Seedfall and Establishment of Engelmann Spruce and Subalpine Fir in Clearcut Openings in Colorado

Daniel L. Noble and Frank Ronco, Jr.

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Abstract

Measurements of 10 years of seed production and dispersal into clearcut openings of various sizes on five National Forests in Colorado, and 14 years of seedling survival, indicate that seed availability generally did not limit regeneration success. Seedbed conditions and other environmental factors controlled regeneration success. Stocking appeared dependent upon size of openings, which should not exceed 8 chains in width. Seedlings surviving to 4 years of age have a good chance of establishment.

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Daniel L. Noble, Plant Ecologist
and
Frank Ronco, Jr., Principal Silviculturist
Rocky Mountain Forest and Range Experiment Station[1]

[1]Central headquarters maintained at Fort Collins, in cooperation with Colorado State University.

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Introduction

Generally, regeneration is the phase of forest management most vulnerable to interruption or failure, especially when forests grow in as harsh and varied an environment as the climax spruce-fir (*Picea engelmanni* Parry and *Abies lasiocarpa* (Hook.) Nutt.) forests of the central Rocky Mountains. Although, there has been considerable regeneration research in these forests (Roe et al. 1970) many reforestation questions remain unanswered.

This paper is the final report of a study conducted from 1961-75 at five locations in the spruce-fir zone of Colorado. It provides managers with additional information concerning amount and frequency of seed crops, seed dispersal in relation to distance from source, and initial stocking of seedlings in clearcut openings.

Study Areas and Methods

Study areas were established in clearcut openings, varying in width from 2 to 13 chains, on the Arapaho, Rio Grande, Routt, San Juan, and White River National Forests (table A-1). Units were selected with a long axis of the cutting boundary at right angles to the prevailing winds (fig. 1).

Seed Source

Seed sources were windward and leeward stands bordering the clearcut openings. These uncut stands, indicative of the forests before harvesting, were typical old-growth spruce-fir. Initially, basal areas—measured on strips 2 chains in from the cut edge—varied from 234 square feet per acre on the Arapaho to 55 square feet per acre on the Rio Grande. Species composition of trees 9.5 inches d.b.h. and larger

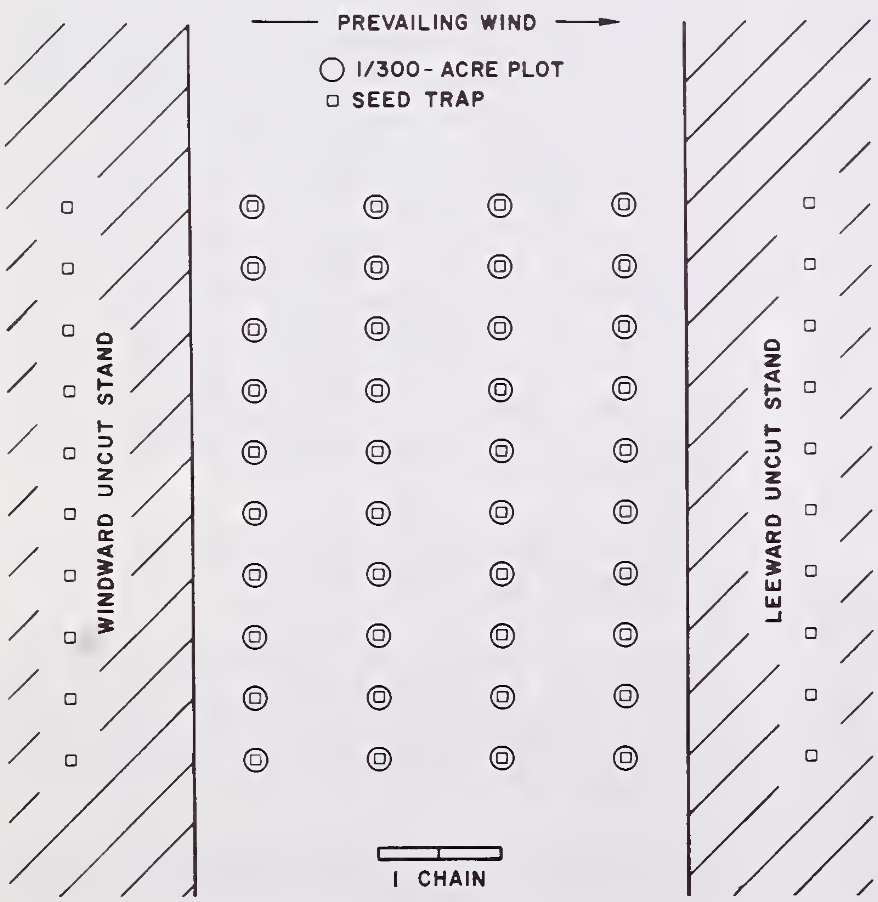

Figure 1. Location of seed traps and seedling survival plots (1/300-acre) in a clearcut opening on the Rio Grande National Forest; study areas on other Forests were similar except for width of cut-over opening.

varied from 93% spruce—7% fir on the Arapaho to 47% spruce—53% fir on the Routt. Some trees were lost to windfall during the winter of 1966-67, and the stands were remeasured in 1968. Stand description and composition data are given in table A-2.

Seed and Seedlings

Quantity of seed produced and dispersal distances were measured with 1 square foot wire seed traps described by Boe (1954). Before traps were installed, trees in openings, including snags that might produce seed or affect the glide path of seeds from the uncut forest edge, were felled. Beginning 1/2 chain from the windward and leeward stands, rows of 10 traps, each parallel with the timber edge, were spaced 1-chain apart across the long axis of the clear-cut openings (fig. 1). An additional row of 10 traps was placed under the uncut stand 1 chain into both the leeward and windward boundary.

Annual seed counts were made each summer through 1971, except on the Rio Grande area, where collections were discontinued after 1965. The percentage of sound seed was determined by cutting tests.

Seedling survival was recorded once a year, during mid-to-late summer, on 1/300-acre circular plots established on each seed trap location within the cutover area (fig. 1). No attempt was made to provide uniform seedbeds on plots within and between Forests. As a consequence, conditions varied between plots depending upon the extent of logging disturbance. However, slash was manually removed from plots—with minimal disturbance of seedbeds—on the Arapaho, Rio Grande, and White River to reduce excessive physical impediments to germination. Plots on these areas were scarified to varying degrees during logging operations. On the Routt and San Juan, where slash was tractor-windrowed and burned, plots were heavily disturbed, and seedbeds were composed of burned ash, mineral soil, and duff in varying concentrations.

All seedlings left on plots immediately after logging were removed, and only those that germinated after the study began were counted. Each year, new seedlings were marked with plastic markers showing year of germination. Seedlings were marked through 1971, and survival counts were continued through 1975 to determine percent survival of all seedlings at least 4 years old.

Results

Seed Production

No correlations were found between seed production and basal area per acre for any of the study areas.

The following categories, proposed by Alexander and Noble (1976) to rate annual seed crop production for sound Engelmann spruce in uncut stands, have been used in this study.

Number sound seeds/acre	Seed crop rating
10,000	Failure
10,000- 50,000	Poor
50,000-100,000	Fair
100,000-250,000	Good
250,000-500,000	Heavy
>500,000	Bumper

Spruce seed crops in uncut stands, based on seed collected beneath windward stands as a measure of seed production, varied considerably by years and areas (table 1). Annual sound seed production, excluding the Rio Grande study area, averaged 328,000 seeds per acre, and ranged from 170,000 on the Arapaho to 605,000 on the White River.

Considering each seed crop by year and area as an independent event, there were a total of 42 area-seed-crop years. Twelve crops were rated as good, heavy, or bumper crops, while 30 were rated fair, poor, or failures. Furthermore, good to better seed years on all areas, were followed by 1 to 3 years of fair to poorer crops. During the entire study period, bumper seed crops were recorded simultaneously on all Forests only in 1968 (Ronco and Noble 1971); whereas, seed crops that were poor or failures were recorded on all study areas in 1963, 1967, and 1970. Considerable seed crop variability among areas occurred in other years.

Table 2 lists the rating of each seed crop for each study area.

Seed crop ratings for subalpine fir are not available. During this study, fir seed only occurred during 2 years on the Arapaho and White River and 3 years on the Routt and San Juan (table 1).

The proportion of total spruce to fir seed averaged over all areas was 94% and 6% re-

Table 1.—Production of filled seeds per acre, and percent of total seedfall that was filled in the windward stands[1]

Year	Species	Arapaho Filled seed	Arapaho Total seedfall	White River Filled seed	White River Total seedfall	Routt Filled seed	Routt Total seedfall	San Juan Filled seed	San Juan Total seedfall	Rio Grande Filled seed	Rio Grande Total seedfall
		Thous.	%	*Thous.*	%	*Thous.*	%	*Thous.*	%	*Thous.*	%
1962	spruce	232	13	97	16	—	—	—	—	48	15
	fir	0	0	0	0	—	—	—	—	0	0
1963	spruce	11	4	0	0	—	—	10	4	0	0
	fir	0	0	0	0	—	—	0	0	0	0
1964	spruce	172	30	231	18	42	8	546	35	90	12
	fir	0	0	0	0	0	0	0	0	0	0
1965	spruce	58	13	263	20	415	34	10	4	271	26
	fir	0	0	0	0	0	0	0	0	0	0
1966	spruce	0	0	4	02	17	14	39	53	16	14
	fir	0	0	0	0	0	0	0	0	0	0
1967	spruce	24	24	17	16	22	29	13	27	—	—
	fir	0	0	0	0	0	0	0	0	—	—
1968	spruce	980	44	5,340	87	2,269	82	845	65	—	—
	fir	57	28	183	42	218	49	157	41	—	—
1969	spruce	52	15	35	11	97	17	57	18	—	—
	fir	0	0	0	0	10	11	13	25	—	—
1970	spruce	9	10	17	5	13	10	26	10	—	—
	fir	0	0	0	0	9	50	0	0	—	—
1971	spruce	157	34	44	10	10	14	4	18	—	—
	fir	19	27	4	7	0	0	4	25	—	—
Aver.	spruce	170	35	605	63	364	58	171	45	85	19
	fir	8	17	19	31	30	45	19	54	0	0

[1]*Seed counts were not started on the San Juan and Routt until 1963 and 1964, respectively. Counts were terminated on the Rio Grande when seed source was harvested in 1967.*

Table 2.—Rating of seed crops, (according to Alexander and Noble (1976)), for all five study sites

Study area	Seed crop rating: Bumper	Heavy	Good	Fair	Poor	Failure
Arapaho	1	0	3	2	2	2
Rio Grande[1]	0	0	1	2	2	0
Routt	1	1	0	1	5	0
San Juan	2	0	0	1	5	1
White River	1	0	2	1	4	2
Total	5	1	6	7	18	5
Percent	11.9	2.4	14.3	16.7	42.8	11.9

[1]*Both windward and leeward stands were harvested on the Rio Grande study area in 1965, terminating the seed production and dispersal studies. Seedling survival studies were continued through 1975.*

spectively. Spruce and fir seed production in general was roughly proportional to the percentage of these species in the stands.

Filled seed for both species was highly variable between study areas (table 1). Filled spruce seed averaged over all years was 50% for all areas, varying from 35% on the Arapaho to 63% on the White River. Filled fir seed averaged 37% for all areas, and varied from 54% on the San Juan to 17% on the Arapaho. However, base numbers determining these percentages greatly varied between years and areas, confounding comparisons.

Differences in percent filled seed were greatest between years (table 1), but no definite relationship occurred between filled seed and size of seed crop.

Seed Dispersal

Seed dissemination data includes both species, since subalpine fir seed averaged less than 3% of the total seed distributed, and showed dispersal patterns similar to spruce. Seed dispersal was influenced by the size of seed crop, distance from source, and prevailing winds (figs. 2 and 3). Seedfall decreased as the distance from windward source increased, except on the narrow, 2-chain-wide opening on the Arapaho. About half of the total number of seeds dispersed fell within 1-1/2 chains of the windward edge. Seedfall continued to decrease for a distance of 3 to 4 chains from the windward edge, and then leveled off in the wider openings before slightly increasing again at about 1/2 chain from the leeward timber edge (fig. 3). Although the seed dispersal pattern was similar in good and poor seed years, more seed fell near the timber edge during years of higher seed production (fig. 2).

Seedling Establishment

More first-season spruce and fir seedlings were found during years of good to better seed crops than when crops were fair to poor. Averaging all study areas, years of good to better seed crops produced approximately 2,000 first-season seedlings per acre, 1/2 chain from the windward edge. In contrast, years of fair to poor seed crops averaged about 125 first-season seedlings per acre at the same distance from windward edge.

Survival

Ten and nine percent of the first-year spruce and fir seedlings respectively, survived to 7 years of age (fig. 4). However, seedlings surviving at the end of the study—that were 4 to 13 years old—averaged only 6% for spruce and 8% for subalpine fir (table 3).

Annual seedling mortality decreased as seedlings grew older (fig 5). About 43% of the total spruce mortality and 48% of the total fir mortality occurred the first year, whereas only 0.7% of spruce and 0.2% of the fir died when they were 10 or more years old.

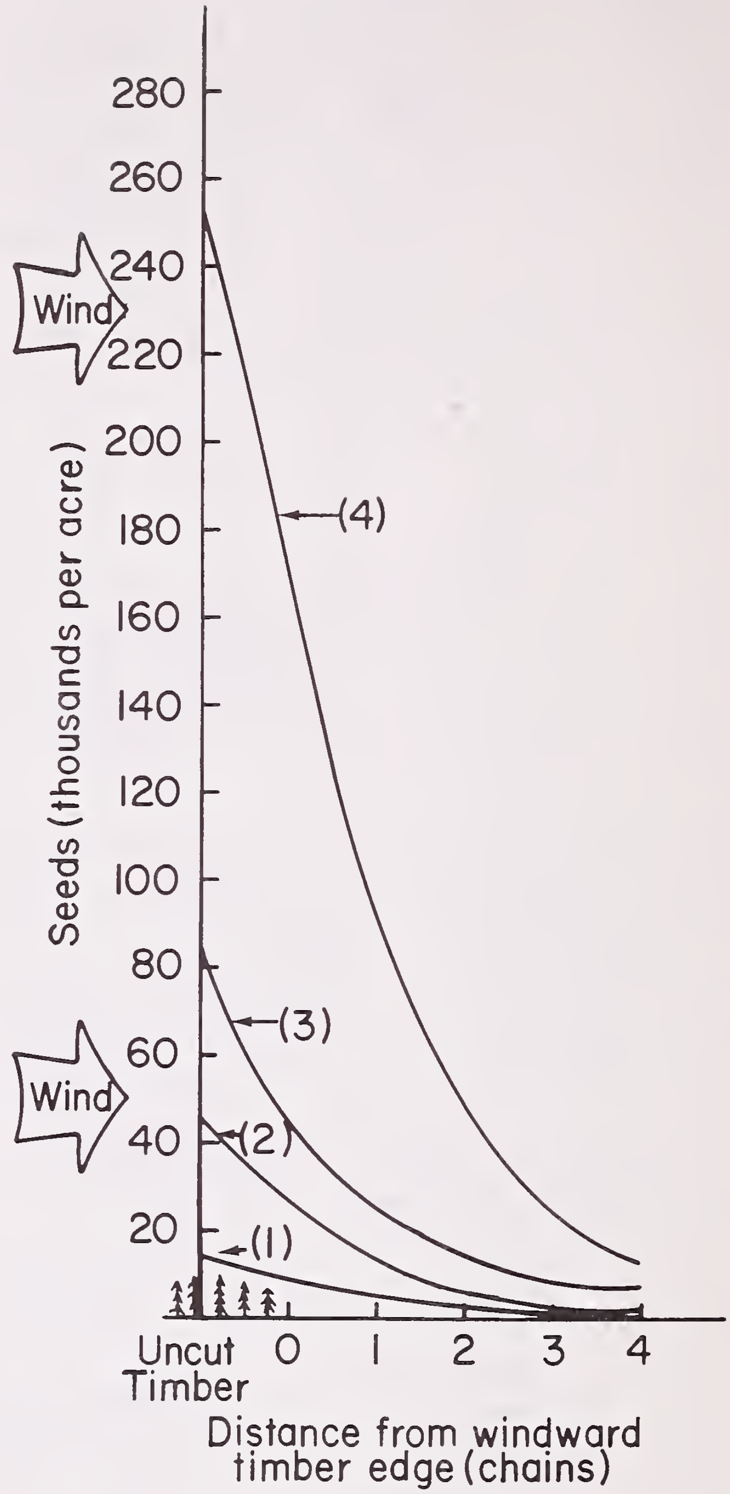

Figure 2. Engelmann spruce-subalpine fir seed dispersal from windward timber edge to 3.5 chains into the opening, averaged over all years and areas, except the Arapaho, illustrates (1) poor, (2) fair, (3) good, and (4) heavy seed crop years.

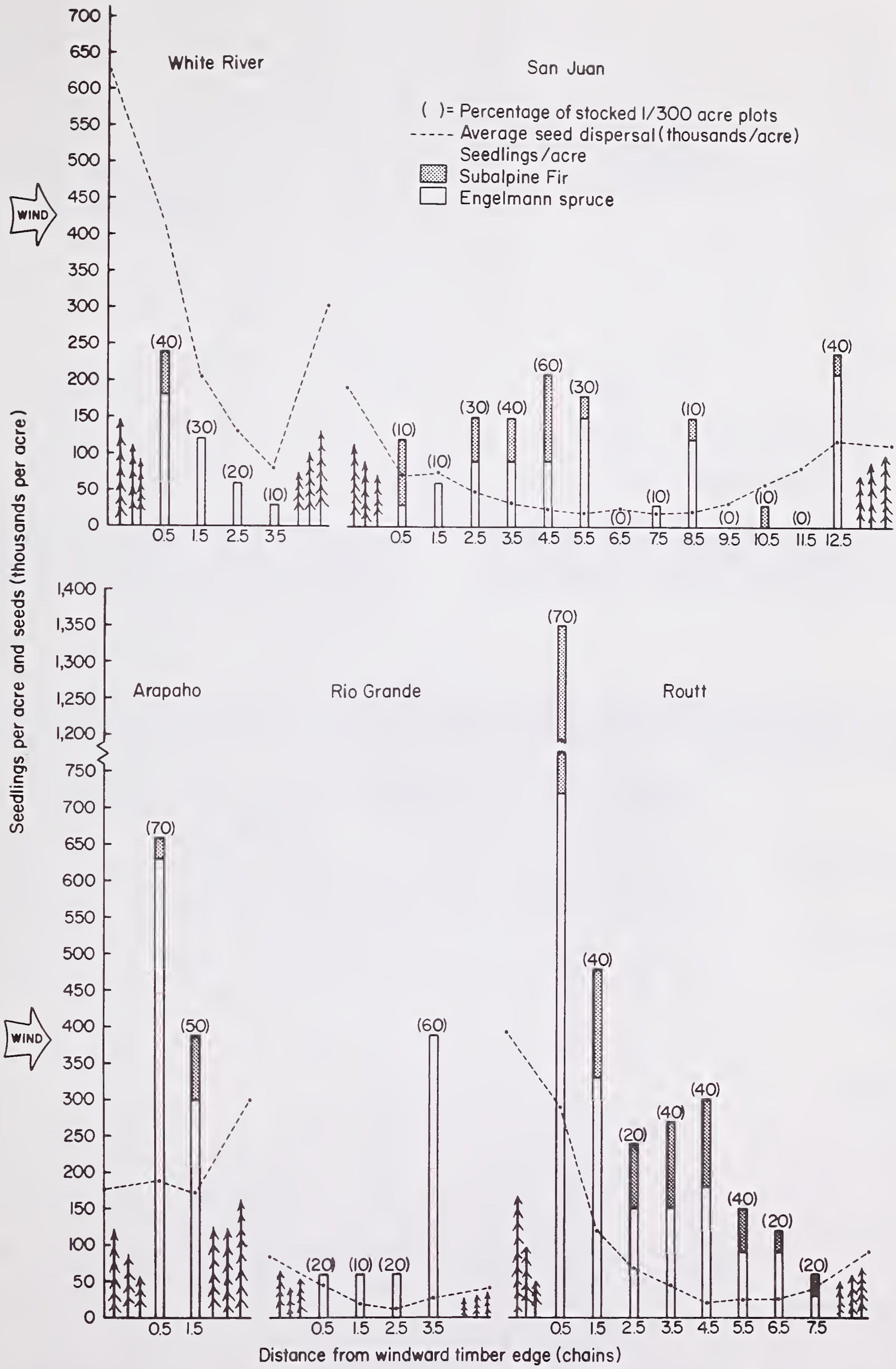

Figure 3. Average seed production, seed dispersal, and stocking of spruce-fir seedlings (ages 4 to 13 years) on five study areas on five National Forests. Seed production and dispersal is the combination of Engelmann spruce and subalpine fir seed. (Fir seed averaged 5% of the crop and ranged from 0% on the Rio Grande to 10% on the San Juan).

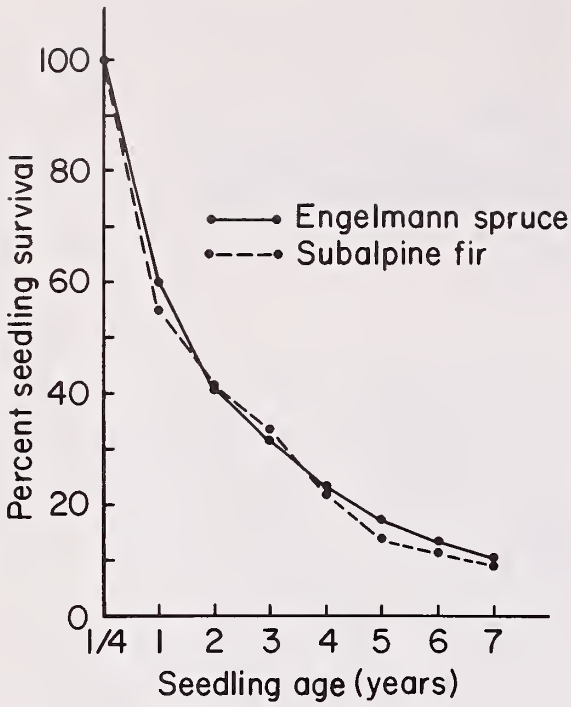

Figure 4. Percent survival of Engelmann spruce and subalpine fir seedlings averaged for all areas at ages 1 through 7. (Base number for spruce was 2,473 seedlings and 834 seedlings for fir).

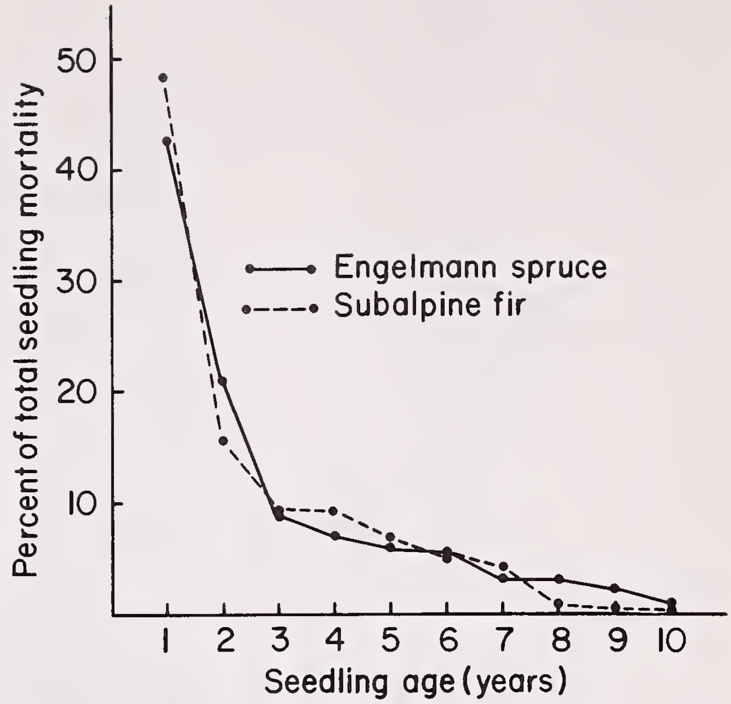

Figure 5. Percent of total mortality of Engelmann spruce and subalpine fir seedlings averaged for all areas at ages 1 through 10 years. (Base number for spruce was 2,325 seedlings and 770 seedlings for fir).

Table 3. Number of first season seedlings per acre, number of established seedlings per acre, percent survival of Engelmann spruce and subalpine fir seedlings that were 4 years old or older, species composition (percentage of the established seedlings), and ratios of (1) seed to first season seedlings, (2) seed to established seedlings, and (3) first season seedlings to established seedlings are given for all five study areas

	Arapaho N.F.			White River N.F.					Rio Grande N.F.				
	Chains			Chains					Chains				
	0.5	1.5	Aver.	0.5	1.5	2.5	3.5	Aver.	0.5	1.5	2.5	3.5	Aver.
First season seedlings/acre													
E. spruce	2,070	2,010	2,040	1,350	1,380	720	480	982	2,640	1,260	1,080	4,200	2,295
Sub. fir	90	330	210	210	90	60	240	150	0	0	0	0	0
All spp.	2,160	2,340	2,250	1,560	1,470	780	720	1,132	2,640	1,260	1,080	4,200	2,295
Established seedling/acre[1]													
E. spruce	630	300	465	180	120	60	30	98	60	60	60	390	142
Sub. fir	30	90	60	60	0	0	0	15	0	0	0	0	0
All spp.	660	390	525	240	120	60	30	113	60	60	60	390	142
Percent survival													
E. spruce	30	15	23	13	9	9	6	10	2	5	6	9	6
Sub. fir	33	33	33	27	(2)	(2)	(2)	7	(2)	(2)	(2)	(2)	(2)
All spp.	31	17	24	15	9	9	6	9	2	5	6	9	6
Species composition (Percentage)													
E. spruce	95	77	89	75	100	100	100	87	100	100	100	100	100
Sub. fir	5	23	11	25	0	0	0	11	0	0	0	0	0
Ratio:seed/1st season seedling													
E. spruce	886	832	860	3,013	1,452	1,748	1,636	2,066	88	78	60	32	58
Sub. fir	678	185	290	48	58	73	9	36	(2)	(2)	(2)	(2)	(2)
All spp.	877	741	806	2,614	1,367	1,620	1,094	1,796	88	78	60	32	58
Ratio:seed/established seedling													
E. spruce	2,910	5,577	3,770	22,597	16,698	20,981	26,180	20,809	3,848	1,629	1,089	343	926
Sub. fir	2,033	678	1,016	167	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
All spp.	2,870	4,446	3,456	16,989	16,742	21,054	26,252	18,083	3,848	1,629	1,089	343	926
Ratio:1st season seedlings/established seedlings[1]													
E. Spruce	3	7	4	8	12	12	16	10	44	21	18	11	16
Sub. fir	3	4	3.5	3.5	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)	(2)
All spp.	3	6	4	7	12	12	16	12	44	21	18	11	16

[1]Established seedlings were considered as those seedlings ages 4 to 12 years surviving at the end of the study period.
[2]Indeterminant; no surviving seedlings.

San Juan N.F.														
	Chains													
	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	8.5	9.5	10.5	11.5	12.5	Aver.
First season seedlings/acre														
E. spruce	2,130	2,400	2,970	1,770	2,700	1,530	360	210	900	270	300	210	1,050	1,292
Sub. fir	660	1,100	840	600	720	450	330	360	390	180	240	240	60	475
All spp.	2,790	3,510	3,810	2,370	3,420	1,980	690	570	1,290	450	540	450	1,110	1,767
Established seedling/acre[1]														
E. spruce	30	60	90	90	90	150	0	30	120	0	0	0	210	67
Sub. fir	90	0	60	60	120	30	0	0	30	0	30	0	30	35
All spp.	120	60	150	150	210	180	0	30	150	0	30	0	240	102
Percent survival														
E. spruce	1	2	3	5	3	10	(2)	14	13	(2)	(2)	(2)	20	5
Sub. fir	14	(2)	7	10	17	7	(2)	(2)	8	(2)	12	(2)	50	7
All spp.	4	2	4	6	6	9	(2)	14	12	(2)	12	(2)	22	6
Species composition (Percentage)														
E. spruce	25	100	60	60	43	83	0	100	80	0	0	0	88	66
Sub. fir	75	0	40	40	57	17	0	0	20	0	100	0	12	34
Ratio:seed/1st season seedling														
E. spruce	279	262	138	154	72	100	590	642	160	856	924	3,120	914	290
Sub. fir	73	31	21	51	24	10	26	50	89	73	127	290	1,742	70
All spp.	230	189	112	126	62	80	321	268	139	543	570	1,611	958	230
Ratio:seed/established seedling														
E. spruce	19,792	10,497	4,544	3,020	2,167	1,021	(2)	4,493	1,199	(2)	(2)	(2)	4,568	5,594
Sub. fior	532	(2)	290	508	145	145	(2)	(2)	1,162	(2)	1,016	(2)	3,485	959
All spp.	5,347	10,497	2,843	1,986	1,012	875	(2)	4,493	1,192	(2)	1,016	(2)	4,433	4,011
Ratio:1st season seedlings/ established seedlings[1]														
E. Spruce	71	40	33	20	30	10	(2)	7	8	(2)	(2)	(2)	5	19
Sub. fir	7	(2)	14	10	6	14	(2)	(2)	13	(2)	8	(2)	2	14
All spp.	23	40	25	16	16	11	(2)	7	9	(2)	18	(2)	4	17

Routt N.F.									
	Chains								
	0.5	1.5	2.5	3.5	4.5	5.5	6.5	7.5	Aver.
First season seedlings/acre									
E. spruce	13,290	17,550	1,710	480	2,820	2,310	1,380	660	5,025
Sub. fir	8,850	3,870	840	720	840	990	750	1,052	2,239
All spp.	22,140	21,420	2,550	1,200	3,660	3,300	2,130	1,710	7,264
Established seeding/acre[1]									
E. spruce	720	330	150	150	180	90	30	30	210
Sub. fir	630	150	90	120	120	60	90	30	161
All spp.	1,350	480	240	270	300	150	120	60	371
Percent survival									
E. spruce	5	2	9	31	6	4	22	4	4
Sub. fir	7	4	11	17	14	6	12	3	7
All spp.	6	2	9	23	8	4	16	4	5
Species composition (Percentage)									
E. spruce	53	69	62	56	60	60	25	50	56
Sub. fir	47	31	38	44	40	40	75	50	44
Ratio:seed/1st season seedling									
E. spruce	151	74	285	680	55	71	121	462	122
Sub. fir	32	37	57	48	21	40	52	21	35
All spp.	103	68	210	301	47	61	97	192	95
Ratio:seed/established seedling									
E. spruce	2,783	3,948	3,252	2,178	855	1,818	5,582	10,164	2,923
Sub. fir	442	958	532	290	145	653	435	726	483
All spp.	1,691	3,014	2,232	1,339	571	1,352	1,722	5,445	2,563
Ratio:1st season seedlings/ established seedlings[1]									
E. Spruce	18	53	11	3	16	26	46	22	24
Sub. fir	14	26	9	6	7	16	8	35	14
All spp.	16	45	10	4	12	22	18	28	20

[1]*Established seedlings were considered as those seedlings ages 4 to 12 years surviving at the end of the study period.*
[2]*Indeterminant; no surviving seedlings.*

Seed:Seedling Ratios

Numbers of seed required to produce a first-season seedling varied greatly between areas, with distance from timber edge, and between species (table 3). For all years and all study areas, the ratio of spruce seed:first-season seedlings averaged 665:1, with a range of 60:1 on the Rio Grande to 2,066:1 on the White River. Subalpine fir averaged 150 seeds per first-season seedling, and ranged from 35:1 on the Routt to 290:1 on the Arapaho.

As expected, the ratio of seed:established seedling 4 to 13 years old at the end of the study increased markedly over seed:first-season seedling ratio. The Engelmann spruce ratio, averaged for all years and sites, was 6,800:1 with a range of 926:1 to 20,809:1. Subalpine fir averaged 755:1, and ranged from 483:1 to 1,016:1.

Ratios of first-season seedling:established seedling varied less than seed:seedling ratios (table 3). The average ratio for Engelmann spruce was 21:1 over all years, with a range of 4:1 to 24:1. Subalpine fir averaged 10:1 and ranged from 4:1 to 14:1.

Seedling Density and Composition

Number of spruce and fir seedlings per acre 4 to 13 years old varied greatly between Forests and with distance from the timber edges (fig. 3). Average number of seedlings across openings appeared inversely proportional to the width of the openings. The Arapaho—the narrowest opening—had 525 seedlings per acre, while the San Juan, with the widest opening, had only 102 seedlings per acre. The Routt, White River, and Rio Grande averaged 371, 225, and 142 seedlings per acre, respectively.

Species composition of seedlings was similar to uncut stands, (table A-2). Spruce seedlings 1/2 chain from the windward edge averaged 324 per acre for all areas, and ranged from 720 per acre on the Routt to 30 on the San Juan. Number of subalpine firs 1/2 chain from windward edges averaged 162 seedlings per acre, and ranged from 630 on the Routt to none on the Rio Grande.

Seedling numbers appeared to be positively correlated with seed dispersal on the Routt and White River, but no relationships were apparent on other areas (fig. 3). However, more seedlings occurred next to a timber edge than farther into openings on all areas.

Stocking Distribution

The percentage of stocked plots within each row of sample plots was highly variable regardless of distance from the timber edge (fig. 3). Forty-two percent of all sample plots 1/2 chain from the windward edge were stocked, while stocking at all distances greater than 1/2 chain from the windward edge averaged only 26%.

Discussion and Conclusions

Ronco (1970) concluded a 5-year progress report on this study by stating that ". . . no recommendation can yet be made concerning the size opening that will restock to natural regeneration, the number of sound seeds needed to produce an established seedling, or total seed production required to adequately restock an area." Following additional years of study, it is now possible to provide additional information and guidelines regarding natural regeneration of Engelmann spruce and subalpine fir in the central Rockies.

Seed Source

Roe (1967) showed a relationship between basal area of Engelmann spruce, 9.5 inches d.b.h. and larger, and seed production. Similarly, Alexander and Noble (1976) reported basal area of dominant and codominant trees and seed production of Engelmann spruce were related in a general way when average percent of live crowns was included. In this study, however, no significant correlations were found, and it was concluded that additional stand factors were involved.

Seed Production and Dispersal

The uncertainty of when and how much seed will be produced continues to be a problem in planning natural regeneration activities. Timing of seedbed preparation is particularly critical, but frequency of seed crops does not appear to be a reliable indication for initiating site preparation. Results of this study show that some Engelmann spruce seed should be produced almost every year, and when a good to better crop occurs, it will likely be followed by 2 to 4 years of poorer crops. For general planning, such seed crop frequency would be adequate, but more intensive management must rely on techniques such as those developed by Roe (1946) and Eis (1967), who used estimates of floral buds to predict cone crops in spruce.

Results from this study indicated that, over a 10-year period, seed production did not limit spruce-fir regeneration. Seed dispersal into openings was influenced by amount of seed produced, distance from source, and direction and velocity of prevailing winds. In addition, our results showed an "effective seeding distance" of about 4 chains from the windward timber edge (fig. 2). The larger the seed crop, the steeper the decreasing dispersal curve, so that at a distance of about 4 chains, except for bumper crops, only a few thousand seed per acre separate a heavy seed crop from a poor crop. Similar results were obtained by Alexander (1967) on the Fraser Experimental Forest. Further, the "effective seeding distance" is compatible with the size of clearcut openings—5 to 8 times tree height—recommended by Alexander (1974).

LeBarron and Jemison (1953) listed subalpine fir as a better seed producer than Engelmann spruce. However, their results were based on the northern distributions of the species and may not reflect conditions in the central and sothern Rockies. In this study, subalpine fir seed production was more unpredictable than spruce, and while size of crops could not be rated, subalpine fir was an infrequent seed producer—only two or three crops of importance occurring in 10 years.

Stocking, Composition, Seedbed, and Environment

Species composition of spruce and fir seedlings on each clearcut opening was nearly the same as in the uncut stands. Seedbed requirements of the two species in the central Rocky Mountains are different (Fowells 1965). Engelmann spruce apparently offsets some of its more restrictive seedbed requirements by producing more seed, more often.

Seedbeds most favorable for spruce regeneration were disturbed areas with exposed mineral soil. Least favorable were those with a heavy cover of competing vegetation or a thick layer of undisturbed duff. Similar findings have been reported elsewhere (Dobbs 1972, Noble and Alexander 1977, Roe et al. 1970). Stocking patterns generally indicated a more favorable environment for seedling establishment existed 1 to 2 chains from timber edges, usually the windward edge, than farther out in the openings. Alexander (1969) reported a similar edge effect for Engelmann spruce regeneration.

It has generally been accepted that 5-year-old spruce and fir seedlings could be considered established from the standpoint of environmental factors. Results from this study and those of Noble and Alexander (1977) support this conclusion, and only unusual factors such as snowmold, fire, trampling, or predation by gophers or snowshoe hares could seriously affect regeneration success after this age. However, survival may be as much related to seedling size as age, since the authors and others have observed that seedlings reaching heights of 3 to 4 inches are likely to survive.[2]

Seed:Seedling Ratios

To estimate how many seeds or first-season seedlings are needed to successfully restock clearcut openings, the variability in size of opening, seedbed conditions, and other complex environmental factors must be considered. Therefore, a brief discussion of each study area and associated ecological observations follows.

The Arapaho study area successfully restocked, mainly because its narrow width assured an excess of seed and created a more favorable regeneration environment. However, the distribution of seedlings was poor. Seedbeds, consisting of variable thicknesses of duff with Whortleberry cover (*Vaccinium* spp.) had received very little disturbance because the area was horse-logged, and were not favorable for germination. This is reflected in the relatively high number of seed—800—per first-season seedling. However, *Vaccinium* does not compete severely with spruce-fir seedlings (Alexander 1958). Rather, it appears to aid survival, as shown by a relatively low seed:established seedling ratio of approximately 3,500:1, and by a 23% survival of first-season seedlings.

The Rio Grande study area was not successfully regenerated, even though all of the opening was within effective seeding distance,

[2]*Personal discussion with R. R. Alexander, Chief Silviculturist, Rocky Mountain Forest and Range Experiment Station.*

because of unfavorable seedbed conditions and an insufficient seed supply resulting from early harvesting of the leave stand. The area was tractor logged, and slash was lopped and scattered, causing some disturbance of the seedbeds. Initially, seedbeds were favorable for germination, as indicated by the low ratio of 60 seeds per first-season seedlings. However, these seedbeds were rapidly invaded with a grass-sedge cover, which created such competition that seedling survival was only 6% of the first-season seedlings. The average ratio of first-season seedling:established seedlings was 16:1. The only successful regeneration occurred in the zone one-half chain from the leeward edge, and was due partly to greater soil distrubance that created more favorable soil moisture conditions than occurred elsewhere.

The Routt study area is probably the maximum size, 8-chains wide, that should be considered within the effective seeding distance for natural regeneration. It was essentially restocked, but distribution was poor. The primary reason for nearly complete restocking but poor distribution was the more favorable soil moisture conditions in the first 3 to 4 chains from the windward edge that resulted in a large number of first-year seedlings; while soil moisture regimes in the last three zones were unfavorable to seedling survival. The area had been tractor logged, and the slash piled and burned, so that duff and *Vaccinium* cover was practically eliminated. The influence of mineral soil seedbeds on moisture availability was reflected by the large number of first-season seedlings and a relatively low average ratio of seed:first-season seedlings (95:1). However, the exposed seedbeds were not as favorable for survival as shown by the 2,600:1 ratio of seed:established seedlings. The ratio of first-season seedlings:established seedling averaged the highest—20:1—of any of the study areas; the 5% survival percentage was lowest. The poor survival was expected, since studies by Noble and Alexander (1977) have shown that openings on south exposures are generally unfavorable to natural regeneration because of high temperatures and solar radiation that rapidly dry out exposed seedbeds.

The San Juan opening was the most poorly restocked of all areas. It had been tractor logged, and the slash was windrowed and burned, so that seedbeds were extensively disturbed. The exposed mineral soil was reasonably favorable for germination, as evidenced by a ratio of 230 seeds per first-season seedling. However, conditions were not favorable for survival. The total number of new seedlings was low, and survival was only about 6%, resulting in a high 4,000:1 ratio of seed:established seedling and a first-year seedling:established seedling ratio of 17:1. Poor regeneration was attributed to the size of the opening and excessive seedbed disturbance. As a result, seedbeds out to a distance of 5 or 6 chains from the windward edge have generally developed a dense cover of vegetation—grasses, sedges, and forbs—that is highly competitive with seedling establishment. Further, except for those seedbeds next to the leeward timber edge, the remaining seedbeds—distances 6 to 12 chains from windward timber edge—received few seeds and have been too hot and dry for anything to become established except a few pioneering grasses and forbs.

The White River area also regenerated poorly because of unfavorable seedbeds. Not only did the area receive more seed than any other, but the general environment should have been favorable because this was a good spruce-fir site. The area had been logged with rubber-tired skidders, and slash was lopped and scattered, resulting in some seedbed disturbance. The study area has a relatively high water table, providing favorable soil moisture regimes that favored a rapid invasion of forbs, especially bluebells (*Mertensia* spp.), resulting in heavy vegetation competition. The ratio of seed: established seedling—18,000:1—was the highest of any area; however, the first-season seedling:established seedling ratio was only 12:1, indicating that when a seed germinated, there was a moderate chance for survival.

In conclusion, spruce-fir clearcuts can be regenerated by natural means. However, results of this study indicate that several factors should be considered. First, openings should not exceed 5 to 8 chains in width at any point. Also, site preparation measures must be taken to expose mineral soil and remove vegetative competition, particularly from sedges and sod-forming grasses. Finally, newly germinated seedlings, particularly those on south and west-facing slopes, must be protected from excessive insolation and moisture loss with a protective cover of slash or other material.

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Appendix

Table A.-1.—Description of five Engelmann spruce-subalpine fir study areas in Colorado

National Forest and Ranger District	Drainage	Elevation	Year logged	Year study established	Width of cut-over	Aspect	Slope
		Feet			*Chains*		%
Arapaho Hot Sulfur	Stillwater Creek	10,400	1958	1961	2	N70E	33
Rio Grande Saguache	California Gulch	10,800	1959	1961	4	N70E	15
Routt Bears Ears	West Prong, South Fork Slater Creek	9,400	1961	1963	8	S37W	16
San Juan Dolores	Spring Creek (on Taylor Mesa)	10,200	1959	1962	13	N38E	5
White River Frying Pan	Rocky Fork Creek	10,100	1956	1961	4	N20W	20

Table A-2.—Stand descriptions adjacent to five spruce-fir clearcuts in Colorado at beginning of study period and again in 1968 after losses from blowdown. (Only trees <9.5 inches d.b.h. were measured)

			Mean Tree Diameter			Basal Area					Density				
Forest	Stand	Year	Spruce	Fir	All spp	Spruce	Fir	All spp.	Spruce	Fir	Spruce	Fir	All spp.	Spruce	Fir
				(Inches)			(Ft²/acre)		. . . .%. . . .			(No. trees/acre)		. . . . . .%.	
Arapaho	Windward	1962	14.3	11.2	14.2	224	10	234	96	4	199	14	213	93	7
		1968	14.6	11.1	14.4	159	7	166	96	4	136	11	147	92	8
	Leeward	1962	16.3	13.7	15.9	182	20	202	90	10	126	20	146	86	14
		1968	15.6	13.8	15.3	122	20	142	86	14	92	19	111	83	17
White River	Windward	1962	15.5	12.6	15.2	157	17	174	90	10	119	19	138	86	14
		1968	15.5	12.7	15.1	154	16	170	90	10	118	18	136	86	14
	Leeward	1962	15.1	12.9	14.7	144	28	172	84	16	116	30	146	79	21
		1968	15.1	12.9	14.7	144	28	172	84	16	116	30	146	79	21
Routt	Windward	1963	14.4	12.0	13.4	86	42	128	67	33	76	54	130	58	42
		1968	14.4	12.0	13.4	86	42	128	67	33	76	54	130	58	42
	Leeward	1962	12.8	12.3	12.6	38	36	74	52	48	42	44	86	47	53
		1968	13.3	12.1	12.7	33	27	60	54	46	34	34	68	48	52
Rio Grande[1]	Windward	1961	13.9	14.2	13.9	119	13	132	90	10	114	12	126	90	10
		1968	—	—	—	—	—	—	—	—	—	—	—	—	—
	Leeward	1961	13.0	11.6	12.8	51	4	55	92	8	56	6	62	90	10
		1968	—	—	—	—	—	—	—	—	—	—	—	—	—
San Juan	Windward	1962	19.2	16.7	18.4	145	55	200	73	27	72	36	108	67	33
		1968	19.1	16.7	18.4	138	52	190	73	27	69	34	103	67	33
	Leeward	1962	18.0	15.1	16.9	107	51	158	68	32	61	41	102	60	40
		1968	17.3	13.5	15.7	39	19	58	68	32	24	19	43	56	44

[1]*Leave stands on the Rio Grande were harvested in 1967.*

Table A-3.—Percent of total seedfall that was spruce and percent that was fir for all study area averaged for all years

	Arapaho	White River	Routt	San Juan	Rio Grande
Spruce	96	97	92	90	100
Fir	4	3	8	10	0

Noble, Daniel L. and Frank Ronco, Jr. 1978. Seedfall and establishment of Engelmann spruce and subalpine fir in clearcut openings in Colorado. Res. Pap. RM-200, 12 p. Rocky Mt. For. and Range Exp. Stn., For. Serv., U.S. Dep. Agric., Fort Collins, Colo. 80521.

Measurements of 10 years of seed production and dispersal into clearcut openings of various sizes on five National Forests in Colorado, and 14 years of seedling survival, indicate that seed availability generally did not limit regeneration success. Seedbed conditions and other environmental factors controlled regeneration success. Stocking appeared dependent upon size of openings, which should not exceed 8 chains in width. Seedlings surviving to 4 years of age have a good chance of establishment.

Keywords: *Picea engelmannii, Abies lasiocarpa,* forest seed production, natural regeneration, silvicultural systems.

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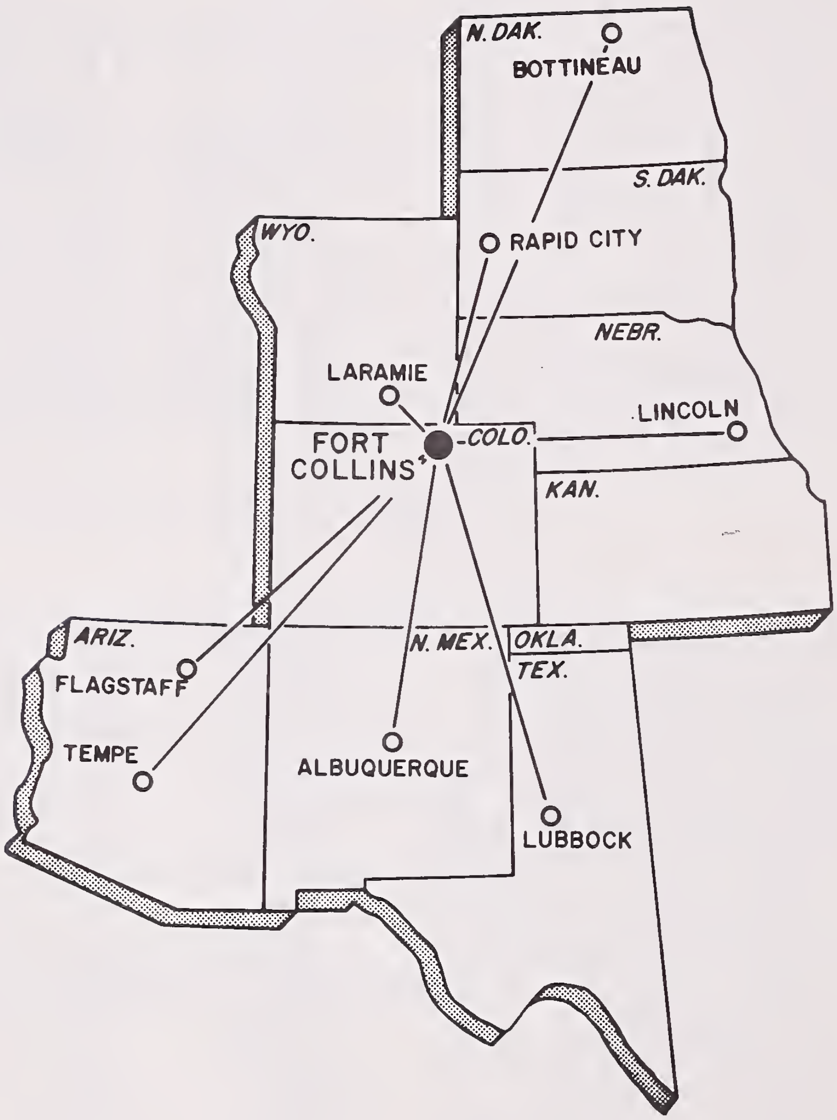
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