LOGGING DAMAGE IN SALVAGING BEETLE-KILLED SPRUCE STANDS

Submitted by

F. Gordon Comer, Jr.

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I HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER MY SUPERVISION BY F. GORDON COMER, JR. ENTITLED LOGGING DAMAGE IN SALVAGING BEETLE-KILLED SPRUCE STANDS BE ACCEPTED AS FULFILLING THIS PART OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF FORESTRY, MAJOR IN FOREST MANAGEMENT.

Charles W. Barney
In charge of Thesis

APPROVED J. L. Deen
Head of Department

Examination Satisfactory

Committee on Final Examination

of Thesis

Walter Schaeffer

Berte R. Lexen

J. L. Deen
Dean, Division of Forestry and Range Management

Permission to publish this thesis or any part of it must be obtained from the Dean of the Division of Forestry and Range Management.

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INTRODUCTION

High winds, which swept Colorado forests in mid-June of 1939 resulted in heavy windthrow in the naturally shallow-rooted stands of Engelmann spruce (*Picea engelmanni* (Parry) Engelm.) especially on exposed sites and the windward side of forests. These fallen trees offered an excellent habitat for the Engelmann spruce bark beetle (*Dendrotoctonus engelmanni* Hopk.), for the heavy winter snows protected the beetles from their natural winter enemy, the woodpecker. Under these conditions, the rise in the beetle population was so rapid that they soon exhausted their original food supply, and moved into the nearby standing timber (2, 8).

The first serious outbreak was not reported until 1942, at which time the infestation on the White River National Forest was examined and deemed beyond control. The following year, surveys made by the Forest Insect Laboratory of Fort Collins, Colorado revealed the infestation to be more extensive than first thought, with infestations found also on the Grand Mesa, Gunnison, and Routt National Forests--all centered around the 1939 blowdown areas. Examination of the Clinetop Mesa Area of the White River Infestation showed a 77.5 per cent kill on 40,000 of the 200,000 acres examined (3).

Little was known of the habits of the Engelmann spruce bark beetle as late as 1943 for control recommendations, so that the following year, regular surveys and a bark beetle study were begun by the Forest Insect Laboratory of Fort Collins, Colorado. The progress of the White River Infestation as charted by these extensive surveys (3, 4) is shown below:

1944 - An estimated 60 per cent of the spruce on the White River Plateau had been killed since 1939. Total kill estimated at two and one-quarter billion f.b.m.

1945 and 1946 - Attack continued; beetles moved to smaller trees.

1947 - Attack subsiding. Kill of trees seven inches d.b.h. and larger estimated to be from 96 to 99 per cent; total kill approximately three billion f.b.m.

1948 - Potential danger of future attacks emphasized by serious advances of beetles on the Routt and Arapahoe National Forests to the east.

Salvage cuttings of the beetle-killed timber were first begun on the Clinetop Mesa Area in 1943, and increased rapidly with the completion of new access roads following the end of the war. In 1947 the cut of beetle-killed spruce on the White River National Forest was in excess of ten million board feet, most of the cut being for sawlogs. The following year the total cut remained about the same, but with an increase of more than 100 per cent in the cut of pulpwood. Present plans are for continued utilization of the dead timber, but on a much larger scale.

As a result of the beetle infestation, there is approximately three billion board feet of standing dead spruce on the White River National Forest alone (3). Studies of the rate of deterioration of beetle-killed spruce made on the Aquarius Plateau of the Dixie National Forest in Utah show approximately 84 per cent of the dead spruce standing 25 years following an infestation. Further examination also revealed very little decay originating following the death of the trees because of the low moisture content characteristic of trees killed by the bark beetle. Cuttings for both sawtimber and pulp from this area in 1948 demonstrate the usability of the dead spruce even after 25 years. Apparently, standing dead trees remain sound indefinitely, since lumber was being cut from spruce on the Grand Mesa National Forest of Colorado which was killed by a bark beetle infestation which took place between 1873 and 1878 (5).

Problem

The Forest Service is confronted not only with the problem of utilization of the dead spruce, but also that of getting the spruce stands back into a productive condition as soon as possible. A proposed pulp mill for this area would do much to solve the utilization problem, but at the same time would impose exacting demands on all potential spruce lands in the future.

Surveys (4) which show that, following the infestation, practically all trees of seed-bearing age have been killed demonstrate the importance of the established reproduction in the satisfactory stocking of these stands in the future. Logging of the beetle-killed timber will destroy varying amounts of this reproduction, and must be controlled to hold losses from this source to a practical minimum.

Summary of past studies

No previous logging damage studies are available for the Engelmann spruce type, probably because of the limited utilization of this type in the past. The importance of logging damage as a factor in the management of spruce-fir stands of the northeast is emphasized by Westveld (12), who states that carelessness, and alteration of site which follows logging often cause such large losses of advance spruce and fir reproduction that reinforcement by subsequent reproduction is essential for satisfactory future stocking.

Trimble (9) concludes that logging damage in spruce-fir pulpwood lands of the northeast is no deterrent to partial cutting when carried out with horse logging. Westveld (12) also discusses logging damage on the northeastern spruce-fir types and concludes that the 18 per cent loss of spruce and fir reproduction in logging was very serious because of the hardwood competition which follows cuttings. Logging damage studies dealing with salvage cuttings are lacking however, and since the salvage cuttings in the beetle-killed spruce are so nearly in the nature of a clear-cut, it is difficult to apply results obtained under partial cutting systems.

<u>Object of study</u>

Extensive stand surveys have shown what is believed to be a satisfactory stand of living reproduction in the uncut beetle-killed spruce stands (8). The purpose of this study is to determine to what extent the stocking of reproduction is altered under prevailing logging practices. It is desirable to use a logging system which will permit full utilization of the beetle-killed timber, and leave a satisfactory stocking of reproduction which will not require supplementing with artificial planting.

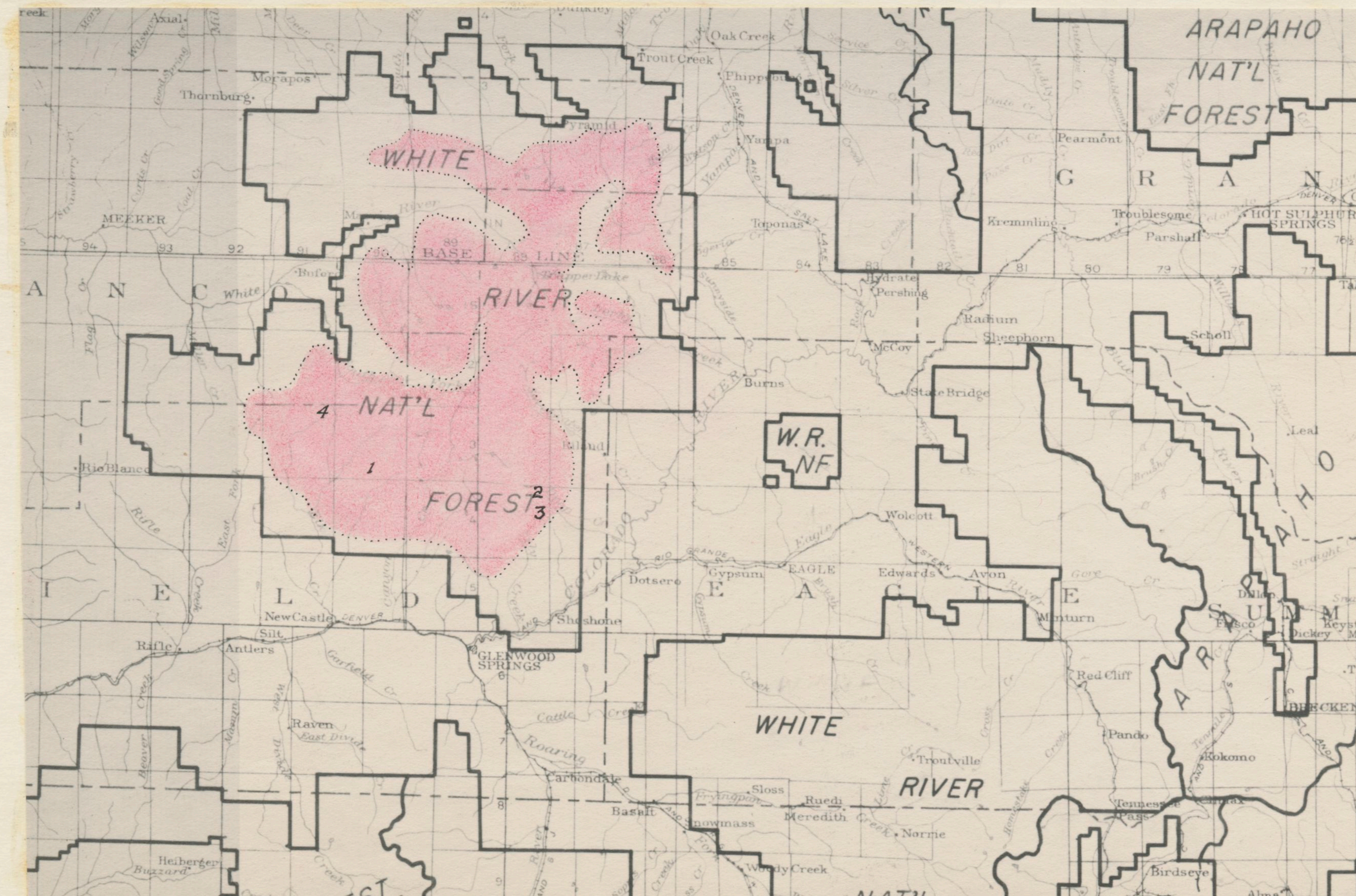
<u>Time and place of study</u>

This study was conducted by the Rocky Mountain Forest and Range Experiment Station of Fort

Collins, Colorado 1/ during the summer of 1948, and was limited to the beetle-killed stands of Engelmann spruce of the White River National Forest north of the Colorado River. Areas of beetle-killed timber and work areas of the 1948 study are shown on a map of the White River National Forest (Figure 1).

1/ The field work for this study was conducted by F. Gordon Comer and Kenneth N. Wiley under the supervision of E. M. Hornibrook of the Rocky Mountain Forest and Range Experiment Station.

Figure 1.--Map of White River National Forest. Areas of beetle-killed timber shown in red, location of logging damage plots shown by numerals. Source of data (4).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NAT'L
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Thornburg
MEEKER
Buford
Rio Blanco
Dunkley
Oak Creek
Trout Creek
Phippsburg
Pyramid
Yampa
Toponas
Hydrate
Pershing
Radium
Sheephorn
McCoy
Burns
State Bridge
Kremmling
Pearmont
Troublesome
Parshall
HOT SULPHUR SPRINGS
Scholl
Leal
Wolcott
Dotsero
Gypsum
EAGLE
Edwards
Avon
Minturn
Dillon
Frisco
Dickey
Shoshone
NewCastle
Silt
Rifle
Antlers
GLENWOOD SPRINGS
Raven
Carbondale
Basalt
Snowmass
Sloss
Ruedi
Meredith
Norrie
Troutville
Red Cliff
Pando
Kokomo
Tennessee Pass
Climax
Birdseye
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MATERIALS AND METHODS

Location of plots

Four five-acre plots were established in areas of beetle-killed timber where the different methods of logging in use on the forest were in progress during the summer of 1948. Before and after reproduction counts were made on the plots to determine losses in logging, and a tally of the merchantable dead spruce was included in the first survey to correlate losses with volumes of timber removed.

Logging methods studied

Plot 1: Ground skidding of tree-length logs with a D-4 tractor.

Plot 1 was located on Clinetop Mesa where logging was in progress by the Consolidated Water Power and Paper Company. Approximately 24 M ft. b.m. per acre of dead spruce was removed in this operation. At the request of the logger, tree-length skidding was allowed; trees were ground skidded with a D-4 crawler type tractor. The tree-length skidding was allowed to test the comparative damage of this system with that of short log skidding, since the logger considered the skidding of tree-lengths to be most efficient for pulpwood operations.

Plot 2: Arch skidding of short logs with a TD-5 tractor.

Plot 2 was located on Coffee Pot Mesa on an area being cut for sawtimber by the Haubrich Brothers Mill. Approximately 47 M ft. b.m. per acre of dead spruce was removed. Sixteen-foot logs were bunched with horses, and then skidded directly through the timber to the mill with a TD-5 crawler type tractor equipped with a bulldozer blade, and drawing a light homemade sulky 1/ (Figure 7).

Plot 3: Ground skidding of short logs with a D-4 tractor.

Plot 3 was also on Coffee Pot Mesa, on a saw-log operation conducted by the E. R. Rippy and Son Mill. Truck roads were bulldozed through the timber and along the contour; sixteen-foot logs were then ground skidded downhill to landings along these roads with a D-4 crawler type tractor, and then trucked to the mill. Logging removed about 49 M ft. b.m. per acre of dead spruce in this operation.

Plot 4: Ground skidding of short logs with horses.

Plot 4 was located near Hiner Spring, which is near the western edge of the beetle infestation. The

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1/ A sulky is wheeled arch commonly used with small to medium sized tractors.

area was logged for pulpwood by H. B. Blomgreen, one of the numerous small pulpwood operators in this vicinity. Approximately 27 M ft. b.m. per acre of dead spruce was removed in the form of 100-inch logs, which were first bucked in the woods and then ground skidded by horses to landings outside the timbered area.

With reference to the logging methods included in this study, it should be kept in mind that they were not specifically planned, but rather were selected as typical of the different types of logging in progress on the forest in the summer of 1948.

All operations studied were in the nature of a commercial clear cut, removing practically all of the merchantable dead timber. The trees were felled by blocks or strips over large areas, and well in advance of any skidding operations. The location of skid trails and roads was left to the logger, and developed with the skidding activities, so there was little advance planning on this phase. No form of slash disposal was used.

Survey procedure

The logging damage plots used in this study were semipermanent in nature; one corner of each plot being marked by a large wood stake set in the ground, and by blazes and orange paint on the nearby trees. This corner was then located by compass and pacing to some permanent topographical feature, and its location with the accompanying plot layout sketched on Forest Service Form 878 (Appendix 2).

Plots were either square or rectangular in shape, and were oriented so that the strip cruise lines would be at right angles to the topography. Strip cruise lines were marked with orange-tipped stakes and by orange timber marking paint along the line to make relocation following logging easier.

Strip cruise lines were located at one chain intervals throughout the plot, the first line being set in one-half chain from the plot boundry (Figure 2). These strip cruise lines were 0.2 chains in width, which gave one mil-acre to each side of the strip center line for each 10 links along the line. Mil-acres to the left of the line were designated as series "A"; those to the right of the line as series "B".

The survey of the logging damage plots proceeded by mil-acre squares, first by determining the stocking of each mil-acre, and then by the tally of additional reproduction on the mil-acre. Stocking was considered as the dominant size or species of tree present on each mil-acre square; if two trees on the same mil-acre were of dominant size, then preference was given to spruce over fir, and to trees of normal form over badly deformed stems. The presence of both spruce and fir on the same mil-acre was noted by placing an "X" under the species column not constituting the stocking. Any additional reproduction on each mil-acre was then measured and included in the general plot tally, but without regard to its location by mil-acre plot. Non-stocked mil-acre squares were recorded as a "O" under the center column of the mil-acre series (See Form RS-23, Appendix 1).

The resurvey of plots following logging was conducted in the same manner as the before logging survey. The losses of reproduction and living trees from all phases of logging activity (felling, bunching of logs, skidding, covered by slash, and any others) was lumped together, as it was impractical to separate them.

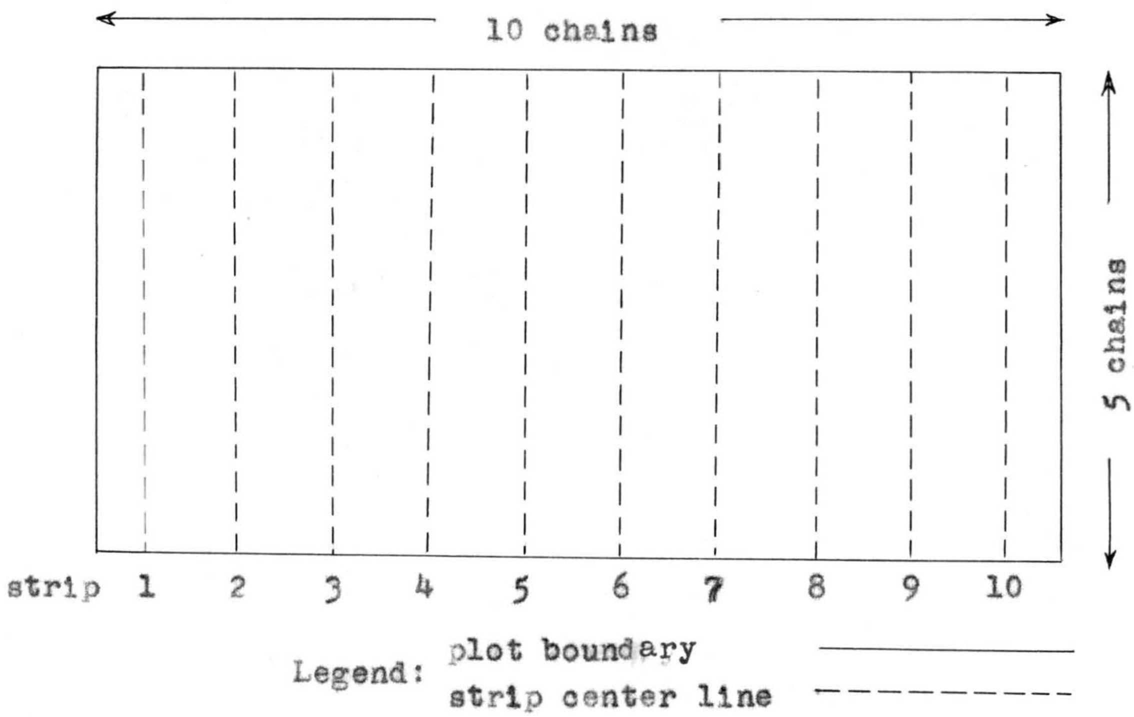


Figure 2.--Diagrammatic layout sketch of logging damage plot no. 1

Plot dimensions can be varied to fit the shape of the area to be logged, but the orientation of the strip cruise lines is at right angles to the topography.

Mil-acre plots are taken in continuous strips on each side of the strip center line, with plots to the left of the line designated as series "A", and those to the right of the line designated as series "B". This gives a strip 0.2 chains in width, which when spaced at one chain intervals, results in a 20 per cent cruise of the area.

ANALYSIS OF DATA

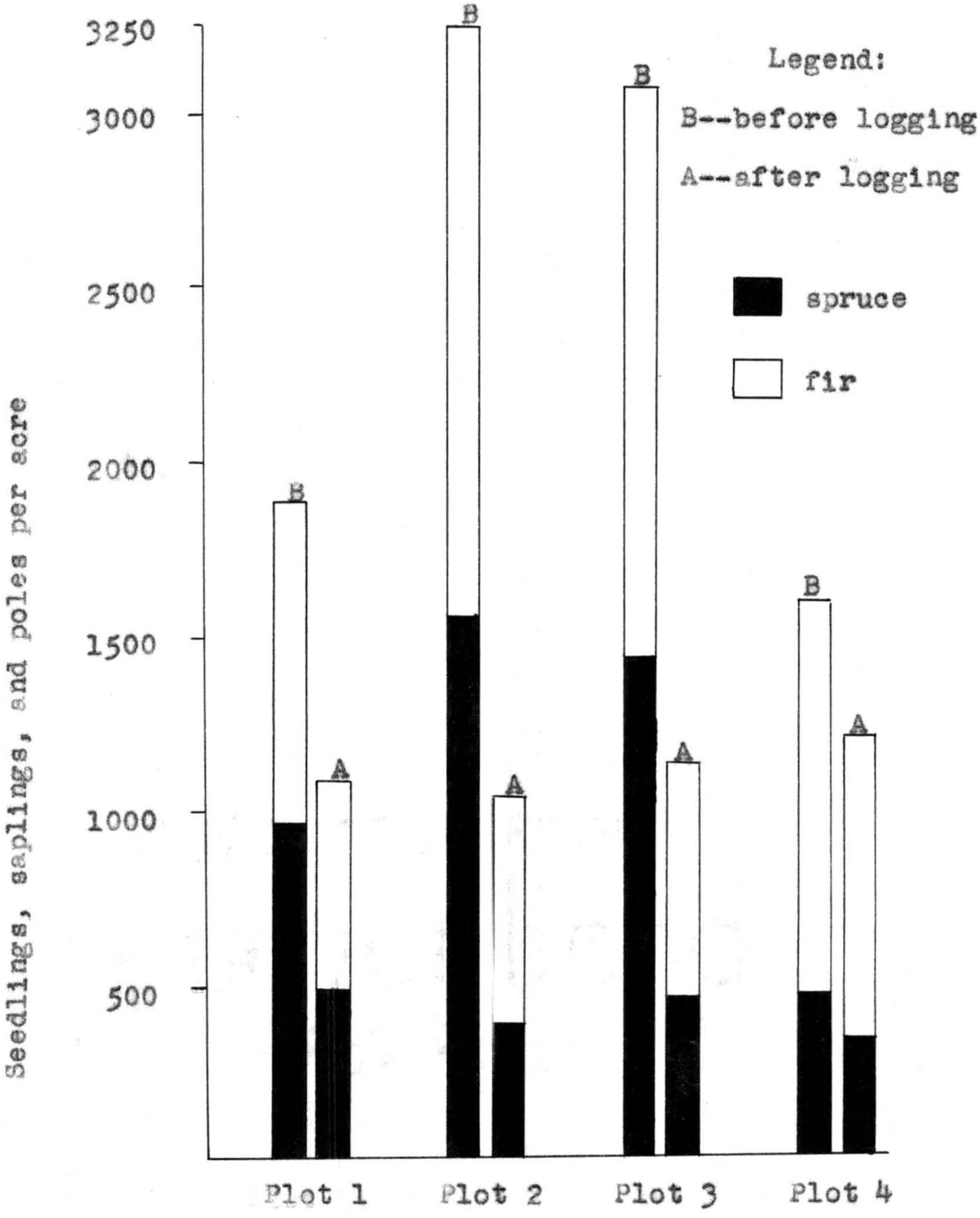
Stand conditions following logging

Before logging surveys showed beetle-killed spruce stands to be well stocked with seedlings, saplings, and pole reproduction of both Engelmann spruce and alpine fir. Average stocking density was 2449 per acre, with a range of 1580 per acre on the most lightly stocked plot, to 3250 per acre on the most heavily stocked plot (Table 1 and Figure 3). Although average logging losses were high, 54.3 per cent, (Figure 3) there remained an average of 1072 seedlings, saplings, and poles per acre from which to develop a new stand. Damage was heaviest on those plots where high volumes of timber were removed, and with tractor skidding. Animal logging in a stand of moderate density produced the least damage.

Stocking density before and after logging is shown graphically by Figure 3. By pure coincidence, the least destructive method of logging studied happened to be on the area of lowest stocking density, so that although considerable differences in stocking density existed on the uncut plots, there remained little difference following logging.

Table 1.--Seedling, sapling, and pole reproduction per acre, before and after logging, all species

Height and dbh class	Before logging Plot				After logging Plot				Percentage loss due to logging Plot			
	1	2	3	4	1	2	3	4	1	2	3	4
0 -4"	833	919	596	298	363	143	152	202	56.4	84.4	74.5	32.2
4"-1'	231	308	393	256	117	94	161	98	49.4	69.5	59.0	61.7
1'-1"	400	1555	1634	714	295	574	633	628	26.2	63.1	61.3	12.0
dbh class												
2"	153	275	310	130	93	128	124	114	39.2	53.4	60.0	12.3
4"	101	111	77	82	70	50	40	72	30.7	55.0	48.1	12.2
6"	68	45	26	56	58	31	17	50	14.7	31.1	34.6	10.7
8"	43	14	18	28	33	8	9	28	23.3	42.9	50.0	0.0
10"	25	9	8	8	23	6	5	8	8.0	33.3	37.5	0.0
12"	14	6	5	2	14	4	3	2	0.0	33.3	40.0	0.0
14"	12	2	2	6	11	0	2	6	8.3	100.0	0.0	0.0
16"	6	3	1	0	6	2	0	0	0.0	33.3	100.0	0.0
18"	3	2	2	0	3	1	0	0	0.0	50.0	0.0	0.0
20"	3	1	0	0	3	1	0	0	0.0	0.0	0.0	0.0
22"	2	0	0	0	2	0	0	0	0.0	0.0	0.0	0.0
24"	1	0	0	0	1	0	0	0	0.0	0.0	0.0	0.0
Total	1895	3250	3072	1580	1092	1042	1148	1208	42.4	67.9	62.6	23.5
2"+	431	468	449	312	317	231	202	280	26.4	50.6	55.0	10.3
8"+	109	37	36	44	96	22	21	44	11.9	40.5	41.7	0.0



Volumes per acre removed in logging

Plot 1 -- 24 M ft. b.m.
Plot 2 -- 46 M ft. b.m.
Plot 3 -- 49 M ft. b.m.
Plot 4 -- 27 M ft. b.m.

Figure 3.--Stocking densities--before and after logging

Table 2.--Stocking densities, before and after logging, by species

	Before logging Plot 1	Before logging Plot 2	Before logging Plot 3	Before logging Plot 4	After logging Plot 1	After logging Plot 2	After logging Plot 3	After logging Plot 4	% lost by plot Plot 1	% lost by plot Plot 2	% lost by plot Plot 3	% lost by plot Plot 4	Av.
A. Engelmann spruce													
seedlings	632	1048	851	224	261	160	250	130	59	85	71	42	71
small saplings	196	401	499	80	140	164	174	62	29	59	65	22	54
large saplings & small poles	110	109	75	146	74	62	27	126	33	43	64	14	34
large poles	19	3	14	18	15	1	7	18	21	67	50	0	24
Total	957	1561	1439	468	490	387	458	336	49	75	68	28	62
B. Alpine fir													
seedlings	432	179	138	330	219	77	63	170	49	57	54	48	51
small saplings	204	1154	1135	634	155	410	459	566	24	64	60	11	49
large saplings & small poles	212	322	338	122	147	147	154	110	31	54	54	10	44
large poles	63	26	17	20	55	17	10	20	13	35	41	0	19
Total	911	1681	1628	1106	576	651	686	866	37	61	58	22	48

Effect of logging on species composition

Spruce was represented in about the same proportion as fir before logging, except on Plot 4, where less than 30 per cent of the reproduction was spruce (Table 2). Logging destroyed a higher percentage of spruce than fir; 62 per cent of the residual spruce being lost in logging as compared to a loss of 48 per cent of the residual stand of fir. Assuming equal densities of both spruce and fir before logging, and uniform distribution, logging losses of spruce averaged almost 30 per cent above losses of fir (Table 3). In the logged-over stands, spruce made up an average of 37.5 per cent of the reproduction present.

Table 3.--Ratio of spruce lost to fir lost in logging. (from Table 2)

Size Classes	Plot 1	Plot 2	Plot 3	Plot 4	Average
seedlings	1.20	1.49	1.32	0.88	1.39
small saplings	1.16	0.92	1.08	2.00	1.10
large saplings & small poles	1.07	0.80	1.18	1.40	0.77
large poles	1.62	1.92	1.22	1.00	1.26
Average	1.32	1.23	1.17	1.27	1.29

The smaller sizes of reproduction were most susceptible to loss, this being most marked in spruce, since in the seedling and sapling stage, it was found on old decayed logs more often than fir (Figure 8). The four different logging methods studied showed no significant differences in the relative losses of spruce and fir, this apparently being influenced by other factors (Tables 2 and 3).

Effect of volume removed on degree of damage incurred

The per cent of loss appears to be influenced by the volume of wood removed in the logging operation (Figure 3). Thus if the effect of the logging method is overlooked, approximately two-thirds of the reproduction was destroyed in logging stands of heavy density (40 to 50 M f.b.m. per acre), while only about one-third was lost in logging stands of moderate density (20 to 30 M f.b.m. per acre).

The least damage occurred using horse skidding for 100-inch logs, while the greatest damage was with the use of a bulldozer-equipped tractor and arch for skidding 16-foot sawlogs. However, comparison of logging damage on Plots 1 and 4 gives a better idea of the relative losses which might occur under tractor versus horse skidding systems, since both plots had about the same stocking density before logging, as well as having approximately the same volumes of wood removed in the logging process (Figure 3). From this comparison, it appears that damage with tractor skidding is about twice that to be expected with horse skidding.

Changes in stocking distribution

Although stocking densities offer one means of comparison of two areas, distribution of the stocking over the area must also be considered. For the purpose of this study, stocking distribution was computed on the basis of the per cent of the area occupied by reproduction, when divided into mil-acre units.

One mil-acre basis

On the basis of one mil-acre units, distribution ranged from 61 to 86 per cent of the area stocked before logging, and from 48 to 54 per cent of the area stocked following logging (Figure 4). Adequate stocking and distribution would assume a minimum of 1,000 trees per acre for 100 per cent stocking on the basis of one mil-acre units.

Four mil-acre basis

Changing the basis of comparison to four mil-acre units, which has the effect of dividing the area into 250 equal parts, it was found that an average of 97 per cent of the area was stocked before logging, with an average of 82 per cent of the area stocked following logging (Figure 4 and Appendix 3).

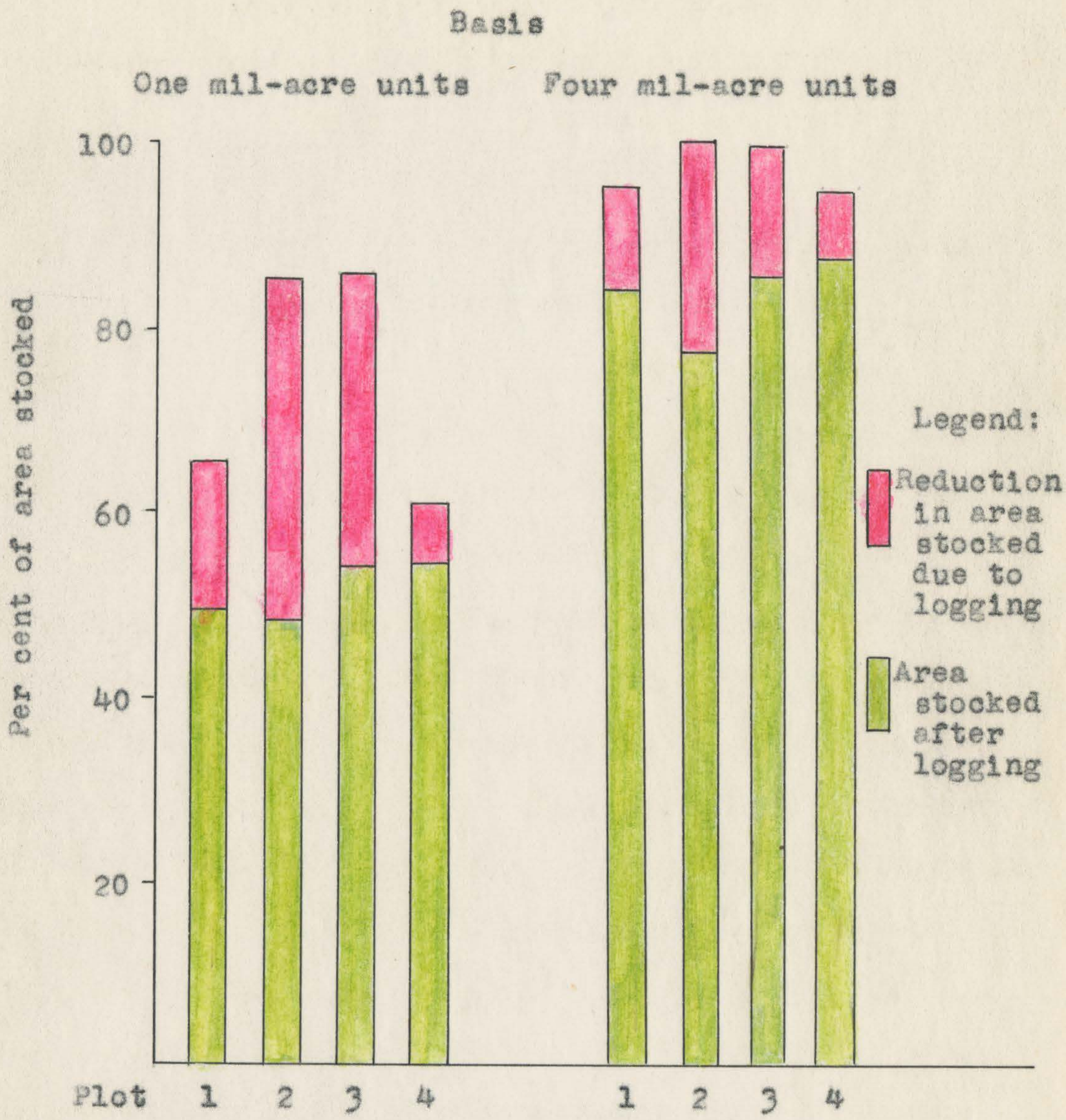


Figure 4.--Stocking distribution

Relation to density losses

Generally, the reduction in area stocked appears to parallel losses in stocking density, being most pronounced under high density losses. However, this was not the case for Plot 2, where the loss of area stocked was much greater than for the otherwise similar Plot 3. Considered on the basis of four mil-acre units this would indicate that the loss of area stocked on Plot 2 was not as uniformly distributed over the entire area as for the other three plots, but was more often in the form of larger unstocked areas. This is shown by Figure 5, which graphs the reduction in area stocked over reduction in stocking density. While this relationship is uniform for all four areas when considered on the basis of one mil-acre units, there is a wide deviation of Plot 2 from the other three plots, when considered on the four mil-acre basis. Since a smaller number of units are involved on the four mil-acre basis, any reduction in area stocked as compared to the other areas and the one mil-acre basis, indicates the presence of large unstocked areas. This is attributed to the use of the bulldozer blade on the skidding tractor used on this plot (Figure 7).

Reproduction losses by size classes

The importance of losses by size classes can

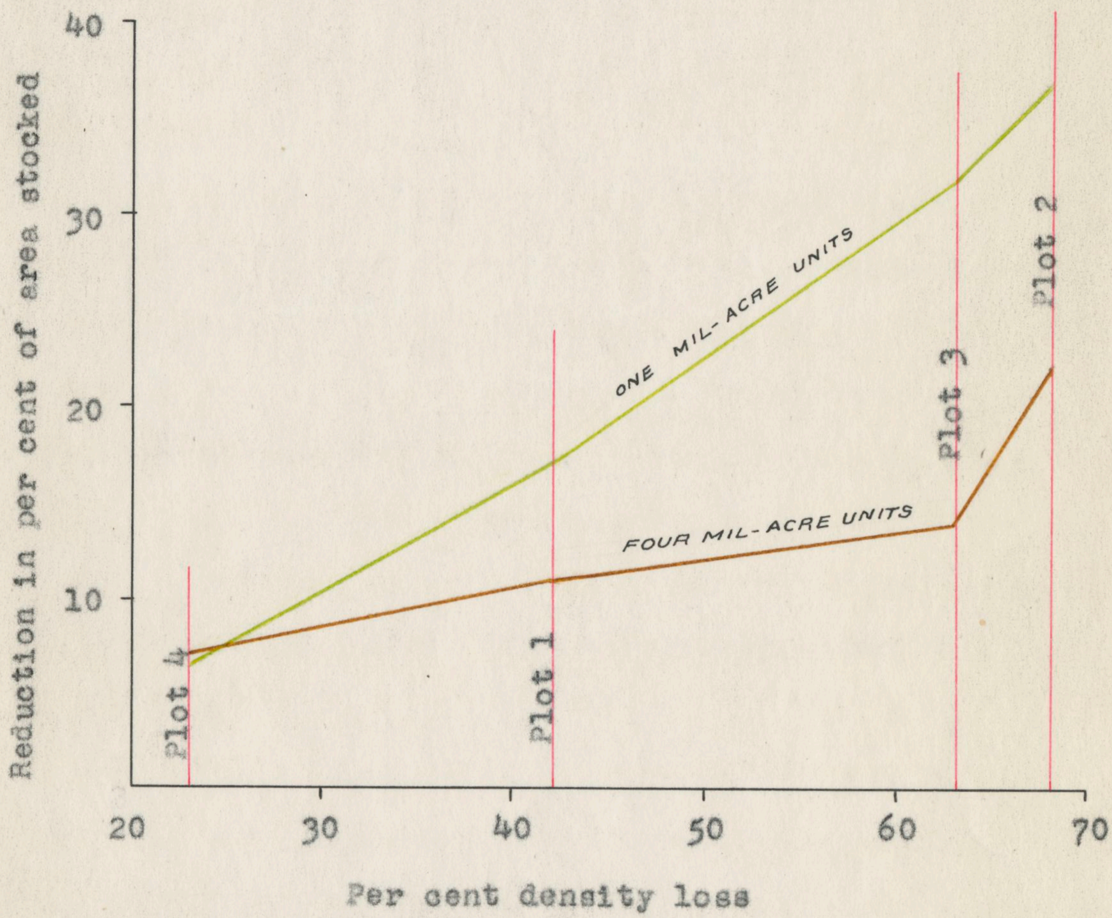
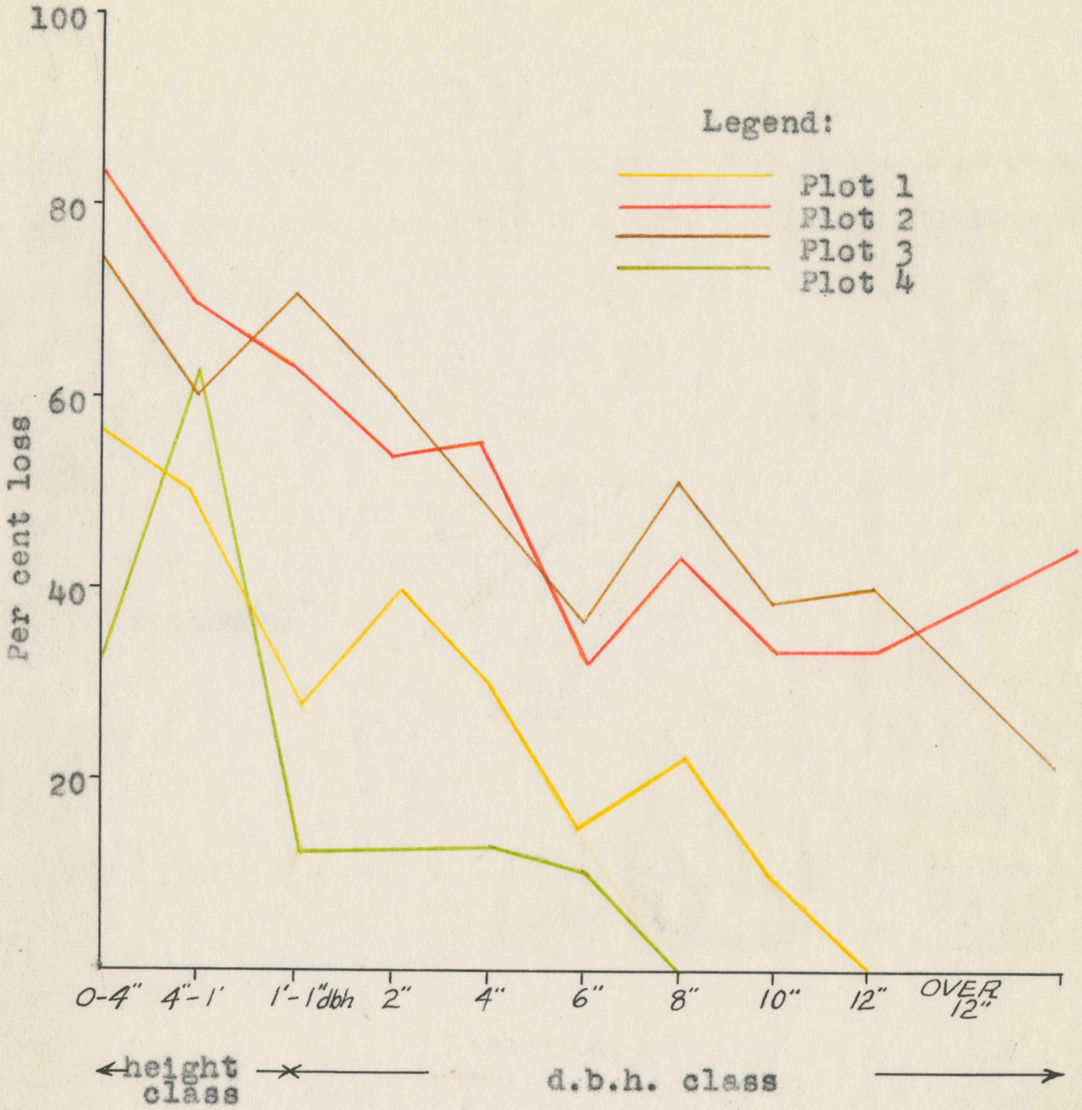


Figure 5.--Distribution changes under different density losses

be emphasized since it takes a much shorter time for the larger saplings and poles to reach seed-bearing age and merchantable size. A high per cent of loss is to be expected in the case of small seedlings and saplings since one of their common habitats, decayed wood, is so highly susceptible to destruction in the process of logging (Figure 8). Figure 6 shows a high per cent of loss for seedlings and small saplings on all four plots.

Large saplings and poles on Plots 1 and 4 suffered a much lower mortality than the smaller size classes, while on Plots 2 and 3, a high rate of loss was sustained throughout the large pole class, and did not decrease markedly even in trees above 12 inches d.b.h. Plot 4 showed no loss in the large pole class, Plot 1 only 11.9 per cent loss; but Plots 2 and 3 showed losses of 40.5 per cent and 41.7 per cent respectively (Figure 6).

This high loss in the larger size classes on Plot 2 was hardly proportional to the volumes of wood removed if compared to Plots 1 and 4, and must be associated with the logging method. It is believed to be due to the lack of care in the use of the bulldozer blade which was attached to the skidding tractor. Frequent wide skid trails, large turning areas, and the pushing of large accumulations of slash and logging debris onto clumps of reproduction all contributed heavily to the



Plot 1: Ground skidding of tree-lengths with a D-4 tractor
Plot 2: Arch skidding of short logs with a TD-5 tractor
Plot 3: Ground skidding of short logs with a D-4 tractor
Plot 4: Ground skidding of short logs with horses

Figure 6.--Destruction by size classes under different logging methods

excess damage on this plot.

Although no bulldozer attachment was used on the skidding tractor on Plot 3, the construction of frequent truck roads through the timber and at right angles to the downhill skid trails contributed to the high rate of loss here. This was in contrast to the practice of skidding directly to open parks before loading on trucks, which was used on the other three study plots.

Figure 7.--Logging on Plot 2

Considering per cent of residual stand destroyed and reduction in area stocked, this was the most destructive of the four logging methods studied. Damage was unusually high in the large pole and sawlog sizes, this believed to be due mostly to the use of a bulldozer blade on the skidding tractor.

CONCLUSIONS

Stand conditions following logging

The results of this study show that, for stands with stocking densities comparable to the four areas included in this study, logging can be safely carried out without the necessity for supplemental planting operations afterwards. When compared to the initial number of 1210 seedlings per acre which accompanies a 6' X 6' spacing used in planting, the average of 1072 seedlings, saplings, and poles per acre which followed logging appears to be acceptable.

Recommendations

Skidding power.--Although logging damage under tractor skidding systems was almost twice that with animal skidding, tractor skidding appears to be permissible on areas which support reproduction densities of 2,000 per acre, or more. For doubtful areas with stocking densities of only 1,000 to 1,500 per acre, horse skidding is believed to be the only safe system of the four studied. Financial considerations attending the use of planting make the use of more expensive logging operations in poorly stocked areas profitable, if this results in saving the reproduction present on these areas. However, since most beetle-killed spruce stands support reproduction densities of 2,000 or more per acre, (Appendix 4), it appears that extensive use of horse skidding will be unnecessary.

Use of bulldozer blade on skidding tractor.--The high rate of damage to the large pole and trees sizes which attended the use of a bulldozer blade on the skidding tractor does not recommend its general use. Barring subsequent losses by insects or windthrow, these trees, 8 inches d.b.h. and larger, should reach merchantable size as well as furnish a seed source for reinforcement of the stand at an early date. Extension of present salvage operations to a period twenty years hence will find a higher preponderance of large saplings and poles in the uncut stands which have developed from the smaller sizes of reproduction now present. This lends further emphasis for the use of logging methods which will not destroy such large numbers of these larger size classes.

Tree-length skidding.--Ground skidding of tree-lengths, as carried out in this study, apparently destroyed no more reproduction for the volume of wood removed than the ground skidding of short lengths. Other studies comparing tree-length skidding with the skidding of short lengths found the use of tree-lengths no more destructive and much more efficient than the latter (13, 14). It is believed that the use of arches in conjunction with the tree-length skidding would lessen the damage, since studies in the ponderosa pine types of Arizona, California, and Oregon showed the use of high wheels with tractors to be generally less destructive than the use of ground skidding with tractors (1, 7, 10).

In conjunction with the use of tree-length skidding, the layout of skid trails prior to felling so that trees may be pointed to or away from the skid trails is very important. This should be the responsibility of a forest officer, who should also maintain a constant check on the operations to see that proper care is exercised in all phases of logging activities.

Care in logging.--Mowat (6), in a study of damage in Idaho ponderosa pine, stresses the importance of care on the part of the logger in saving the reproduction. Much of the damage sustained with tractor logging on plots 2 and 3 is believed to be the result of careless practices. It appeared that the operators using horse skidding and tree-length skidding exercised reasonable care which contributed materially to the lower rate of damage on these two plots.

Recommendations of other studies

It is believed that the recommendations made as a result of other studies would reduce the damage sustained in the tractor logging of these stands. Mowat (6) recommends detailed logging plans, and the prescribing and enforcing of specific operating rules as means of controlling logging losses. Perry (7) and Wales (10) both recommend the use of a yarding line on tractors to take logs from clumps of reproduction as this resulted in considerably less damage than the hooking of such logs directly onto the tractor.

Need for further studies

Although stocking densities on the four logged-over areas appear satisfactory, it should be kept in mind that a high percentage of the residual living reproduction is in the form of small seedlings. The high mortality of these under natural conditions is likely to be increased by the change of site which follows logging, as well as from the competition from the vegetative cover which might become dense in these extremely open stands. On the other extreme, subsequent losses due to windthrow of trees six inches d.b.h. and larger might be severe in the very open stands which follow logging (Figure 9). On the basis of these two possibilities, it appears that a resurvey of the logged-over plots as well as the uncut stands would add much to the knowledge gained from the 1948 study.

Figure 8.--Logging damage on Plot 2

The habit of Engelmann spruce regenerating on old decayed wood makes it highly susceptible to destruction in logging. Note the spruce sapling shown by red arrow, which was uprooted by logging on Plot 2. Many other small seedlings on the log, which are not visible in the first picture, were destroyed when the decayed wood was disturbed.

Figure 9.--Interior view of logged over stand - Plot 2

Logged over stands of beetle-killed spruce support few living trees over eight inches d.b.h. In stands as open as this one, subsequent loss due to windthrow is likely to be heavy. This is an interior picture of Plot 2 following logging, which formerly supported a stand of better than 50 M ft. b.m., but now an average of only 22 trees per acre, eight inches d.b.h. and larger, remain.

SUMMARY

The bark beetle infestation which followed the windthrow of a storm in June of 1939 resulted in the death of approximately three billion ft. b.m. of Engelmann spruce, on the White River National Forest alone.

Standing dead spruce remains sound for an extended period of time, so that the salvage of the entire kill is planned. Lacking sufficient living trees of seed-producing size in areas of the infestation, future stands will be dependent on reproduction by-passed by the beetles, so that logging must be controlled to protect this reproduction.

Studies were made on the area of the White River Infestation in the summer of 1948, by the Rocky Mountain Forest and Range Experiment Station, which covered the various types of logging in use on the forest, for the comparison of damage with each method.

The results of logging in the dead spruce stands showed horse logging to be by far the least destructive; a tractor equipped with a bulldozer blade being the most destructive. In spite of the heavy losses of reproduction, which averaged 54.3 per cent, a fair stand of reproduction of all sizes which averaged 1072 per acre remained following logging.

Spruce was more susceptible to destruction by logging than fir, owing to its regeneration habits, but the various logging methods showed little differences in the relative losses of spruce and fir produced.

Damage was correlated with volumes of wood removed in logging, with stands of heavy density producing the highest rates of damage. Tree length logging, allowed on one plot, was no more destructive than the short lengths skidded on two other areas.

Damage was well distributed throughout the logged over areas except for Plot 2, where it occurred more in large individual areas. Logging on this plot was also above average in damage to large poles and tree sizes.

Due to good average stocking densities for uncut stands, it is believed that horse logging will not be necessary except in poorly stocked areas. Tree-length logging with the use of tractors seems permissible on the basis of this study.

Careful logging should be stressed, and definite controls over the logging operations seem advisable to maintain a degree of care demanded by the condition of the uncut stand, and the characteristics of the logging method.

Considerable mortality on the logged-over areas is expected in the next five years, and a recheck of the areas should be made.

A P P E N D I X

APPENDIX TABLE OF CONTENTS

Appendix 1.--Form RS-23, Rocky Mountain Forest and Range Experiment Station

RS-23 (New)
EMH 5/13/48

DAMAGE STUDY - BEFORE AND AFTER LOGGING

Plot Number ____________ Location ____________
Strip Number ____________ Date ____________
Before ______ After ______ Crew ____________

Quadrat No.	SERIES A S	SERIES A F	SERIES B S	SERIES B F	Quadrat No.	SERIES A S	SERIES A F	SERIES B S	SERIES B F	Quadrat No.	SERIES A S	SERIES A F	SERIES B S	SERIES B F
1					36					71				
2					37					72				
3					38					73				
4					39					74				
5					40					75				
6					41					76				
7					42					77				
8					43					78				
9					44					79				
10					45					80				
11					46					81				
12					47					82				
13					48					83				
14					49					84				
15					50					85				
16					51					86				
17					52					87				
18					53					88				
19					54					89				
20					55					90				
21					56					91				
22					57					92				
23					58					93				
24					59					94				
25					60					95				
26					61					96				
27					62					97				
28					63					98				
29					64					99				
30					65					100				
31					66									
32					67									
33					68									
34					69									
35					70									

Reprod and Stand tally

Height class	E. Spruce	A. Fir	Beetle Killed	TOTAL
4" or less				
4" to 1 ft.				
1 ft. to 1" dbh				
d.b.h. class				
2				
4				
6				
8				
10				
12				
14				
16				
18				
20				
22				
24				
26				
28				
30				
32				

S = Spruce; F = Fir

Appendix 2.--U.S. Forest Service

Form 878

Form 878
ev. Feb. 1930)

UNITED STATES DEPARTMENT OF AGRICULTURE—FOREST SERVICE

__________ Land district. Mag. declin. __________ Area __________ acres

__________ (Case designation) __________ (Subdivision and section) T. __________ R. __________ Mer. Scale __________ inches = 1 mile

eld work by __________ Date __________ Platted by __________

emarks __________

pproved __________, 19___

____
Approving Officer.

U. S. GOVERNMENT PRINTING OFFICE 8—3466

Appendix 3.--Per cent of forest stocked before and after logging

Per cent of forest stocked before and after logging.

Basis: 1, 2, and 4 mil-acres as the unit of measure.

Plot No.	Per cent of area stocked — Before logging — Mil-acre units			Per cent of area stocked — After logging — Mil-acre units			Reduction in area stocked due to logging losses — Mil-acre units			Beetle killed trees 10" dbh plus	Volume killed spruce per acre
	1	2	4	1	2	4	1	2	4		
	(per cent)			(per cent)			(per cent)			(number)	(ft. b.m.)
1	65.4	83.4	94.8	48.9	66.8	83.6	16.5	16.6	11.2	61	24,220
2	85.1	96.4	99.6	48.3	66.2	76.6	36.8	30.2	23.0	155	46,880
3	85.7	95.0	99.2	53.7	71.0	84.8	32.0	24.0	13.4	159	48,990
4	61.0	79.6	94.4	54.2	71.2	87.2	6.8	8.4	7.2	140	27,330
Mean	76.2	89.9	97.4	50.9	68.5	82.6	25.3	21.4	14.8	129	

Appendix 4.--Number of living trees per acre in uncut stands

Number of living trees per acre, both spruce and fir, in <u>uncut</u> stands of beetle-killed Engelmann spruce, based on extensive stand survey.

Height class	d.b.h. class	Plot B	Plot G	Plot H	Plot I	Plot J	Plot M	Plot N	Total	Average
		Number per acre								
4" or less		856	150	550	1234	2322	144	2558	7814	1116
4" to 1 ft.		384	142	416	285	1783	76	875	3959	566
1 ft. to 1" d.b.h.		1172	1391	1441	592	2123	583	1650	8952	1279
	2	228	433	283	92	217	144	409	1806	258
	4	97	158	73	52	48	50	96	574	82
	6	71	93	46	58	53	39	52	412	59
	8	37	58	35	47	20	21	13	231	33
	10	18	18	15	27	5	10	8	101	14
	12	14	11	8	14	3	3	16	69	10
	14	5	1	6	2	1	2	4	21	3
	16	1	1	-	2	-	-	3	7	1
	18	-	1	1	-	-	1	-	2	0.3
	20	-	-	-	-	-	-	1	1	0.1
	22	1	-	-	-	-	-	2	3	0.4
Total		2884	2457	2873	2403	6575	1073	5687	23952	3421
Total 2" d.b.h. & larger		472	774	466	294	347	270	604	3227	460
Total 8" d.b.h. & larger		76	90	64	92	29	37	47	435	62

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