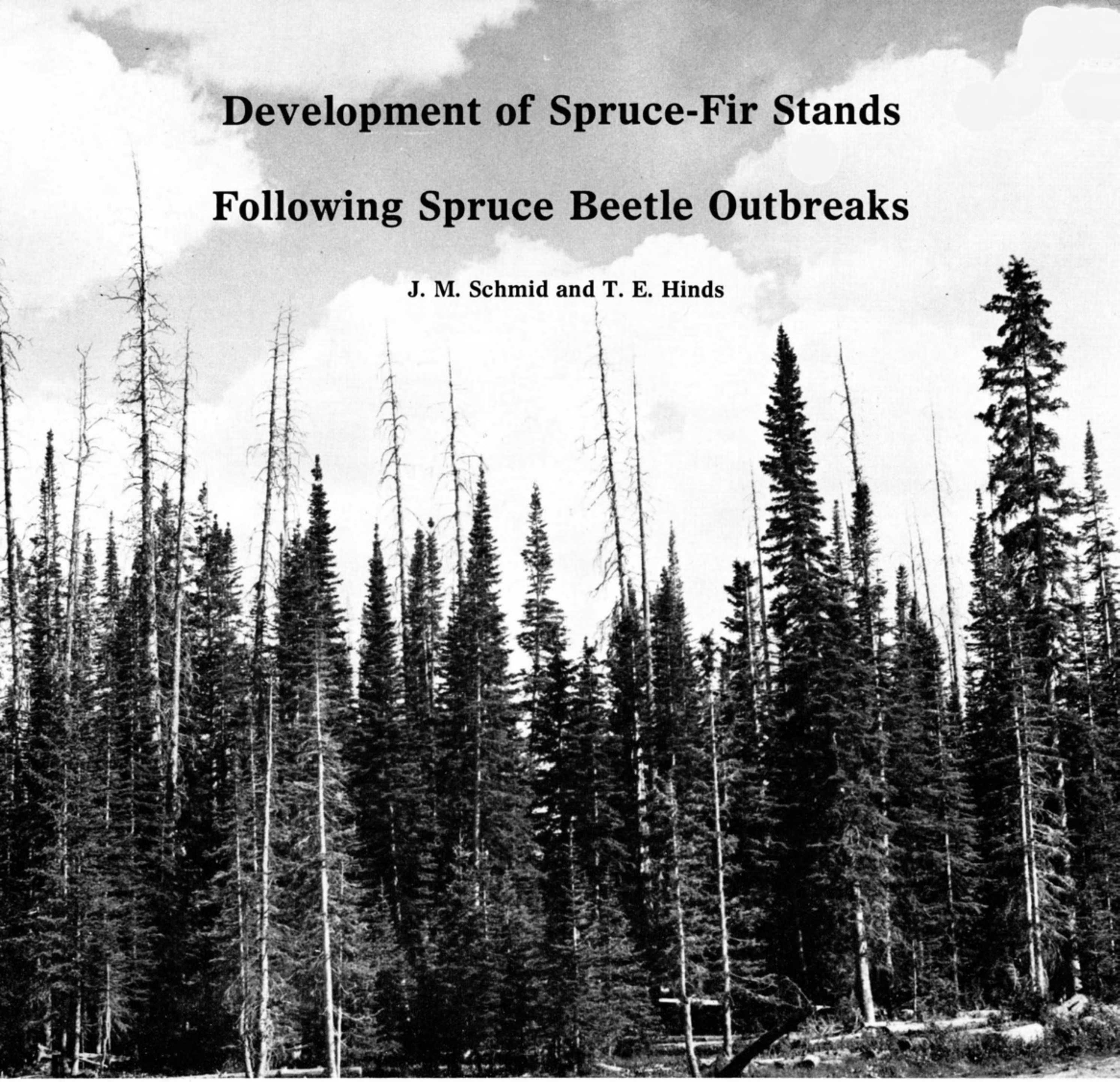
Development of Spruce-Fir Stands Following Spruce Beetle Outbreaks

J. M. Schmid and T. E. Hinds



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Abstract

Logged and unlogged stands of Engelmann spruce-subalpine fir were evaluated in spruce beetle outbreak areas infested about 15, 25, 50, and 100 years ago. Seedling regeneration was generally adequate except in heavily logged areas, although seedlings were often damaged, apparently by animals. Species composition was dramatically altered in favor of fir in the unlogged spruce-fir type. In the overstory, fir may predominate for many years but eventually the spruce will replace it. When the forest reaches a basal area of 150 to 200+ ft^2 per acre in predominantly large spruce, the potential for spruce beetle outbreaks increases. Changes in species composition with different intensities of beetle infestations and over several centuries are hypothesized.

Keywords: *Picea engelmannii, Abies lasiocarpa, Dendroctonus rufipennis,* insect outbreaks, forest succession.

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Contents

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J. M. Schmid and T. E. Hinds

Spruce-fir (*Picea engelmannii* Parry and *Abies lasiocarpa* (Hooker) Nutt., respectively) stands in the Rocky Mountains have periodically been ravaged by the spruce beetle (*Dendroctonus rufipennis* (Kirby)). Beetle infestations are usually in stands composed of older, larger diameter trees. When trees within these stands are blown down either individually, in scattered groups, or complete stands—as frequently happens—resident spruce beetle populations infest the windfallen spruce and may multiply to outbreak proportions. If an outbreak develops, the surrounding trees and adjacent stands may suffer varying degrees of mortality. The most extraordinary and damaging outbreak documented in recent times, decimated spruce stands in the White River area in Colorado during the 1940's (Wygant 1958).

Forest managers faced with a beetle outbreak have two basic alternatives: (1) attempt to control the outbreak and prevent further mortality, or (2) let the outbreak run its course. In the past 30 years, decisions have generally been to attempt to control the outbreaks through logging, trap trees, chemical methods, or a combination of these methods. Cold winter temperatures and woodpeckers aided control efforts in some instances. Few outbreaks ran their course without control measures being instigated.

Evidence of man's control activities, primarily logging in the infested spruce stands, has been obvious. Large openings, piles of logging residuals, scarred trees, and absence of adequate tree reproduction, have been observed by foresters and others alike. Their concern over the appearance of logged areas and the costs and values involved has led them to ask "Wouldn't it have been better to let the outbreak run its course?" This Paper attempts to answer that question by evaluating the structure, stocking, growth, and species composition in logged and unlogged spruce-fir stands formerly infested by spruce beetles.

Methods

Sampling areas were selected within four old outbreaks (fig. 1). Selection of a sampling area

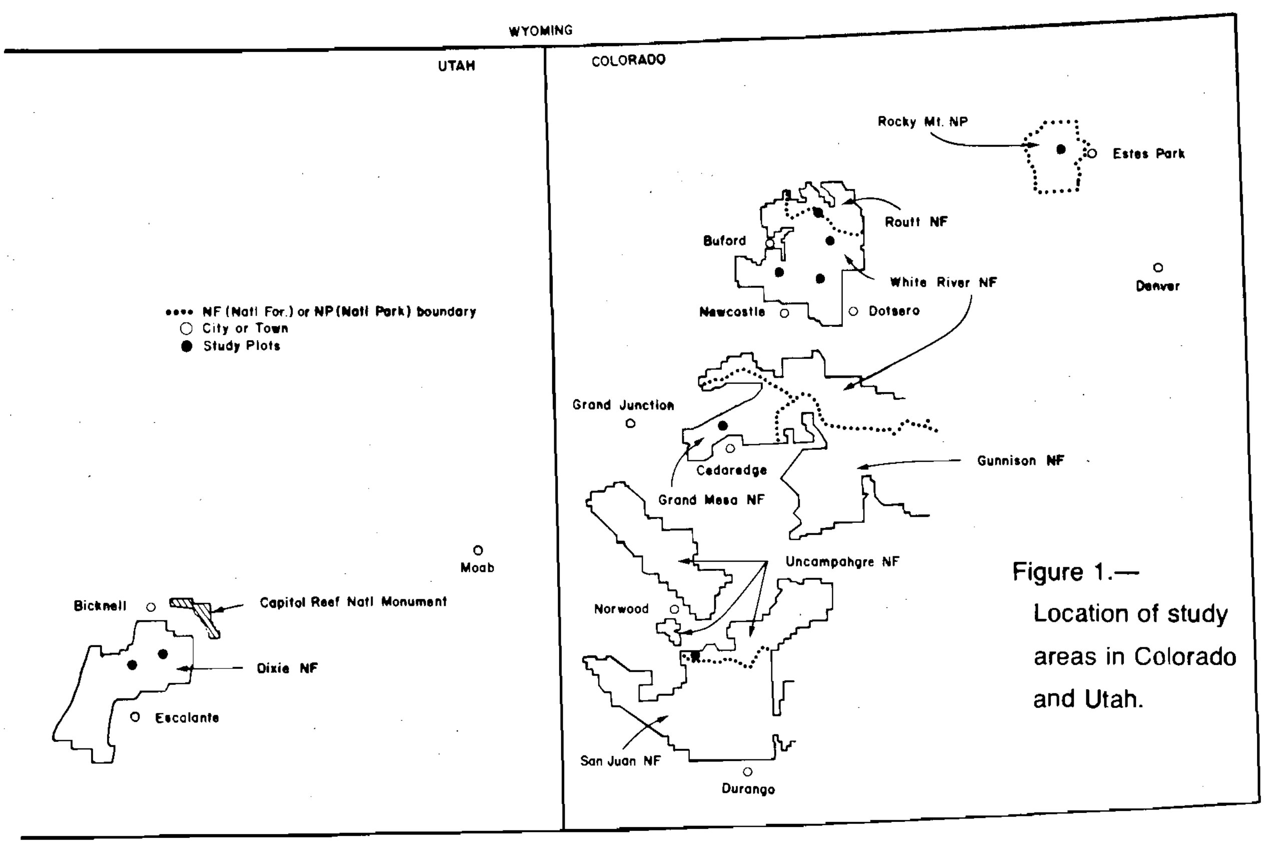

Figure 1.— Location of study areas in Colorado and Utah.

was based on: (1) dated records of an outbreak(s), and (2) evidence of logging. Most locations were visited prior to the actual sampling to acquaint us with the former outbreak area and to locate "typical" logged and unlogged sampling sites. Both the sampling sites and the number of sample plots were arbitrarily selected. A stand in Rocky Mountain National Park not subjected to known outbreaks or logging activity but with an endemic spruce beetle population was also sampled.

A series of 0.1 acre (0.04 ha) circular temporary plots was established in each old outbreak. Generally, 10 plots were established in a specific area of the outbreak. At Ripple Creek Pass, near Buford, Colorado, less than 10 were taken because permanent plots established in 1951 were used, and sites in the logged area differed. Ten previously established plots were also used near the Rio Blanco Ranch, White River National Forest.

Temporary plots were located 2 chains (40 m) apart on a compass line. If more than 25 percent of a plot consisted of herbaceous vegetation and it was judged to have existed as such prior to the outbreak, the plot was then reestablished further along the compass line where its entire area occurred on a previously forested site. In some areas, the stands consisted of small patches or strips so that 10 successive plots could not be taken along one line. The compass line was then offset 2 or 3 chains (40-60 m) and returned on a parallel course.

All live trees greater than 3 inches (7.6 cm) in height were recorded by species as follows:

Small seedlings—3.0 inches (7.6 cm) to 2 ft (0.6 m) in height.
Large seedlings—2 ft (0.6 m) high to 1.5 inches (3.6 cm) d.b.h. (diameter at breast height, approximately 4.5 ft or 1.4 m).
Saplings—1.6 (4.1 cm) to 2.5 inches (6.4 cm) d.b.h.
Pole-sawtimber—2.6 inches (6.6 cm) d.b.h. and larger measured to the nearest 0.1 inch (0.25 cm).

Seedlings and saplings were classified as healthy or damaged (fig. 2). Healthy trees had no obvious defects, while damaged trees were either deformed or sparsely foliated. Crown classes were assigned to trees 2.6 inches (6.6 cm) d.b.h. and larger.

One seedling of each species in each category was collected from each plot. Age, height, and diameter were determined later in the laboratory. One sapling in each species was cut after estimating its height, and a cross section was removed for aging in the laboratory. Increment cores were removed from trees of various diameters and later measured for annual growth to the nearest 0.001 inch (0.025 mm) in the laboratory. Heights were measured for several trees of different crown classes.

All dead trees were recorded by species and d.b.h., including downed trees and their cause of felling: knocked over by other falling trees, windthrown, or butt rot. The d.b.h. of cut trees was estimated from the diameter of the stump.

Basal area, which was used as an index of species composition, was computed for trees 2.6 inches (6.6 cm) d.b.h. and larger. For increases in basal area (growth) on the unlogged Rio Blanco and Ripple Creek Pass areas, basal area was computed for trees 5.0 inches (12.7 cm) d.b.h. and larger because when these permanent sample plots were established, 5.0 (12.7 cm) was the lowest d.b.h. recorded.

History and Description of The Study Areas

Grand Mesa, Colorado

Grand Mesa is a high-elevation (10,000 ft or 3,050 m) mesa with escarpments along some parts of the rim. Broad benches exist below the rims, and drainages from these benches form natural lakes or have been dammed to form artificial lakes. Spruce and fir predominate in the forested parts of the mesa and upper benches, and form patches of forest interspersed with meadowland. Meadowland is more common on the mesa, and is grazed by cattle.

Sudworth (1898b) reported 25 to 40 percent of the mature spruce on the mesa was killed around 1875 by spruce beetles. Another infestation in the 1940's killed the larger spruce.[2] During this latter outbreak, over 50 percent of the merchantable volume was killed but this included less than half the number of live trees (thus indicating the preference of the beetle for larger trees). Numerous pole-sized trees (5 to 9 inches d.b.h.) remained. Salvage logging was done during and after the 1940's outbreak, but not the 1875 infestation. The Scales Lake and Flowing Park Reservoir plots were on the mesa, while the Big Creek Reservoir plots were on the benches below the rim. According to Struble's 1944 report, the Scales Lake area was lightly infested while the Flowing Park and Big Creek Reservoir areas were heavily infested.

[2] *Struble, G. R. 1944. The Engelmann spruce beetle—a progress report of 1944 studies on the Grand Mesa National Forest, Colorado. 25 p. Unpubl. rep. on file, Rocky Mt. For. and Range Exp. Stn., Fort Collins, Colo.*

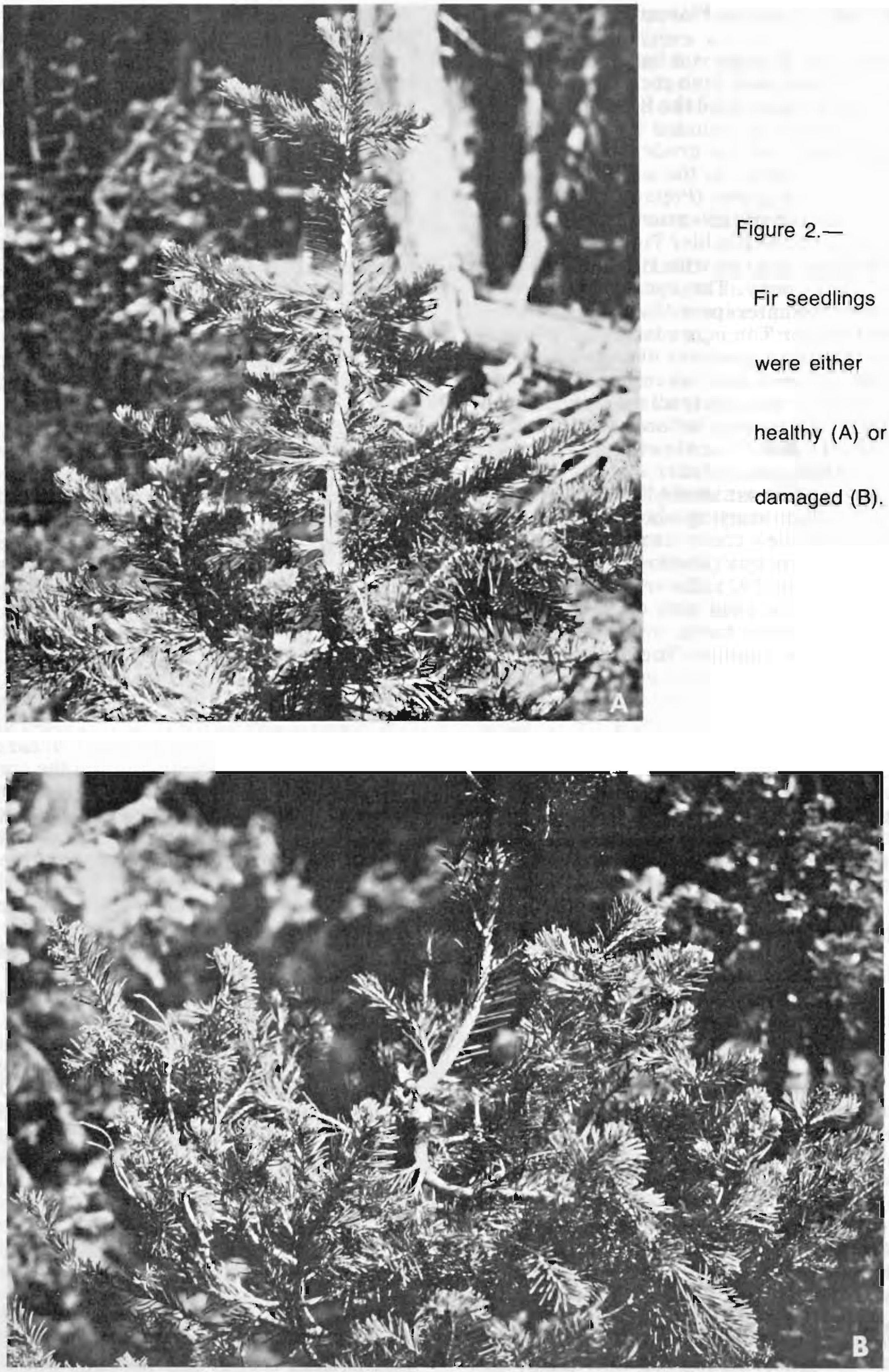

Figure 2.—Fir seedlings were either healthy (A) or damaged (B).

Boulder Top—Aquarius Plateau, Utah

The Aquarius Plateau is a basaltic extrusion which culminates in a high mesa (11,000 ft or 3,350 m), commonly called the Boulder Top. The Boulder Top Mesa is bounded by escarpments on the north and east but grades gradually into the rest of the Plateau to the southwest.

Spruce, fir, and aspen (*Populus tremuloides* Michx.) are mixed in the spruce-fir type of the Plateau, while on the Boulder Top, spruce exists in pure stands. Sites on the Boulder Top are poor and very rocky. The spruce-fir at lower elevations is less interspersed with grasslands, while the Boulder Top is predominantly grassland with only small patches of pure spruce.

Between 1916 and 1918, an infestation began that eventually killed nearly all the large spruce on the Aquarius Plateau before it subsided in 1928-29 (Mielke 1950). Local ranchers cut small numbers of dead trees for corral poles, fencing, and house logs almost immediately after the trees were killed. Starting about 1935, larger volumes of smaller trees were annually removed for mine props (Mielke 1950) and this was continuing in 1971. Salvage logging for saw logs began in 1944 and was continuing in 1971 on a limited basis. Initially, cutting started below the Boulder Top, moved to the Boulder Top in 1948, and was continuing in 1971 on its eastern edge. Early skidding was done with horses; skidding in 1971 used mechanized equipment.

Plots on the Boulder Top were located on the east side in pure spruce logged with mechanized equipment. Additional plots on the Aquarius Plateau but off the Boulder Top were established near Roundy Reservoir in a mixed stand logged with horses.

White River Plateau, Colorado

The White River Plateau, composed of several mesas, varies between 10,000 and 11,500 ft (3,050 and 3,505 m) in elevation and is subdivided by several drainages. Spruce and fir form small patches or irregular stands interspersed with meadows. The forested areas are more predominant on slopes or ridges angling downward from the Plateau. Lodgepole pine (*Pinus contorta* Dougl.) and aspen may be mixed with the spruce and fir on these lower slopes or ridges.

A spruce beetle outbreak occurred on the Plateau around 1875 (Sudworth 1898a). Another infestation began in 1939 and continually expanded during the 1940's (Massey and Wygant 1954) from one part of the Plateau across canyons to other parts until eventually, nearly all spruce 8 inches (20 cm) d.b.h. or larger was killed. In some areas, a few scattered, individual spruce trees up to 16 inches (40.6 cm) d.b.h. survived. Salvage logging was initiated for pulpwood and saw logs in several locations in the late 1940's.

Plots near Hiner Spring (near Newcastle) were in the western part of the Plateau, while the Deep Lake plots were on the southeastern part. Approximately 50,000 cords (128,000 m^3) of timber were cut in the general vicinity of the logged plots near Newcastle, but stands were not cut uniformly. Trees were cut only 1 to 3 chains (20 to 60 m) in from the edge of the stand. For unknown reasons, some trees were cut while others of equal accessibility and soundness were left. Logged plots near Deep Lake were in an area where 200,000 cords (510,000 m^3) of timber were removed. Full-length trees were skidded by mechanized equipment. Plots near Rio Blanco Ranch and Ripple Creek Pass were on a north-facing slope and a ridge, respectively. The Rio Blanco site was predominantly lodgepole pine-Engelmann spruce prior to the infestation. On the logged plots at Ripple Creek Pass, only the larger dead trees were logged and these were skidded with horses. One logged site was quite wet.

Lone Cone, Colorado

This area was in a valley between two ridges at an elevation of 8,500 ft (2,900 m), and differed from most of the previous study areas in that very few meadows existed within the spruce-fir forest. It also differed from the other areas because the infestation was detected and the infested trees logged or chemically treated before the infestation became extensive. Logged areas were clearcut; full-length trees were skidded with mechanized equipment.

Rocky Mountain National Park, Colorado

This spruce-fir area was on a north-facing slope at an elevation of 10,300 ft (3,140 m). On some wet sites, running water was probably available in early summer. The area was chosen because it was a mature stand that never had been logged. Also, spruce beetles had killed or are currently killing scattered, large-diameter trees, but an extensive outbreak has not occurred in the last 100 years.

Results and Discussion

Number of Live Trees

The average number of seedlings, saplings, and pole-sawtimber trees varied greatly from area to area within and between infestations.

Fir seedlings generally outnumbered spruce seedlings in all areas except on one logged site at Ripple Creek Pass and in the pure spruce of Boulder Top (table 1). On some sites, fir seedlings outnumbered spruce 10:1, while on other sites their numbers were nearly equal. Fir saplings outnumbered spruce saplings on most of the White River areas and in Rocky Mountain National Park; elsewhere spruce saplings were as numerous or more abundant than fir (table 1). In trees over 2.6 inches d.b.h., spruce was generally less numerous than fir on the White River but more numerous on the other areas (table 1).

Differences in the number of live trees on the unlogged and logged plots on the Lone Cone and White River areas resulted from several factors, but logging was probably the primary reason. Logging can destroy 50 to 70 percent of the trees less than 1 ft tall (USDA Forest Service 1948) or 50 percent of the advanced reproduction (Alexander 1963). However, as Alexander (1963) notes, the amount of reproduction destroyed is greatest where logging activity is greatest. Where logging was heavy at Lone Cone and Deep Lake on the White River, herbaceous vegetation now appears to preclude natural establishment of seedlings. Roe et al. (1970) noted that shrubs and other lower growing vegetation may occupy a site after a disturbance (insect outbreak, clearcut) and preclude the establishment of tree species for many years unless seed falls soon after the disturbance. Elsewhere on the White River (Hiner Spring and Ripple Creek Pass) logging was not so destructive, perhaps because of less intensity. The Hiner Spring area, like Deep Lake, consisted of strips of timber separated by meadows, but considerably fewer beetle-killed trees were cut. Also, in the Hiner Spring area, trees were logged a few chains in from the edge and selected material was skidded with horses. Under this type of logging, damage was not nearly so severe as near Deep Lake, and consequently logged and unlogged plots had similar numbers of small seedlings.

Table 1.--Characteristics of study areas, by outbreak location, logging status, years since infestation(s), and average number per acre of seedlings, saplings, and trees 2.6 inches and larger d.b.h.

Outbreak location and logging status (L = Logged) (U = Unlogged)		Approximate years since infestation(s)	SEEDLINGS					SAPLINGS			TREES 2.6 INCHES D.B.H. AND LARGER		
			SPRUCE		FIR								
			<2 ft tall	2 ft tall-1.5 inches d.b.h.	<2 ft tall	2 ft tall-1.5 inches d.b.h.	Total	SPRUCE	FIR	TOTAL	SPRUCE	FIR	TOTAL
GRAND MESA													
Grand Mesa NF													
Scales Lakes	-U	100,25	141± 27	114± 20	417± 51	631± 88	1,303	52± 6	66± 14	118± 16	291±24	212±29	503±42
Big Creek Reservoir	-U	100,25	283± 56	81± 13	858±175	697±128	1,919	32± 6	95± 20	127± 19	144±18	268±26	412±32
Flowing Park Reservoir	-L	100,25	660±127	337± 58	948±145	433± 52	2,378	53± 8	16± 9	69± 11	226±36	84±14	310±32
AQUARIUS PLATEAU													
Dixie NF													
Boulder Top	-U	50	119± 34	211± 30	1± 1	1± 1	332	110±19	0	110± 19	187±23	1± 1	188±22
Boulder Top	-L	50	407±115	361± 65	2± 1	0± 0	770	27± 6	0	27± 6	98±15	0	98±15
Roundy Reservoir	-L	50	59± 10	323± 62	59± 17	111± 45	[1]638	80±17	16± 7	[1]148± 25	265±42	21± 9	[1]365±35
WHITE RIVER PLATEAU													
White River NF													
Ripple Creek Pass	-U	100,25	354± 49	30± 30	529± 34	69± 69	982	47±14	99± 18	146± 22	54±16	248±37	302±39
Ripple Creek Pass	-L	100,25	110± 40	402± 61	28± 10	138± 39	678	67±14	50± 19	117± 27	55±19	155±26	210±31
Ripple Creek Pass	-L	100,25	107± 32	340± 43	155± 37	660±184	1,262	33± 2	142± 44	175± 43	35± 8	278±46	313±42
Mirror Lake	-U	100,25	95± 22	227± 57	301± 53	472±108	1,095	53±17	72± 14	125± 22	151±20	168±25	319±22
Hiner Spring	-L	100,25	13± 6	52± 10	102± 24	426±109	593	24± 5	70± 28	94± 30	179±26	116±28	295±46
Cliff Lake	-L	100,25	65± 14	222± 48	321±133	407± 70	1,015	42±12	65± 21	107± 28	130±18	152±34	282±40
Deep Lake	-U	100,25	47± 11	228± 37	53± 25	325± 48	653	35± 8	94± 17	129± 16	46±14	222±33	268±38
Deep Lake	-L	100,25	8± 3	70± 15	[2]22± 7	74± 14	174	15± 5	10± 3	25± 4	19±10	35± 7	54±12
Deep Lake	-L	100,25	7± 4	41± 8	14± 6	256± 47	[2]318	7± 3	40± 7	[2]47± 9	25± 7	63±12	[2]88±16
Rio Blanco Ranch	-U	100,25	677±159	636±138	1,389±184	1,648±111	[2]4,386	46±15	111± 16	[2]157± 15	28± 9	175±19	[2]204±17
LONE CONE													
Uncompahgre NF													
Lone Cone	-U	15	258± 61	203± 33	418± 62	302± 41	1,181	40± 7	32± 11	72± 16	179±26	87±16	266±25
Lone Cone	-L	15	27± 8	71± 16	81± 22	116± 22	295	8± 3	6± 3	14± 5	12± 4	21± 5	33± 9
ROCKY MOUNTAIN NATIONAL PARK													
Hidden Valley	-U	--	189± 37	94± 13	637±122	606±117	1,526	4± 3	44± 11	48± 12	117±12	93±18	210±17

[1]Includes some aspen.
[2]Includes some lodgepole pine.

Although logging intensity was not as great at Ripple Creek Pass as at Deep Lake, logging, site, and competition of herbaceous vegetation influenced differences in the number of small seedlings on the logged and unlogged plots. Rapid growth of herbaceous vegetation after logging on the more moist sites (fig. 3) reduced successful establishment of seedlings. However, this dense herbaceous growth does not explain why the number of large seedlings is substantially less on unlogged plots. Since sites were noticeably different, this difference in seedlings might be a prime example of the variability in spruce stands suggested by Alexander (1971). It is also possible that seedlings in the logged area grew out of the smaller category in response to logging. If both categories of seedlings are combined, the differences between logged and unlogged areas are not so great.

The number of seedlings on the Boulder Top was considerably greater in the logged area than in the unlogged area (table 1). Trees 2.6 to 13 inches d.b.h. were generally more numerous on the unlogged plots than on logged plots, but for trees greater than 13 inches d.b.h. the situation was reversed. These differences—as well as just the number of trees—illustrate the effects of site, stand, and logging factors. The number of live trees (table 1) indicates a poor site, because tree numbers are substantially less than on areas of the White River even though the Aquarius Plateau was infested 25 years previously. The trees that survived the infestation are open grown, which reflects stand conditions, but could also account for differences in seedling numbers. Such trees would probably bear seed more often than trees grown in a dense stand and could therefore contribute seed after logging. The lower proportion of pole-sawtimber trees and the higher proportion of damaged seedlings on the logged plots evidences the influence of logging.

Seedlings near Roundy Reservoir (table 1) were more numerous than on the unlogged Boulder Top and slightly less numerous than on the logged Boulder Top. Logging partially accounts for these differences in two ways. First, salvage logging began in the 1940's near Roundy Reservoir with horses. This type of logging probably damaged the residual stand less, and when combined with a better site allowed greater numbers of pole-sawtimber trees to survive. In addition, the earlier logging aided establishment of seedlings which by now have grown into the large category. As the stand developed after logging, competition became greater and reduced survival of subsequent seedlings. Thus, the present number of small seedlings near Roundy Reservoir is less than on the Boulder Top, where logging is more recent and consequently less competition.

Seedlings near Scales Lake were less numerous than near Flowing Park Reservoir (table 1),

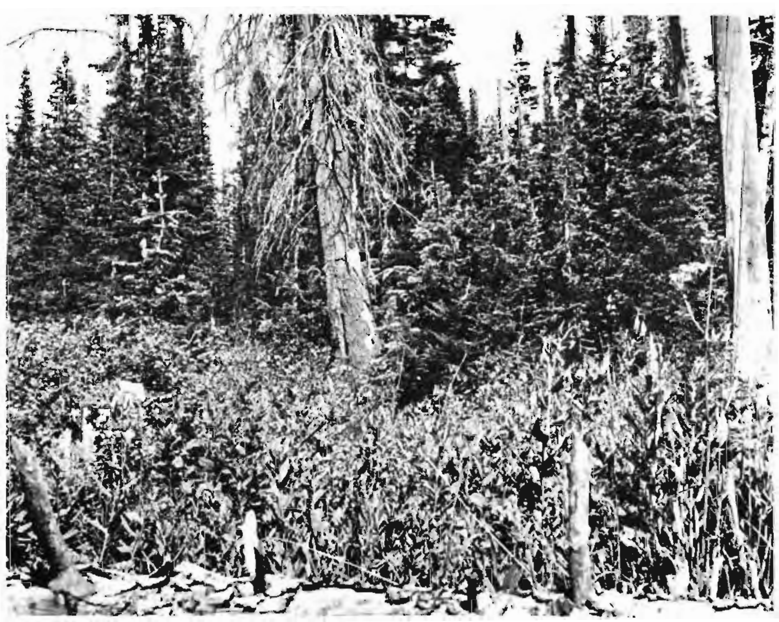

Figure 3.—Dense herbaceous vegetation inhibits seedling establishment—Logged site at Ripple Creek Pass.

but saplings and pole-sawtimber trees were more abundant. Intensity of the infestation and subsequent logging seem to account for these differences. Although Sudworth (1898b) indicates 25 to 49 percent of the stand on the mesa was killed, a substantial number of intermediate and perhaps codominant spruce remained to become the stand attacked by the beetle in the 1940's. Struble's report indicates that the area near Scales Lake was lightly infested, while the area near Flowing Park Reservoir was heavily infested. Since logging was used for control, logging was concentrated where the infestation was heaviest so that more pole-sawtimber trees were removed near Flowing Park Reservoir. This logging created favorable sites for seedlings, and subsequent seedfall from the remaining live trees established a greater number of seedlings in this area.

Seedling Damage

Damaged seedlings were found in all areas. Proportions ranged from 9 to 60 percent for fir and 5 to 45 percent for spruce on unlogged plots, and from 20 to 61 percent and 16 to 40 percent for fir and spruce, respectively, on logged plots. The percentage of damaged small seedlings of both species averaged about 10 percent less than for large seedlings. The percentage of damaged fir seedlings averaged about 8 percent more than spruce on unlogged plots, while on logged plots, about 25 percent more fir were damaged.

Although the differences in damaged seedlings on logged versus unlogged plots seems to suggest logging as a major injurious factor, the type of damage generally indicated that logging contributed only indirectly to damage.

Windfalls damaged some seedlings, either by stripping off branches or holding the seedling in a bent-over position so that its main vertical growth is not directly above its root system. Hinds et al. (1965) estimated that beetle-killed spruce fall at the rate of 1½ percent per year, so this type of damage can be expected to continue for at least another 30 years.

The most important damage factor appeared to be browsing, either by domestic livestock, elk (*Cervus canadensis* (Erxleben)), deer (*Odocoileus hemionus* (Rafinesque)), or small rodents. Most damaged seedlings had the terminal leader missing or deformed (fig. 2B). Frequently, when this leader was gone, a lateral shoot became the terminal. The seedling took on a broomed look, and while apparently healthy otherwise, became bushy and lost height growth.

Food is plentiful when the deer and elk inhabit the spruce-fir, so they probably account for little if any of the damage. Wallmo et al. (1972) reported practically no browsing of mule deer on Engelmann spruce and subalpine fir in logged and unlogged strips in Colorado. Kufeld (1973) indicates spruce and fir have negligible food value for elk.

Sheep and cattle are more probable causal agents because most of these infested areas were in their summer range on mesas consisting of stands of spruce-fir interspersed with meadows. The stands provide natural shade and cover for livestock between the meadows. Since herbaceous vegetation has increased after the White River outbreak (Yeager and Riordan 1953), the animals would tend to forage in the strips of forest as well as in the meadows. In addition, the herbaceous vegetation is apparently even more abundant in logged areas so that logging may indirectly account for some damaged seedlings because it creates more attractive forage areas. Where stands are more contiguous and occupy greater areas, thus inhibiting stock movements, perhaps the damage would be more attributable to elk, deer, small rodents, or freezing temperatures. Rabbits may be a factor in winter when they browse on leaders above the snowline. Both early and late frosts may also kill new growth.

The greater amount of damage to fir seedlings reduces the fir's advantage in succession of the stand. Since fir seedlings usually outnumber spruce, fir has a better chance of eventually dominating the overstory. The damage factor may compensate for the numerical advantage, and allow spruce to gain a height advantage.

It should be stressed that these damaged seedlings are generally alive but deformed. They have survived the mortality factors of young seedlings cited by Ronco (1961, 1970), but have incurred or are incurring damage by other factors. Our minimum size limit for seedlings placed most of them beyond the size Ronco considered, but the mortality factors he cited as well as others are killing seedlings smaller than our minimum. As no data are available upon which to predict the growth response of damaged seedlings, these damaged seedlings could easily recover and become mature trees if further damage is not incurred.

Stocking

The minimum stocking requirements for spruce-fir stands are 600 seedlings and saplings per acre of good form and vigor and free of defect before cutting (Alexander 1971); or 300 well-established and well-distributed acceptable seedlings per acre or 150 saplings after cutting (Roe et al. 1970). Although our combined seedling category does not correspond exactly with Alexander's, the categories are similar enough so that the two logged Deep Lake sites, the logged Lone Cone, and unlogged Boulder Top sites are below or slightly above these minimum requirements (table 1). Considering the number of damaged or deformed seedlings found, stocking in these areas is well below minimum standards. Other areas averaging about 600 to 700 seedlings per acre (table 1) are only slightly above minimum standards when the damaged seedlings are subtracted from the totals. Since similar conditions may have prevailed in the 50- and 100-year-old beetle-killed stands, this light stocking including damaged seedlings may be adequate for new stands. This remains to be seen in the 25-year-old infestations, particularly those in unlogged or lightly logged areas.

Growth

Diameter growth at breast height of pole-sawtimber spruce and fir varied considerably between trees, plots, and areas. Trees in logged and unlogged areas increased in diameter following the beetle outbreak and/or logging as would be expected since the number of living trees was greatly reduced.

Increases in diameter of individual trees ranged from 0.02 to 0.35 inch per year, although the higher rates were not maintained for more than a few years. Diameter growth generally averaged between 0.5 and 1.5 inches for 10-year periods. A growth rate of less than 0.4 inch per 10 years should probably be considered as poor; 0.5 to 1.0 as average, 1.1 to 1.5 as good, and anything more than 1.5 per 10 years, excellent.

Two areas, Rio Blanco and Boulder Top (both unlogged), showed distinct differences in diameter growth prior to and after the beetle infestation. Diameter growth averaged less than 0.3 inch per 10 years for 2 decades prior to the beetle attack in the Rio Blanco area and averaged about 1 inch per 10 years for the 20 years following the outbreak. Similarly, diameter growth on the Boulder Top averaged less than 0.2 inch per 10 years for 30 years prior to the outbreak, and about 1 inch per 10 years for 40 years following the infestation.

Height growth of fir and spruce seedlings less than 2 ft tall ranged from 0.35 to 0.85 and 0.40 to 0.80 inch per year, respectively (table 2). Average height increment for both species was lowest on those sites with the larger basal areas of live trees. Average annual height increment was about equal for both species on the same sites. Thus, height growth of seedlings is promoted by outbreaks because it reduces competition from larger trees. Salvage logging,

Table 2.--Average height growth (inches per year) of fir and spruce seedlings less than 2 feet in height

Outbreak location and logging status (L = Logged) (U = Unlogged)		SPRUCE	FIR
GRAND MESA Grand Mesa NF			
Scales Lakes	-U	0.45	0.37
Big Creek Reservoir	-U	.48	.47
Flowing Park Reservoir	-L	.59	.42
AQUARIUS PLATEAU Dixie NF			
Boulder Top	-U	.53	(1)
Boulder Top	-L	.58	(1)
Roundy Reservoir	-L	.45	.49
WHITE RIVER PLATEAU White River NF			
Ripple Creek Pass	-U	.78	.47
Ripple Creek Pass	-L	.80	.85
Ripple Creek Pass	-L	.74	.64
Mirror Lake	-U	.60	.65
Hiner Spring	-L	.60	.57
Cliff Lake	-L	.64	.74
Deep Lake	-U	.58	.56
Deep Lake	-L	(1)	(1)
Deep Lake	-L	.81	.66
Rio Blanco Ranch	-U	.68	.64
LONE CONE Uncompahgre NF			
Lone Cone	-U	.40	.37
Lone Cone	-L	(1)	(1)
ROCKY MOUNTAIN NATIONAL PARK			
Hidden Valley	-U	.40	.35

[1]Species absent or numbers so low we did not remove seedlings.

however, did not generally influence height growth of the established seedling. Site also influenced height growth of seedlings, and compensated for increased competition from higher densities of seedlings. The Rio Blanco area with high average height growth and high seedling densities illustrates this case.

Age determinations of the seedlings less than 2 ft in height indicated more than 80 percent of the spruce seedlings in the four White River areas originated after the outbreak. Thus, even though an outbreak may kill over 99 percent of the dominant trees, a few trees remain to provide some seed for restocking.

BA (basal area) increased at the average rate of 0.35 and 1.2 ft^2 per acre per year on the unlogged Rio Blanco and Ripple Creek Pass areas, respectively. Assuming BA growth continued at these rates, it would take about another 335 and 150 years, respectively, to achieve the pre-outbreak BA values on these locations. This wide difference in projected recovery time reflects the destruction on the two sites; after the outbreak, the Rio Blanco area had only 40 trees per acre over 5.0 inches d.b.h. while the Ripple Creek Pass area had 148. The rate of BA growth should increase, so that time to achieve pre-outbreak values would be considerably less. Species composition complicates the BA picture, however. Both stands are now over 85 percent fir, so that if the stands do achieve prior BA values with the existing species composition, they would not be the same as existed prior to the outbreak. In addition, fir generally begin to die when they reach a d.b.h. of 15 to 18 inches (125 to 175 years) which would decrease the rate of BA increase and, consequently, lengthen the time to achieve pre-outbreak levels. To achieve those values with the same pre-outbreak percentage of spruce will require at least 300 years.

Species Composition

Spruce comprised 80 percent of the BA in the unlogged Lone Cone area while fir comprised 20 percent (table 3). Seedling composition was about 40 percent spruce and 60 percent fir (see table 1). On the logged area, fir comprised 79 percent of the BA while spruce was 21 percent. Seedling composition was about the same as on the unlogged area except for small seedlings, where numbers were too small to be significant. The infestation coupled with the logging altered the species composition and essentially reversed the most prevalent species from spruce to fir in pole-sawtimber trees.

The spruce component in stands on the White River changed dramatically. Prior to the outbreak, spruce comprised over 90 percent of the BA on the Ripple Creek Pass, Mirror Lake, and Deep Lake unlogged plots. After the outbreak, spruce comprised about 15, 50, and 15 percent of the BA respectively (table 3). On the logged plots, the percentage of spruce in the live BA was about 10 to 20, 50 to 70, and 20 for the same respective areas. Spruce comprised about 35, 30, and 45 percent of the seedlings on the unlogged plots (see table 1). The infestation altered the pole-sawtimber spruce component, but subsequent logging did not essentially change these percentages of spruce and fir. The effect of the infestation on the species composition of seedlings could not be determined. Logging coupled with the infestation appears not to have altered species composition in most cases, although the percentage of spruce seedlings was less on one logged area near Hiner Spring and greater on one area near Ripple Creek Pass. This was just the inverse of the percentage of spruce in the live BA for the respective areas.

Species composition on the Rio Blanco area of the White River differed from the other areas. Lodgepole pine and Engelmann spruce comprised essentially all of the BA prior to the outbreak, with lodgepole pine accounting for 60 percent. Now, lodgepole pine above 2.6 inches d.b.h. is essentially nonexistent, spruce comprises less than 10 percent of the BA, and fir accounts for the rest (table 3). Spruce comprises about 33 percent of the seedlings while fir accounts for the remaining percentage (see table 1). Since considerably less than 1 percent of the seedlings were lodgepole pine, their numbers were not separately indicated in table 1. The infestation dramatically altered species composition because lodgepole pine will probably disappear from the stand as it matures. This area also exemplifies an abnormal attack by the spruce beetle on lodgepole pine. The volume constitutes a substantial part of the 500 million fbm of pine destroyed by the beetle according to Massey and Wygant (1954).

Species composition did not change on the Boulder Top where before and after the outbreak, over 99 percent of the BA consists of spruce (table 3). Seedling composition on the Boulder Top also remains essentially pure spruce (see table 1). Neither the infestation nor logging affected the species composition in this area.

The Roundy Reservoir area had 74, 3, and 23 percent of the BA in spruce, fir, and aspen, respectively (table 3). Small seedlings were 48 percent spruce, 48 percent fir, and 4 percent aspen, while large seedlings were 62, 23, and 15 percent, respectively. Since pre-outbreak conditions are not known, changes in species composition, if they did occur, cannot be dis-

Table 3.--Average basal area (ft^2/acre) by size class

Outbreak location and logging status (L = Logged) (U = Unlogged)		SPRUCE					FIR					
		2.6-4.9	5.0-9.0	9.1-20.9	21.0+	Total[1]	2.6-4.9	5.0-9.0	9.1-20.9	21.0+	Total[1]	Total[1]
GRAND MESA Grand Mesa NF												
Scales Lakes	-U	9±1	27± 4	89± 6	7± 4	132	6±1	26±5	29± 5	0	61	193±25
Big Creek Reservoir	-U	3±1	13± 2	49± 8	2	67	8±2	27±3	53±14	0	88	162± 9
Flowing Park Reservoir	-L	6±1	19± 4	69±14	7± 4	101	1±0.3	9±2	32± 8	0	42	142±17
AQUARIUS PLATEAU Dixie NF												
Boulder Top	-U	5±1	16± 4	40± 5	0	61	0	<1	0	0	<1	62± 7
Boulder Top	-L	1±0.4	8± 2	48± 6	3	60	0	0	0	0	0	61± 7
Roundy Reservoir	-L	6±1	27±14	62± 8	0	95	1±0.3	1±1	3± 2	0	5	[2]129±11
WHITE RIVER PLATEAU White River NF												
Ripple Creek Pass	-U	2±1	5± 2	4± 3	0	11	8±1	23±4	41± 7	0	72	82±12
Ripple Creek Pass	-L	2±1	5± 4	2± 2	0	9	5±1	17±2	17± 6	0	39	49± 5
Ripple Creek Pass	-L	1±0.4	4± 2	0	0	5	9±2	23±4	37± 7	0	69	74±11
Mirror Lake	-U	4±1	11± 3	36± 7	0	51	4±1	18±3	28±10	0	50	101±12
Hiner Spring	-L	3±1	22± 4	40± 6	0	65	4±2	9±6	18± 5	0	31	97± 6
Cliff Lake	-L	3±1	12± 3	29± 4	0	44	5±2	13±3	25± 6	0	43	88± 9
Deep Lake	-U	2±1	4± 2	1± 1	0	7	8±1	24±5	16± 0.4	<1	48	57± 5
Deep Lake	-L	1±1	2± 1	0	0	3	1±0.3	3±1	7± 3	0	11	14±10
Deep Lake	-L	1±0.3	2± 1	1	0	4	2±0.5	3±1	9± 3	<1	14	22± 6
Rio Blanco Ranch	-U	1±0.6	1± 0.8	0	0	2	8±1	16±3	5± 2	0	29	[3]33± 4
LONE CONE Uncompahgre NF												
Lone Cone	-U	4±1	11± 3	82±11	36± 7	133	2±0.5	8±2	23± 3	0	33	167±10
Lone Cone	-L	0.3±0.2	2± 1	2± 1	0	4	0.3±0.2	2±2	14± 6	0	16	21± 6
ROCKY MOUNTAIN NATIONAL PARK												
Hidden Valley	-U	0.3±0.1	4± 1	99±13	68±14	171	3±0.6	7±1	25±10	3	38	209±24

[1]Some inconsistencies in total basal area and sum of the subtotals for spruce and fir due to rounding.
[2]Includes some aspen.
[3]Includes some lodgepole pine.

tinguished between the beetle or logging as causal factors. It appears that fir was becoming more numerous and aspen less so at the time of the outbreak. Logging may have stimulated aspen suckering and enhanced spruce seedling survival.

Near Scales Lake and Flowing Park Reservoir (Grand Mesa National Forest), about 70 percent of the BA was spruce, while fir accounted for the other 30 percent (table 3). Seedling composition on those areas was different; the unlogged Scales Lake area had about 15 to 25 percent spruce while the logged Flowing Park Reservoir area had 40 to 45 percent spruce (see table 1). Big Creek Reservoir area had nearly a 1:1 ratio in BA of spruce and fir, but spruce comprised only 10 to 25 percent of the seedlings. As on the Aquarius Plateau, the effect of the beetle or logging on species composition cannot be defined. Logging may have favorably influenced spruce seedling survival on the Mesa because the percentage of spruce was greater on the logged area.

All areas were covered by vegetation; none had expanses of bare soil. Logged stands of the Lone Cone and White River areas and some unlogged White River stands had especially dense growths of *Mertensia, Lupinus, Delphinium,* *Ranunculus*, *Arctostaphylos*, and *Heracleum* (fig. 4). This dense vegetation competes with existing seedlings and prevents successful establishment of postoutbreak or postlogging seedlings.

Species composition of trees in spruce-fir stands could be altered by the following factors: (1) composition of the stand at the time of the outbreak, (2) intensity of the outbreak (number of trees killed per acre), (3) size of the outbreak (number of acres), and (4) time and intensity of logging.

If the stand is essentially pure spruce, then neither beetles nor logging would alter the spruce component unless the intensity of logging is so great as to convert the stand to herbaceous vegetation.

If the stand is dominantly spruce-fir (as in the central Rockies) or spruce-lodgepole pine, then various interactions are possible between the stand, outbreak and logging:

1. A spruce-fir stand sustaining an intensive attack over hundreds of acres would be altered to predominantly fir in pole-sawtimber trees, but seedling composition would not immediately change. Since the remaining seedbearing spruce would not immediately produce seed, and would be so few in comparison with the total number of fir, the percentage of spruce seedlings would probably decline in the unlogged stand.

Figure 4.—Dense herbaceous vegetation inhibits seedling establishment—Unlogged site at Deep Lake.

If logging begins immediately after the outbreak, light cutting to remove only the dead spruce would not essentially alter the pole-sawtimber spruce-fir ratio, and would slightly increase the percentage of spruce seedlings. However, since only a few seed-bearing spruce are alive in the immediate area and the size of the infestation would prevent seeding from adjacent uninfested stands, available germination sites would generally be taken by fir seedlings or herbaceous vegetation.

If cutting is heavy (both dead spruce and merchantable fir removed), then the percentages of pole-sawtimber spruce and fir would change because the fir component is reduced. The spruce-fir seedling percentages would change to that species able to provide seed. If logging is so intense that all dead spruce is salvaged and most of the live trees are cut or destroyed during logging, then the site would be occupied by herbaceous vegetation.

2. A spruce-fir stand sustaining an intense attack over a limited area (for example, only a few acres) would be altered to fir in pole-sawtimber trees, but would not immediately change its seedling composition. Fir seedlings would be favored in subsequent years if the soil were not disturbed. Seedbearing fir in the infested area as well as fir and spruce in the adjacent uninfested area would provide seed, but the fir would be more successful in the undisturbed site. Limited logging would create more favorable sites for spruce, but changes in the seedling composition would be related to seed production of each species coincident with logging. Logging equivalent to clearcutting could change the infested area to herbaceous vegetation.

3. A spruce-fir stand sustaining a light infestation over either an extensive or limited area would reduce the percentage of pole-sawtimber spruce, but would not immediately alter the seedling composition. Both spruce and fir would contribute seed, but the undisturbed stand would favor fir. If logging were initiated, anything short of clearcutting would increase the spruce component but would again depend on the production of seed coincident with the creation of favorable germination sites by logging. Otherwise, the sites would be occupied by herbaceous vegetation.

Big-Game, Recreational, Fire, and Decay Implications

Death of the larger trees may have long-term effects on big-game populations. Initially, the killing of the stands improves the summer forage for deer and elk (Yeager and Riordan 1953). This improvement probably continues until the site is fully occupied and forage does not decrease in quantity until new trees begin competing with it. Judging by the rate of seedling and BA growth, forage would not decline substantially for several decades. However, the increasing numbers of fallen dead trees may inhibit the movements of elk and deer, both foraging and between their summer and winter ranges.

Beetle-killed stands also pose a problem for recreationists and land-managing agencies. The recreationist must maintain constant awareness in these stands, while the agency has increased trail maintenance and campground costs.

Beetle-killed spruce become hazards for recreationists because the trees decay and fall, or are windthrown before decaying. In spruce-fir, Hinds et al. (1965) found 12 percent of the volume of each tree decayed and 25 percent of the trees windthrown within 20 years after the outbreak. On our Ripple Creek plots, 10 percent of the trees were windthrown the first 10 years after the outbreak, another 12 percent the second decade, and an additional 26 percent the third decade. Thus, about 1.5 percent of the dead spruce are windthrown each year, although the rate of windfall is increasing. While standing trees do not decay rapidly, fallen trees will decay in 5 years if they are touching the ground. Decomposition is slower for the parts of the logs that do not touch the ground.

Windthrow losses are greater in dead spruce-lodgepole pine stands. In the Rio Blanco Ranch area, windthrow averaged 3.0 and 2.3 percent per year for spruce and lodgepole pine, respectively, for the past 25 years. Why 63 percent of the dead spruce-lodgepole have fallen in the Rio Blanco area while only 46 percent of the spruce have fallen near Ripple Creek Pass is not known.

Windthrow in pure spruce on the Boulder Top amounted to 16 percent about 30 years after the infestation (Mielke 1950). In 1971, 63 percent of the spruce had fallen in the unlogged sample area, thus indicating an average rate of 1.3 percent per year.

Since beetle-killed spruce in a large infestation cannot normally be immediately salvaged, how long can salvage operations continue? Decay and windthrow data indicate salvage could continue up to 20 years after the infestation. Salvage can continue after that period if special uses (mine props) for the dead spruce can be found. However, such operations are marginal and the longer they continue, the less profitable they become.

Beetle-killed trees originating from outbreaks may become a high fire hazard. In 1951, then Forest Service Chief Watts suggested that the spruce beetle outbreak was creating a very serious fire hazard in Colorado, and money for control should be expended to reduce this hazard (U.S. Senate 1952). During the 25 to 30 years since the outbreak, no major fires developed. Furthermore, widespread fire seems to be a rare event in the spruce-fir type. Mielke (1950) stated that no large fires have burned in the spruce-fir in Colorado since 1900, and one major fire in 1879 in northern Colorado (Routt National Forest) was started by Indians. Miller (1970) noted that evidence of widespread fires between 1750 and 1830 is lacking on the White River Plateau. Although the beetle-killed snags are potential lightning rods and the massive number of dead trees has created a large fuel buildup, the fire hazard seems overexaggerated. Lightning in summer thunderstorms could start fires in these snags, but the accompanying rainfall apparently dampens the surrounding vegetation enough to prevent development of a widespread fire. Thus the importance of the fire hazard in the spruce-fir is less than in other timber types.

Characteristics of Potential Outbreak Stands

Analysis of these four infestations suggests some characteristics of potential outbreak stands: (1) spruce-fir stands of predominantly spruce in the canopy—the higher the percentage of spruce the greater the potential; (2) BA of 150 to 200+ ft per acre, with the BA concentrated in older, large-diameter spruce; (3) single- or two-storied stands; and (4) an average rate of diameter growth of 0.04 inch or less per 10 years.

Most of these characteristics were present in the infestations. They indicate those stands with high susceptibility that can develop into outbreak areas if the beetle population builds up. Because strong winds, lack of windfirmness, and endemic beetle populations are typical throughout the spruce type, the probability is high that a substantial outbreak could develop whenever these conditions are found. Because these characteristics are generally absent in some stands does not mean they could not be attacked by beetles. It does mean, however, that chances for development of an outbreak are considerably less.

Succession in Spruce-Fir Stands

The characteristics of potential outbreak stands and the changes in species composition caused by beetle infestations provide a basis for speculating on ecological succession in the spruce-fir type. Daubenmire (1943) classified spruce-fir as the climatic climax. Alexander[3] predicts that spruce is the climax species in the central Rockies, and will eventually replace the fir if the stand is not disturbed. Miller (1970) correlated age structure in spruce-fir stands in the central Rocky Mountains with spruce beetle outbreaks, but did not speculate on stand succession. We agree with Miller, but further suggest that the combined forces of spruce beetles, and *Dryocoetes confusus* Swaine and associated fungi alter the status of the spruce and fir components over the years, first toward fir, then toward spruce, and then back to fir as each species matures and spruce beetles periodically reach outbreak status.

The development of a spruce-fir forest over several centuries might be as follows: Assume a stand like one of those on the White River National Forest after the beetle outbreak in the 1940's; 80 percent fir-20 percent spruce in trees larger than 3 inches d.b.h., and the same or a higher percentage of fir in the seedling class. Both species grow rapidly. Fir continues to predominate and slightly increases its components in the overstory (fig. 5). As the overstory firs reach a diameter of 16 to 18 inches d.b.h. or 125 to 175 years they begin to die and fall out of the overstory. Why fir dies is not completely understood, but Swaine (1933) cites *D. confusus* Swaine as a mortality agent in British Columbia, and Molnar (1965) identified a *D. confusus*-fungus complex as killing 6- to 15-inch fir. The total BA curve reflects these decreases due to the loss of fir (fig. 5). Younger spruce and fir use these unoccupied sites and increase in size, but the spruce component in the overstory increases proportionately more than the fir.

Meanwhile, more seedlings are becoming established so that the spruce component is

[3]*Personal communication with Robert R. Alexander, Principal Silviculturist, Rocky Mt. For. and Range Exp. Stn., USDA Forest Service, Fort Collins, Colo.*

increasing slightly because of two factors. First, even though fir seedlings vastly outnumber spruce seedlings, the original removal of the canopy by the beetles favors the less tolerant spruce more than it does the highly tolerant fir. This allows spruce seedlings to compete more vigorously with fir, whereas prior to the outbreak fir was in the more advantageous position. Secondly, more leaders of fir seedlings are heavily damaged by animals or other factors than spruce, so spruce gains valuable height on fir. Eventually, since spruce lives longer and attains greater size (LeBarron and Jemison 1953), it becomes dominant. At this point, the fir occupies a lesser percentage of the canopy.

Total BA begins to increase rapidly and proceeds toward the potential of the site as the maturing spruce grow. At periodic intervals, spruce beetle outbreaks reduce the total BA and the spruce component, as Miller (1970) suggests, but the initial outbreaks kill less than 50 percent of the spruce (probably 10 to 20 percent as Frye and Flake (1972), or 25 to 40 percent as Sudworth (1898b) report) before the beetle population subsides because of natural factors.

Such outbreaks are probably examples of the "pocket biology" of the spruce beetle—a situation where the beetles reach outbreak status in a generally immature stand with pockets of larger diameter trees.[4] The spruce component decreases and fir increases, but the spruce still occupies more than 50 percent of the live BA. As the stand recovers after each outbreak, the stand tends more toward a single story. The stand continues to grow and approaches maximum BA. It is now highly susceptible to spruce beetle outbreaks. Eventually, given the moisture and wind conditions characteristic in the central Rockies, blowdown occurs. Spruce beetles develop to outbreak proportions in the downed material, and attack the surrounding standing spruce, killing it so that the stand becomes fir and the transition from predominantly fir to spruce to fir is complete.

The trend of the total BA curve after the stand reaches the site potential and sustains an outbreak (fig. 5, point A) is open to further investi-

[4]*Personal communication with R. H. Frye, and H. W. Flake, Jr., Entomologists, USDA Forest Service.*

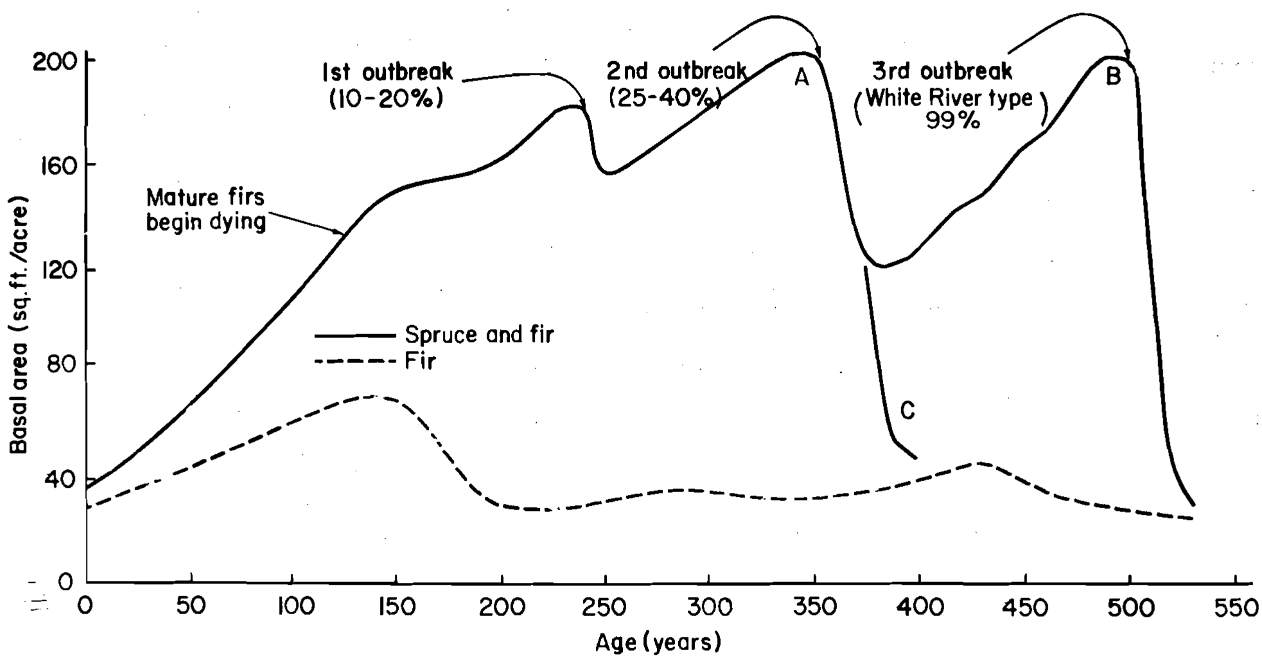

Figure 5.—Hypothetical succession curve of spruce-fir.

gation. It may proceed in a wavelike trend resulting from intensive outbreaks (point B), continue downward from an expanding initial infestation (point C), or remain relatively static with minor fluctuations due to endemic infestations (not shown). Historical data and knowledge of spruce-fir stands suggest the wavelike trend is probably the most likely.

Conclusions

In answering the original question "Wouldn't it have been better to let the outbreak run its course," a qualified "no" is appropriate. Assuming the Lone Cone outbreak threatened the spruce-fir type of the San Juan country and the White River outbreak threatened the same type in Colorado, northern New Mexico, and southern Wyoming (Brannan in U.S. Senate 1952) then control was expedient, not because of the potential fire or flood hazards (both overexaggerated) but because of the total resource value. We do not have enough specific information to assign positive or negative values to the recreation, wildlife, and other considerations. However, within some specific areas of the Lone Cone and White River infestations, the control or salvage methods used were contrary to the objective of perpetuating the timber resource. Clearcutting and mechanized skidding operations badly disrupted the forested area, and may have delayed natural regeneration for 50 to 100 years. Restricted salvage, on the other hand, would have allowed a limited recovery of the timber resource without undue damage to the future forest.

Our qualified answer may not be appropriate, depending on a person's point of view about whether natural forces should be allowed to operate uninhibited in the forest. However, most should agree that factors such as values saved or lost, desires of the public, objectives of the land manager, and finances create a complex situation for which there is no answer agreeable to all.

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