lodgepole pine ingress occurred for up to 11 growing seasons after scarification, but approximately 80% of the expected seedlings would be present following the eighth growing season after logging. Crossley found that ingress of surviving regeneration lasted for 8 to 12 years following scarification (9 to 15 years following harvest) and peaked in the third year following scarification, if scarification was not delayed beyond the first year following harvest. Crossley's data indicated that 80% of surviving seedlings were present approximately nine years following harvest (eight years following scarification). The present study generally supports the pattern of ingress outlined by Crossley, showing a peak at three years following scarification. Of most apparent significance was that, over time, differences in number of plots with seedlings, average number of seedlings per plot, or percentages of areas stocked with seedlings were minimal between areas scarified following harvest and areas with no post-harvesting scarification.

CONCLUSIONS AND RECOMMENDATIONS FOR MANAGEMENT

Generalizations on lodgepole pine can be vague, with this species showing wide adaptability. Establishment is generally only limited in situations where climate may restrict release of cone scales and/or seedling germination and early survival, provided that all other conditions of cone distribution, acceptable seedbed, and moisture are favourable. Nevertheless, caution is advised in the extrapolation of results from the present study to zonal ecosystems where major vegetation species may prevent seedling establishment. For example, moss-covered or thick humus layers require thorough disturbance, unlike the mainly calamagrostis cover in this study; and some areas may have an inadequate seed supply, in which less than 50% of the stand has a serotinous cone habit. The following observations appear to apply for the majority of sites supporting stands of lodgepole pine within the southern Interior of the province:

1) Minimum satisfactory stocking levels will be attained on most areas four to five years following logging of lodgepole pine by a combination of feller-buncher/grapple-skidder, whether or not areas have been scarified. This condition is dependent upon a minimum of one acceptable quality cone being present on approximately each square metre of area available for tree production. A lack of cones on specific portions of an area prior to scarification does not necessarily indicate that seedlings will not establish after scarification.

2) Ingress of lodgepole pine regeneration on most areas is fairly rapid following harvest and scarification, but does not peak until three or four years after the disturbance. To ensure that areas of lodgepole pine have the best chance of becoming restocked naturally with minimum time delay, optimum conditions must be provided. Optimum conditions are those where: 1) some serotinous cone-bearing slash is left scattered over the areas to complement amounts normally remaining from logging; and 2) areas are scarified to provide a high-quality seedbed as outlined in Ministry of Forests standards. Some effort should be made to increase the amount of cone bearing slash remaining after a feller-buncher/grapple skidder logging operation, and scarification should be scheduled before seed is shed from the cones.

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