NATURAL REGENERATION

Of Sierra Nevada Mixed Conifers After Logging

N. Stark

Abstract. Studies of natural reproduction following logging under unit area control started in 1948 at the Stanislaus-Tuolumne Experimental Forest in California. Results from 119 permanent and 468 temporary quadrats show that when logging preceded a good seedfall, 67 percent of the total reproduction established in the first year remained after 12 years. With rodent control, 4 percent of the 1948 seedfall gave rise to new seedlings. Bare soil or light litter in semishade made good seedbeds, but tolerance to sun and litter depth differed among species. Incense-cedar and white fir were the most common seedlings. Sugar pine comprised 10 percent of the new regeneration. Ponderosa pine seedlings grew fastest, sugar pine next, and white fir and incense-cedar, which were browsed heavily, the slowest.

LOGGING CREATES microenvironments for seed germination which are rarely encountered in virgin forests. What types of microenvironments support the best germination and survival of the major tree species? What is the species composition of the new reproduction after logging? What range of microenvironments are found in logged areas? What microenvironments hinder seedling establishment? How fast do the native species grow under natural conditions after logging? Do the logging techniques produce seedbeds favorable to one species but not another?

To answer such questions, quadrat studies were established in 1948 and 1949 after logging in the Stanislaus-Tuolumne Experimental Forest near Pinecrest in Tuolumne County, California. Both permanent and temporary quadrats stretched in transects across the openings created by logging. Over a 12-year period, seedfall per acre was correlated with seedling establishment at intervals of 1 to 3 years.

THE AUTHOR was on the staff of the Pacific Southwest Forest and Range Expt. Sta., Forest Service, U. S. Dept. Agric., Berkeley, Calif., when this research was conducted.

Stanislaus-Tuolumne Experimental Forest

The Stanislaus-Tuolumne Experimental Forest lies in the mixed conifer zone of the west slope of the Sierra Nevada. Trees sometimes reach 200 feet in height and 7 to 8 feet in diameter. Common species at 5,800 to 6,400 feet elevation include ponderosa pine (*Pinus ponderosa* Laws.), sugar pine (*Pinus lambertiana* Dougl.), Jeffrey pine (*Pinus jeffreyi* Grev. & Balf.), white fir (*Abies concolor* [Gord. & Glend.] Lindl.), and incense-cedar (*Libocedrus decurrens* Torr.). California black oak (*Quercus kelloggii* Newb.) grows on the drier ridges. California red fir (*Abies magnifica* A. Murr.) occurs above 6,000 feet elevation. Lodgepole pine (*Pinus contorta* Dougl.) is found on damp, cool sites.

The area is plagued by vigorous brush, especially mountain whitethorn (*Ceanothus cordulatus* Kell.), littleleaf ceanothus (*Ceanothus parvifolius* [Wats.] Trel.), greenleaf manzanita (*Arctostaphylos patula* Greene) bearmat (*Chamaebatia foliolosa* Benth.), and Sierra evergreen-chinkapin (*Castanopsis sempervirens* [Kell.] Dudley).

An important limitation to seedling establishment is the summer-dry climate. Precipitation averages 36 inches and falls mainly as snow, which forms packs 10 to 12 feet deep. Summer thunderstorms rarely deliver enough rain to significantly raise the soil moisture level. Over a 30-year period annual precipitation has ranged from 20 to 63 inches.

Summers are moderately warm; air temperatures seldom exceed 96° F or fall below the 40's. In winter the range is from −10° to about 60° F.

Soil temperatures in summer at one-fourth inch below the ground surface can differ by more than 80° F between adjacent sunny and shaded slopes. In the open, soil surface temperatures may reach to 150° F.

The soils are mainly sandy loams derived from granite or diorite. Glacial moraine and old lava flows capping granite cover much of the area.

Methods

Logging in the Experimental Forest in 1948 and 1949 was the first demonstration of unit area control—the detailed control of stocking on small homogeneous stand areas (*2, 5, 6, 7*). One of its objectives was to see if pine regeneration could be encouraged. Earlier studies indicated that the older logging methods left poor pine stocking (*3*).

The forest was carefully mapped and cruised before logging. Cutting was based on unit areas that could be logged and managed individually. Only a few units were partially logged as improvement cuts. Most of them were logged during the summer in harvest cuttings designed for natural regeneration or planting. Site preparation included soil scarification, slash disposal, and rodent control. To reduce rodent populations and provide a better chance for natural regeneration, 600 acres covering the landings and adjacent areas were poisoned with sodium fluoroacetate-treated grain in 1948.

After the units were logged, milacre transects were run across the openings and into the forest. Three transects sampled conditions created by logging in 1948, two sampled ground cleared in 1949. Each transect had 45 temporary milacre quadrats and 5 regularly spaced, permanent milacre quadrats.

Seedlings on both temporary and permanent quadrats were counted periodically over a 12-year period. Individual seedlings on permanent quadrats were mapped and measured. Data recorded in midsummer, or later, included rates of germination, seedling height growth, and mortality. Seedlings were counted in six years: 1949, 1950, 1951, 1954, 1957, and 1960.

Seedfall was recorded from seed traps placed along transects. The trapped seeds were identified and counted each fall from 1948 through 1956. Seed viability and soundness were not estimated.

The permanent quadrats, marked with pipes, were mapped according to litter and soil conditions and hours of summer sunlight. The six litter classes were:

Litter class	Depth
	(*Inches*)
1. None	0
2. Light	<½
3. Medium	½-2
4. Heavy	2-8
5. Half litter, half bare, litter to about 2 inches.	
6. Litter and soil mixed.	

Quadrats were classified by the estimated amount of summer sunlight falling on them. The three classes were:

Light class	Sunlight
	(*Hours per day*)
1. Full sunlight	Over 5
2. Half shade	2-5
3. Dense shade	Under 2

Results and Discussion

Natural regeneration. — Reproduction after logging in 1948—a good seed year—was much more abundant than that after logging in 1949—a poor seed year (*4* and Table 1). A good seed crop developed in the spring of 1949, but insects destroyed most of the cones before seedfall. Through 1956, annual seedfall varied considerably in composition (Table 2).

Conifer seeds fell at the rate of 196,394 per acre in 1948, and produced 8,234 seedlings per acre the following spring (Tables 1, 2). Thus, even with rodent control, the seedfall was only 4.2 percent efficient. About 53 percent of the seedlings originating from the 1948 seed crop died in 1949—an unusually dry year.

TABLE 1.—NATURAL REGENERATION AFTER CLEARCUTTING DURING A GOOD SEED YEAR (1948) AND A POOR SEED YEAR (1949), STANISLAUS-TUOLUMNE EXPERIMENTAL FOREST, 1949-1960

Year examined	Sugar pine		All pines		White and red fir Year of Cut		Incense-cedar		All conifers	
	1948	1949	1948	1949	1948	1949	1948	1949	1948	1949
	Seedlings per acre									
1949	527	—	552	—	7,682	—	0	—	8,234	—
1950	405	14	460	35	3,842	0	120	74	4,422	109
1951	373	9	427	32	2,988	0	49	39	3,465	72
1954	498	123	557	157	2,570	236	1,260	1,188	4,387	1,581
1957	470	97	524	118	1,995	532	1,114	1,028	3,633	1,678
1960	480	140	550	290	2,120	400	2,190	1,080	5,520	2,000

TABLE 2.—SEEDFALL, BY SPECIES, ADJACENT TO CLEARCUT AREAS ON THE STANISLAUS-TUOLUMNE EXPERIMENTAL FOREST, 1948-1956

Seed year	Sugar pine	Ponderosa & Jeffrey pines	All pines	White and red fir	Incense-cedar	All conifers
	Number of seeds per acre					
1948	29,014	380	29,394	167,000	0	196,394
1949	0	3,600	3,600	0	3,285	6,885
1950	140	172	312	0	0	312
1951	0	0	0	17,500	115	17,615
1952	180,328	4,885	185,213	60	30,335	215,608
1953	457	122	579	30	30	639
1954	39,113	2,925	42,038	244	7,203	49,485
1955	5,364	0	5,364	140	0	5,504
1956	50,374	2,910	53,284	8,700	0	61,984
Total	304,790	14,994	319,784	193,674	40,968	554,426

From the 1949 seed crop, only 109 conifer seedlings per acre—representing about 1 percent of the seedfall — could be found in the spring of 1950. Fortunately, new reproduction is possible for many years after logging. Only 1.9 percent of all seedlings became established the first year after logging in 1949.

During the 12-year span, 1948-1960, some seedlings died and were replaced by new seedlings. Stocking in 1960 was 5,520 conifer seedlings per acre, or 67.1 percent of the 1948 stocking. After 11 years, there were 2,000 conifer seedlings per acre on areas logged in 1949.

The 1954 survey showed that the high seedfall in 1952 considerably increased the stocking (Tables 1 and 2).

Light and litter.—Light (and, indirectly, heat) and litter depth are two of the many factors that influence seedbeds and germination. Evaporation and plant competition for soil moisture limit seedling survival. Even "full sunlight" is not a dependable constant because of differences in slope and aspect.

Although data collected from seedbeds stratified by "litter depth" and "hours of sunlight" did not produce conclusive results, they do have value as guides to more refined studies on microenvironments and related germination and survival (Table 3). Some rough comparisons are valid.

When litter depths were considered irrespective of sunlight, conifers germinated best on bare soil and light and medium litter. Survival was best on light litter, litter mixed with soil, and medium litter. White fir survival in heavy litter was greater in shade, an observation evident in many of the dense litter sites.

Bare soil.—Germination and survival on bare soil were not as high as would be expected from studies on seedbed preparation. What then is bare mineral soil? Some soils are compacted and hard, some form soft mounds, some are dried and

"You really have to watch this machine to realize how good it is in yarding and loading," Bond says. "Here's a one-man logging operation with a money-making machine that I'd be proud to show off to every logger in the Northwest."

Using the 250 to skid logs to the landing eliminates the need for an extra tractor.

And it's always on stand-by for "odd jobs."

Precision 3-valve control lets the 250 deftly handle one big stick—or several small ones.

TABLE 3.—GERMINATION AND SURVIVAL, BY SPECIES, UNDER VARIED LIGHT CONDITIONS AND LITTER DEPTH ON 119-MILACRE QUADRATS, STANISLAUS-TUOLUMNE EXPERIMENTAL FOREST, 1948-1960

Light classes and species	Litter classes: Bare		Light		Medium		Heavy		Half litter, half bare		Litter and soil mixed		All	
	Germ.	Surv.	Germ.	Surv.	Germ.	Surv.	Germ.	Surv.	Germ.	Surv.	Germ.	Surv.	Germ.	Surv.
	No.	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*	*No.*	*%*
Full sun:														
Wf[1]	8	12	154	27	34	26	2	0	16	31	16	31	230	27
Ic	16	31	47	70	18	67	0	—	40	78	4	75	125	67
Sp	12	33	26	69	2	50	3	0	6	33	6	17	55	47
Pp	0	—	0	—	1	100	0	—	0	—	5	80	6	83
Total	36	—	227	—	55	—	5	—	62	—	31	—	416	42
Half shade:														
Wf	138	6	36	33	78	29	86	14	40	30	81	25	459	19
Ic	67	55	20	45	18	78	4	50	39	64	34	53	182	58
Sp	16	19	9	67	13	8	10	50	3	0	3	33	54	30
Pp	1[2]	100	0	—	1	0	1	100	2	100	1	100	6	83
Total	222	—	65	—	110	—	101	—	84	—	119	—	701	31
Shade:														
Wf	16	50	20	5	63	49	60	37	19	26	4	0	182	36
Ic	18	28	4	50	75	35	2	0	7	57	2	100	108	36
Sp	0	—	1	100	14	7	12	8	6	0	0	—	33	9
Pp	0	—	0	—	0	—	1	0	0	—	0	—	1	0
Total	34	—	25	—	152	—	75	—	32	—	6	—	324	33
Basis: Number of quadrats	21		28		26		19		17		8		119	

[1] Wf = white fir, Ic = incense-cedar, Sp = sugar pine, Pp = ponderosa pine. Jeffrey pine and red fir were found in such small quantities that they are not included here.

[2] Where only a few seedlings were found, survival amounts were not valid for comparisons and generalizations.

cracked, some are mixed with debris and litter, and some are swept clear of needles but otherwise undisturbed. These conditions of bare mineral soil fall in all ranges of full sunlight, partial shade, and full shade. Each of these combinations created a different microenvironment for seed germination and survival. The germination and survival results on unclassified "bare mineral soil" in this study undoubtedly were related to surface drying, soil moisture, and other vagaries of microsite. Therefore, future studies of this kind should define the conditions of "bare mineral soil."

Species differences.—When sunlight (using the 1948-1949 descriptions) and litter were considered together, and some reasonable soil moisture conditions were assumed, a reproduction pattern emerged for each species. In full sunlight white fir germinated well, but only 27 percent survived. Mountain whitethorn protected many of the surviving white firs from deer browsing, intense radiation, and frost damage. But brush provided severe root competition during the seedling stage. There is some evidence, however, that the surface 3 inches of soil under brush retained more moisture than the same zone in the open. If this is true, brush would favor early growth of seedlings until their roots reached to the depth of the brush roots. Another possible benefit to seedlings is the nitrogen-fixing capacity of ceanothus.

White fir germinated well in light litter, but survived better in litter and soil mixed. In half shade, it germinated best on bare soil, but only 6 percent of the seedlings survived. On the densely shaded sites, white fir seed germinated well, and seedling survival was good on medium litter. Considering all conditions studied, white fir appeared to germinate well in half shade on bare soil, and in full sun and light litter. It survived best in dense shade with medium litter and on shaded bare soil.

Incense-cedar germinated best in light litter and survived well in all but full sun and bare soil. Although germination was good on bare soil, only 55 percent of the seedlings survived in half shade. In dense shade, incense-cedar germinated well on medium litter, but survival was best in areas with litter and bare soil. All in all, this species appeared to germinate best in half shade on bare soil, but survived best in half shade on medium litter.

Sugar pine germinated and survived best in full sunlight on light litter. Survival under all light classes was best in seedbeds of light litter, and for all litter classes survival was best under full sunlight. Germination and survival of sugar pine were notably poor under dense shade.

Few seeds of red fir, ponderosa pine, and Jeffrey pine were produced in the area. Seeds of white fir and incense-cedar were more numerous than those of sugar pine so that germination data reflected seedbed conditions and seed availability.

Tree growth.—After 12 years, the tallest trees were the natural ponderosa pines at 3.1 feet. Sugar pines were 2.2 feet tall, red firs 1.1 feet, white firs 0.8 foot, and incense-cedars 0.7 foot (Table 4). The slow growth of white fir and

TABLE 4.—AVERAGE HEIGHTS OF ALL NATURAL SEEDLINGS, REGARDLESS OF AGE, 12 YEARS AFTER LOGGING, STANISLAUS-TUOLUMNE EXPERIMENTAL FOREST

Species	Average height	Seedlings in 119 quadrats
	Feet	*Number*
White fir	0.77	163
Red fir	1.08	10
Incense-cedar	0.67	154
Sugar pine	2.17	46
Ponderosa pine	3.08	9

TABLE 5.—SPECIES COMPOSITION OF REPRODUCTION AFTER LOGGING, BASED ON SURVIVAL, STANISLAUS-TUOLUMNE EXPERIMENTAL FOREST, 1948-1960

Species	1948-1957		1958-1960		All years		
	Seedlings[1]	Composition	Seedlings[1]	Composition	Seedlings[1]	Composition	Seedlings per acre
	No.	*%*	*No.*	*%*	*No.*	*%*	*No.*
White fir	163	41.5	28	34.6	191	40.3	1,374
Red fir	10	2.5	1	1.2	11	2.3	79
Incense-cedar	154	39.2	50	61.7	204	43.0	1,467
Sugar pine	46	11.7	2	2.5	48	10.1	345
Ponderosa pine	9	2.3	0	0	9	1.9	64
Jeffrey pine[2]	11	2.8	0	0	11	2.4	79
Total	393	100.0	81	100.0	474	100.0	3,408

[1] Total number of seedlings in 119-milacre quadrats.
[2] Jeffrey pines were planted.

incense-cedar was reported in earlier studies (*9*). Slow initial net growth of these two species resulted from heavy browsing damage.

Species composition. — The species composition of young reproduction after logging showed that 43 percent of the young trees were incense-cedar (Table 5). Percents of other species were: white fir 40.3, sugar pine 10.1, red fir 2.3, ponderosa pine 1.9, and planted Jeffrey pine 2.4. The scarcity of ponderosa pine and red fir seedlings was considered a reflection of the scarcity of seed trees in the area—not directly of unfavorable seedbed conditions.

The logged units represented prime sugar pine sites, but much of their potential growing space was taken by incense-cedar, white fir, and brush under natural regeneration. At least two explanations may be given for this: (1) white fir and incense-cedar may be adapted to such a wide variety of seedbeds and microsites that they dominate the site, or (2) logging practices may leave more seedbeds favorable to incense-cedar and white fir than to pines. The true explanation is not known, but it probably involves both of these possibilities.

The pine reproduction story is not gloomy, if one considers that the amount of sugar pine reproduction established (10 percent) is not far from the goals of unit area control for this particular stand.

If pines maintain their advantage in height growth, they could eventually dominate the site. Past experience in this area, however, indicates they may not hold their advantage. For example, plots in the Cow Creek area on the Stanislaus National Forest were thinned in the 1930's by C.C.C. crews. All white firs which were thought to have a possibility of competing with pine any time in the future were removed. When these stands were examined in 1948, white fir was an important competitor in the forest canopy. Therefore, cultural treatments probably will be necessary in the future to insure continued dominance by the sugar pine and ponderosa pine now established.

The results of this study were based on observations of crude groupings of natural conditions. They suggest reasons for the conifer reproduction patterns occurring in different microenvironments after logging. This study shows that the best conditions for germination are not always the best for survival.

Literature Cited

1. COSENS, R. D., and D. TACKLE. 1950. Costs of rodent control in pine regeneration in California. U. S. Forest Service, California Forest and Range Expt. Sta. Res. Note 173. 5 pp.
2. EICHEL, G. H. 1957. Management of spruce-balsam stands toward natural regeneration. Forestry Chron. 33(3): 233-237.
3. FOWELLS, H. A., and G. H. SCHUBERT. 1951. Natural reproduction in certain cutover pine-fir stands of California. Jour. Forestry 49:192-196. Illus.
4. ————, and ————. 1956. Seed crops of forest trees in the pine region of California. U. S. Dept. Agric. Tech. Bul. 1100. 48 pp. Illus.
5. HALLIN, W. E. 1951. Unit area control in California forests. U. S. Forest service, California Forest and Range Expt. Sta. Res. Note 77. 7 pp. Illus.
6. ————. 1954. Unit area control —its development and application. U. S. Forest Service, California Forest and Range Expt. Sta. Misc. Paper 16. 10 pp.
7. ————. 1959. The application of unit area control in the management of ponderosa-Jeffrey pine at Blacks Mountain Experimental Forest. U. S. Dept. Agric. Tech. Bul. 1191. 99 pp. Illus.
8. SCHUBERT, G. H. 1953. A trial of three chemicals as rodent repellents in direct seeding. U. S. Forest Service, California Forest and Range Expt. Sta. Res. Note 84. 2 pp.
9. ————. 1956. Early survival and growth of sugar pine and white fir in clear-cut openings. U. S. Forest Service, California Forest and Range Expt Sta. Res. Note 117. 6 pp. Illus.