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SHELTERWOOD CUTTING IN A YOUNG-GROWTH, MIXED-CONIFER STAND IN NORTH CENTRAL CALIFORNIA

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SUMMARY

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In 1958, a mixed-conifer stand on a high site was logged to two-stage shelterwood specifications. The primary goal was to test the applicability of a modified shelterwood method to a young-growth stand. Changes in species composition and stand structure, seedfall, regeneration, and growth of the residual stand were evaluated.

Because slash volumes are high and aggressive hardwood and brush populations build up quickly after logging, combination slash disposal and site preparation techniques must be applied. Treatments compared were piling by bulldozer immediately after logging, piling just before seedfall from a heavy cone crop, and top-lop and branch-scatter.

Cutting removed 68 percent of the stand basal area and 70 percent of the merchantable volume. Most of the remaining volume was in the 12 trees per acre (30 per ha) that constituted the shelterwood.

These trees produced seed abundantly during the 5-year period after logging. In fact, fifteen conifer and two hardwood seed crops were produced, and four out of five conifer species generated at least one moderately heavy seed crop. Cone counts proved valuable in assessing the number of trees with cones and the number of cones per tree, but were poor quantifiers of sound seed. Seed trap catches gave more accurate results, indicating a total seed production of 134,000 sound seed per acre (330,980 per ha) during a 3-year period. In general, young-growth trees, even on this high site, produced high percentages of unsound seed.

Regeneration was exceptional on the prepared ground beneath the shelterwood. After 50 months, about 3700 ponderosa pine seedlings per acre (9139 per ha), and 600 shade-tolerant conifer seedlings (1482 per ha) were established. Corresponding stocking values were 62 percent for ponderosa pine and 19 percent for the tolerant conifers. An additional 320 26-month-old tolerant conifer seedlings per acre (790 per ha) also were present.

Seedlings survived better when slash was piled just before seedfall than when it was piled immediately after logging, or when branches were lopped and scattered.

Hardwood seedlings and sprouts also were abundant, numbering about 3000 per acre (7410 per ha), but the seedlings were poorly distributed and rather slow growing. Sprouts were the most serious competitors of the conifer seedlings, especially of the more tolerant conifers.

In general, the species composition of the new stand regenerated by this shelterwood application closely resembled that of the stand before logging.

Seedfall and regeneration were compared to a control block. Nine times more seeds were produced in the shelterwood, more seeds were sound, more sound seeds germinated, more seedlings resulted, a lower proportion of the seedlings died, and the seedlings were better distributed throughout the area.

Basal area growth of individual trees in 5 years exceeded that of the control for nearly all conifer and hardwood species and diameter classes. In the shelterwood, sugar pine responded best to cutting, and its basal area growth rate was twice that of ponderosa pine and Douglas-fir.

Increased amounts of seed and seedlings, plus accelerated growth rates of residual trees, are gains in productivity that the landowner may realize from applying the shelterwood method to young-growth stands. Because reforestation is accomplished by natural regeneration rather than by expensive nursery stock, the shelterwood cutting method is attractive to a wide range of forest landowners, including those having small acreage and limited capital.

Nearly 30 years ago Hawley (1946) noted that the shelterwood cutting method was particularly applicable to young-growth conifer stands. Yet in the Western United States, this method has been only sparingly applied. A 70-year-old western hemlock stand was cut in three stages in western Washington (Herman 1962), and a Douglas-fir stand under 90 years of age was logged by a modified shelterwood cutting in Oregon. In the latter study, the overstory trees were removed by several partial cuttings over a 30-year period (Starker 1970).

Because of its wide silvicultural application, the shelterwood method now is being used much more frequently, by a more diverse audience, and with a broader spectrum of objectives. Shearer (1971) noted that the shelterwood method provided a high output of both commodities and amenities: timber, wildlife and livestock forage, water, and esthetics. Indeed, Rickard and others (1967) found that the method opened up the stand, thus improving visual penetration and scenic enjoyment.

The shelterwood method is particularly useful as an alternative to clearcutting. It is a gentler method; the land is never without trees and their presence lessens the harshness of the environment. The habitat provided is midway between the open sunlit clearcut and that of the dense shady uncut forest.

Owners of small parcels of timberland also can benefit from the shelterwood method. Large increases in productivity can be realized, and by means of natural seedfall and natural regeneration, a new tree crop can be "established without high capital outlays for nursery stock and planting crews.

The shelterwood method can be applied in many environments and for such diverse silvicultural objectives as protecting regeneration, establishing difficult-to-regenerate species, conversion to more desirable species, and natural regeneration of large areas.

For propagating species whose regeneration requires protection from adverse environmental factors such as high temperatures, frosts, or strong sunlight, the shelterwood method is without peer. It has been used to protect hybrid spruce in Canada from frost damage (Day 1970); black and white spruce, balsam fir, and northern white cedar from frost in mixed-conifer swamps in Michigan's Upper Peninsula (Benzie 1963); Scots pine and Norway spruce from frost in Sweden and other Scandinavian countries (Hagner 1962); and white pine from excessive soil surface temperatures and improper amounts of light in the Northeastern United States (Hawley and Clapp 1942; Smith 1951).

A well-applied shelterwood cutting is ideal for regenerating an infrequent seed producer and a difficult-to-plant species such as longleaf pine. It produces enough shade to inhibit brush, grass, and other competitive vegetation until enough seed crops have occurred to provide adequate regeneration (Croker 1969).

The shelterwood method also is used for converting to a more desirable species, like spruce, in the spruce-aspen stands of Manitoba (Lees 1964), and in the hardwood-spruce stands of the Northeastern United States (Westveld 1938). Sometimes a different mixture of species is desired. In northeastern Washington, shelterwood cutting favors western larch and Douglas-fir over lodgepole pine and western white pine (Pacific Logger & Lumberman 1971).

In addition to protection and conversion, the shelterwood method is applicable where evenly distributed natural regeneration is desired over large areas, as in the spruce-beech-fir forests of southern Germany and nearby countries (Spurr 1956), and in the western larch forests of Montana and northern Idaho (Roe 1955).

At the Challenge Experimental Forest in north central California,[1] early research goals were to evaluate shelterwood and other cutting methods in terms of species composition, seedfall, regeneration, and growth of residual trees. Information on these components, for the various cutting methods, is sorely needed for young-growth stands. By comparing cut stands to a control, this research also encouraged investigation of an increasingly important concern of silviculture–cutting-caused vegetative succession, not just on the ground or into the overstory, but into each stand stratum. Further, the comparison permitted quantification of the gain in productivity for seed crops, seeds, seedlings, and growth resulting from shelterwood cutting.

This study embraces the principles of protection

[1] U.S. Forest Service research at the Challenge Experimental Forest is conducted in cooperation with the Soper-Wheeler Company, Strawberry Valley, California.

and conversion: protection for shade-tolerant conifer seedlings and advance reproduction from strong sunlight and high temperatures, and conversion in the sense of reversing normal plant succession and converting the vegetation to an earlier serial stage. This report documents results from a two-stage shelterwood cutting on the Challenge Experimental Forest, as observed about 5 years after logging. Three slash disposal treatments as well as species composition, stand structure, seedfall, regeneration, and growth of the residual stand were evaluated. The cutting was found to maintain the character of the stand before logging and to increase productivity of the cut blocks as compared to the uncut control.

METHODS

Site and Stand Characteristics

Research on the Challenge Experimental Forest is applicable to about 1.5 million acres (600,000 ha) of highly productive timberland along the lower west slopes of the Sierra Nevada. An important attribute of the Experimental Forest is its high site. The dominant species, ponderosa pine (*Pinus ponderosa* Laws.) averages 140 feet (43 m) in height in 100 years (Arvanitis and others 1964). Deep soil, warm temperatures, and an average annual precipitation of 68 inches (1680 mm) lead to rapid site occupancy by vegetation. With time, this vegetation has resulted in conifer and hardwood stands (*fig. 1*).

In stand volume, ponderosa pine is the dominant species, followed by Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) with lesser amounts of sugar pine (*Pinus lambertiana* Dougl.), white fir (*Abies concolor* [Gord. & Glend.] Lindl.), and incense-cedar (*Libocedrus decurrens* Torr.). Hardwoods, principally California black oak (*Quercus kelloggii* Newb.), tanoak (*Lithocarpus densiflorus* [Hook. & Arn.] Rehd.), and Pacific madrone (*Arbutus menziesii* Pursh), are scattered throughout as individual trees, clumps, or groves. They often form extremely dense stands.

Four 6-acre (2.4-ha) rectangular compartments with generally eastern exposure and slopes of 15 percent or less were selected for the shelterwood study. Each compartment supported a stand of conifers and hardwoods of about 248 stems per acre (613 per ha) 3.5 inches (8.9 cm) or more in diameter at breast height (d.b.h.). Basal area was about 270 ft^2 per acre (62 m^2/ha). Stand volume of trees larger than 12 inches (30 cm) in diameter averaged slightly under 54,000 board feet per acre Scribner rule (308 m^3/ha).

Figure 1—This 90-year-old mixed-conifer stand is typical of the Challenge Experimental Forest, Yuba County, California, in 1958.

Cutting Plan, Logging, and Slash Disposal

In the summer of 1958, each compartment was cut to form a modified shelterwood. Shelterwood cutting in young-growth, windfirm stands on high sites can differ considerably from cutting in old-growth stands, 200 or more years in age. First, because much quicker establishment of regeneration often is a management goal, the classical shelterwood stages of "preparatory" and "seed" can be combined. The combined operation plus the removal stage form a two-stage shelterwood. Second, not only must enough trees remain to provide the desired level of protection to advance reproduction or new seedlings, but also the trees left must produce seed. Seed production cannot be as readily assumed as in old-growth stands. Some trees in young-growth stands are physiologically incapable of producing cones even though they are full crowned and appear thrifty. Thus, after considering the number of trees to leave evenly spaced over each acre, the silviculturist should further consider leaving trees that show evidence of past cone production.

To form the desired two-stage shelterwood, 12 large, vigorous, full-crowned trees were evenly spaced throughout each compartment. All other trees larger than 12 inches d.b.h. were harvested. Trees with cones on the ground below were chosen as leave trees whenever possible. Conifers other than ponderosa pine were desired, but because this species predominated, it constituted about 60 percent of the shelterwood. After logging, Douglas-fir, white fir, and sugar pine advance reproduction, small poles, and large poles remained in the understory, both as individual trees and in thickets. Because they could be expected to prosper in the shelterwood environment, they were retained.

Flexibility was the rule in logging, and landings were quickly and cheaply constructed near the compartments at appropriate locations. Timber fallers cut all unmarked conifers and were careful not to injure designated shelterwood trees. Skidding was done by 113-drawbar horsepower, dozer-equipped tractors (D-7 and TD-20). Loading also was done with a large tractor equipped with a hydraulic fork. Other than in the small landings, soil compaction appeared to be negligible.

Slash volumes tend to be heavy in young-growth stands on high sites–Sundahl (1966) found slash volumes to range from 88 to 110 tons per acre (80 to 100 metric tons per ha). Also, over one-third of the total stand density was less desirable pole- and sapling-sized incense-cedar and Pacific madrone. Therefore, a combined slash disposal and site preparation treatment was advisable.

To ascertain the effectiveness of the regeneration medium provided, three widely differing intensities of site-preparation-slash-disposal were installed on equal acreages in each compartment. These were:

1. Pile with bulldozer immediately after logging. Burn piles later.
2. Delay piling until late summer of an obviously good seed year. Burn piles later.
3. Lop and hand scatter.

In the dozer-piled operations, many hardwoods and small incense-cedars were eliminated deliberately. Few were removed in the lop-and-scatter treatment. In the process of piling, much mineral soil was bared; little was bared, and that only by logging, in the lop and scatter treatment. Delaying slash disposal until just before seedfall provided a fresh, friable seedbed.

Within each 6-acre compartment a 4-acre (1.6-ha) rectangular cut block was delineated. An adjacent compartment of similar size, with similar terrain and timber stand structure, was used as a control. Here, about 20 percent of the volume in trees over 12 inches d.b.h. was removed in a light improvement cut in 1958. Slash was piled and burned on about 15 percent of this compartment. Within it, a 4-acre "control block" was defined for measurement.

After the light cutting and slash disposal, the control block contained almost the same number of trees (252 per acre or 622 per ha) as the average cut block before logging (269 trees per acre or 664 per ha). A statistical comparison of the control block after logging and the cut blocks before logging, based on species and 4-inch (10-cm) diameter classes, showed no significant differences between cut blocks and control ($p = 0.05$).

Data Gathering and Analysis

Within each 4-acre cut block, every tree larger than 3.5 inches d.b.h. was tagged to facilitate remeasurement. Trees smaller than 3.5 inches in diameter were not tallied until they reached this diameter. Then they were recorded separately as ingrowth. Trees were measured before logging in 1958, after logging in 1959, and after five full growing seasons (1963). Tree mortality was recorded annually. In the 4-acre control block, all trees above 3.5 inches d.b.h. also were tagged and recorded.

Stand Structure

Stand tables by species and 4-inch diameter classes were prepared for each cut block and for the control block as of 1958 and 1963, and analyzed statistically for differences between blocks.

Seedfall

Seedfall data were gathered annually for the first 5 years after cutting (1958-62). Cone counts and seeds caught in traps quantified seedfall.

Cone counts—All cones produced in the shelterwood cut blocks and control, except cones of incense-cedar, were counted each year using 7 x 35 binoculars. The number of cones observed was increased by a factor of 1.5 for ponderosa pine and white fir (Fowells and Schubert 1956) and by 1.6 for Douglas-fir. Cones of Douglas-fir are difficult to count because they are small, clustered, and often blend with the surrounding foliage. Because the count was taken during the short ripening period when cones are yellowish and counting is easiest, I chose a factor of 1.6 instead of 2 as used by Garman (1951). All sugar pine cones were seen readily.

Dissection of Douglas-fir cones revealed about 50 fully developed (sound) seeds in each. Ponderosa pine cones contain about 70 sound seeds per cone, white fir about 185, and sugar pine about 215 (Fowells and Schubert 1956).

Seed traps—In 1960, 18 seed traps, 1 foot square, were systematically arranged (random start) in each shelterwood block and the control block. This sampling intensity was tested for the seed crops produced in 1960, 1961, and 1962, and reflected the true proportion of sound seed ($p = 0.05$). The traps were emptied annually in winter and cleaned and checked in late summer.

Regeneration

For sampling, 30 circular milacre plots (each containing 4 m^2) for each shelterwood block and for the control block were arranged along three transects whose points of origin were randomly located. Each transect traversed a given slash disposal treatment in each block and consisted of 10 milacre plots. Every plot was visited in the spring, and all seedlings, both coniferous and hardwood, were recorded. At the first measurement in 1959 only those plants less than 4.5 feet (1.4 m) tall rated as "seedlings." Each clump of hardwood sprouts was recorded as one plant even though the individual sprouts per clump often were numerous. All new seedlings were marked to denote species and year of origin.

The effect of slash disposal treatment was tested by analysis of variance using transformed (arc-sine) stocking percentages. Separate analyses of variance tested initial (2-month-old) seedling stocking and established (26-month-old) seedling stocking for both ponderosa pine and the combined tolerant conifers. Significant differences were examined further by Tukey's test (Hamilton 1965).

Basal Area Growth

Growth increment (accretion) for the 5-year period 1959 through 1963 included the basal area growth added to all living trees greater than 3.5 inches d.b.h., and the growth added to trees that died during the measurement period. Basal area growth rates per tree for each shelterwood block were combined and averaged to form a composite block value when no significant differences between blocks were found.

RESULTS

After logging and slash disposal, a change in stand structure in the cut blocks was evident. And after 5 years, beneficial effects in productivity from cutting were noticeable in seedfall, amount of regeneration, and growth of the residual stand.

Stand Structure and Species Composition

Because statistical analyses of the stand tables for 1958 and 1963 showed no significant differences ($p = 0.05$) among cut blocks for species, data for all cut blocks were combined (*table 1*). Five years after cutting, however, stand structure had changed considerably. In the 3.5- to 20-inch (51-cm) diameter classes, the average cut block contained one-seventh the number of ponderosa pines in the control block, one-half of the incense-cedars, and one-sixth of the hardwoods. In the diameter classes above 20 inches d.b.h., the cut block contained one-third of the number of ponderosa pines in the control.

The reduction of trees in the cut blocks was accounted for as follows:

	Trees lost per acre (ha)
Cause of reduction:	
Cutting	57 (141)
Site preparation-slash disposal	131 (324)
Natural mortality	5 (12)
Total	193 (477)

Changes in basal area and stand volume were similar in magnitude. They indicate the intensity of this cutting method and the cultural practices that were applied. Stand basal area was reduced 68 percent to 88 ft^2 /acre (20 m^2 /ha). More than half the reduction occurred in the size classes above 20 inches. Volume decreased by 70 percent or 38,000 board feet per acre (217 m^3/ha). Nearly all of the remaining volume (16,000 fbm per acre or 91 m^3/ha) was in shelterwood trees.

Changes in the species composition of various stand strata varied widely (*table 2*). Relatively minor changes were realized in the small tree size class (trees 3.5 to 12 inches d.b.h.), where the proportion of Douglas-fir and sugar pine increased at the expense of incense-cedar and the hardwoods. In the medium tree size class (trees 12.1 to 20 inches d.b.h.) a major change resulted. Ponderosa pine was reduced by 30 percent whereas most of the other species gained. Only slight changes appeared in the large tree size class; sugar pine gained proportionally and Douglas-fir lost.

Natural mortality from 1958 to 1963 was evaluated for all species in the three size classes. In the smallest category an average of five trees per acre were lost: two of incense-cedar, and one each of Douglas-fir, white fir, and ponderosa pine. Windsnap was the leading cause of mortality, with delayed death from logging damage and unknown causes equally important in second place. Mortality from insects ranked next. None of the medium-sized trees died, because nearly all trees of this size were removed in logging or slash disposal. Only three large ponderosa pines in the entire shelterwood overstory of 192 trees were lost–the sole agent being the western pine beetle (*Dendroctonus brevicomis* Lec.). Virtually no hardwoods died. The overall effect of natural mortality on stand structure and species composition was small.

Natural mortality in the control differed markedly from that in the shelterwood blocks. Nearly twice as many trees per acre died; all three tree size classes were affected, and cause of death as related to species generally differed. In the small trees, the average per acre was one ponderosa pine killed by insects and six hardwoods killed by suppression. The western pine beetle also killed one medium-sized ponderosa pine and one large ponderosa pine per acre.

Table 1—*Stand table for composite shelterwood block before logging in 1958 and five years later, Challenge Experimental Forest, California*

Species	Trees per acre by diameter class (inches)[1]													
	3.5 to 8.0		8.1 to 12.0		12.1 to 16.0		16.1 to 20.0		20.1 to 30.0		30.1+		All classes	
	1958	1963	1958	1963	1958	1963	1958	1963	1958	1963	1958	1963	1958	1963
Conifers:														
Douglas-fir	29	8	17	10	8	2	3	0	4	1	3	1	64	22
Ponderosa pine	2	0	6	2	10	1	7	0	15	4	5	3	45	10
Sugar pine	1	0	1	1	1	0	1	0	1	1	1	1	6	3
White fir	6	2	3	1	1	0	1	0	1	1	0	0	12	4
Incense-cedar	52	11	12	5	3	1	1	0	1	0	0	0	69	17
All conifers	90	21	39	19	23	4	13	0	22	7	9	5	196	56
Hardwoods:														
California black oak	6	2	3	1	2	1	1	0	1	1	1	0	14	5
Tanoak	10	2	4	1	2	1	1	1	1	0	0	0	18	5
Pacific madrone	31	6	9	4	1	0	0	0	0	0	0	0	41	10
All hardwoods	47	10	16	6	5	2	2	1	2	1	1	0	73	20
All species	137	31	55	25	28	6	15	1	24	8	10	5	269	76

[1] Data include ingrowth into 1963 diameter classes.

Table 2–*Species composition by tree-size classes in shelterwood blocks before logging and 5 years later, Challenge Experimental Forest, California*

Size class and species	Before logging	After 5 years	Change
		Percent	
3.5 to 12 inches d.b.h.:			
Ponderosa pine	4	4	0
Sugar pine	1	3	+2
Douglas-fir	24	30	+6
White fir	5	6	+1
Incense-cedar	33	29	–4
hardwoods	33	28	–5
12.1 to 20 inches d.b.h.:			
Ponderosa pine	41	11	–30
Sugar pine	3	5	+2
Douglas-fir	26	30	+4
White fir	5	3	–2
Incense-cedar	9	16	+7
Hardwoods	16	35	+19
20+ inches d.b.h.:			
Ponderosa pine	58	59	+1
Sugar pine	8	16	+8
Douglas-fir	19	12	–7
White fir	5	4	–1
Incense-cedar	3	0	–3
Hardwoods	7	9	+2

In the cut blocks, the most abundant ingrowth species were hardwoods, particularly tanoak and Pacific madrone. They constituted 41 percent of the new trees. Next was Douglas-fir (36 percent), followed by incense-cedar (14 percent), white fir (7 percent), sugar pine (1 percent), and ponderosa pine (1 percent). Altogether, ingrowth in the cut blocks averaged 6 trees per acre over the 5-year period.

In the control block, ingrowth averaged 16 trees per acre (40 per ha) of the same species, similarly ranked, as in the cut blocks.

Seedfall

Ponderosa pine produced a few cones in 1958 and a bumper seed crop in 1960. Douglas-fir bore cones in 1958, 1960, 1961, and 1962. Sugar pine yielded cones in 1960 and 1962. White fir produced a light cone crop in 1958, 1960, and 1962, and incense-cedar bore cones in 1960 and 1962. California black oak produced a bumper seed crop in 1958; Pacific madrone did the same in 1960. Tanoak yielded a few acorns nearly every year of the study.

The 1960 seed year was remarkable both for the amount of cones produced and for the number of species that bore them. Even small trees produced cones. The ponderosa pine crop was outstanding. Trees over 20 inches in diameter produced from 8 to 540 cones per tree, averaging 325. Trees 12 to 20 inches d.b.h. averaged 78 cones per tree in the range of 40 to 117, and trees smaller than 12 inches d.b.h. produced about 15 cones per tree in the range of 6 to 24.

Douglas-fir also produced a bountiful cone crop in 1960. Trees over 20 inches in diameter yielded an average of 987 cones per tree in a range of 2 to 3634. Trees 12 to 20 inches d.b.h. bore an average of 63 cones per tree in the range of 21 to 120, and trees less than 12 inches in diameter averaged 60 cones per tree in the range of 1 to 240.

Douglas-fir produced cones on smaller trees than did other species. For example, the smallest fruitful Douglas-fir was 3.6 inches (9 cm) in diameter and produced 21 cones. The smallest productive ponderosa pine was 11.2 inches (28 cm) d.b.h. and yielded 6 cones. This and the tendency to bear frequent light- to medium-cone crops is characteristic of Douglas-fir on the Experimental Forest.

Most cone production was from larger trees. For example, the proportion of the total crop produced by trees 20 inches d.b.h. and larger was as follows:

	Percent
Year and species:	
1958	
Ponderosa pine	100
1960	
Pondersoa pine	97
Sugar pine	100
Douglas-fir	80
White fir	100
1961	
Douglas-fir	67
1962	
Douglas-fir	84
White fir	100

Not only did trees in the largest diameter class contribute most to the total cone crop, but they also had the highest proportion of fruitful trees. This was true in both shelterwood and control blocks. In the shelterwood, however, a higher proportion of trees in nearly all diameter classes bore cones than in comparable classes in the control block:

Year, species, and diameter class (inches):	Percent of trees which bore cones: Shelterwood	Control
1960		
Ponderosa pine		
Under 12	19	14
12 to 20	77	52
Over 20	90	51
Douglas-fir		
Under 12	28	0
12 to 20	29	77
Over 20	95	88
1961		
Douglas-fir		
Under 12	3	1
12 to 20	11	6
Over 20	32	0
1962		
Douglas-fir		
Under 12	9	0
12 to 20	46	10
Over 20	86	75

The trend of higher cone production in the shelterwood cuttings, as opposed to the control, was even more manifest in terms of estimated seed from the cones:

Year and species:	Estimated sound seed per acre: Shelterwood	Control
1958		
Ponderosa pine	1,540	2,730
Douglas-fir	29,000	11,200
White fir	7,215	0
1959		
Ponderosa pine	350	0
1960		
Ponderosa pine	144,970	113,750
Sugar pine	35,905	645
Douglas-fir	95,550	83,100
White fir	5,920	555
1961		
Douglas-fir	2,100	2,000
1962		
Ponderosa pine	840	210
Sugar pine	1,398	0
Douglas-fir	31,200	21,000
White fir	9,250	93

The supremacy of seed production in shelterwood blocks over that in the control block is even better demonstrated for estimates of seed production from seed traps:

Year and species:	Estimated sound seed per acre: Shelterwood	Control
1960		
Ponderosa pine	110,110	12,100
Sugar pine	8,470	0
Douglas-fir	1,815	2,420
White fir	1,815	0
Incense-cedar	3,630	0
1962		
Douglas-fir	1,815	0
Incense-cedar	6,050	0
Total	133,705 (330,251 per ha)	14,520 (35,864 per ha)

Regeneration

The sampling plan encouraged year-by-year observation of the survival of individual seedlings. Mortality trends also were readily definable. Because new seedlings were 1 to 2 months old at the time of the yearly survey, most viable seeds had germinated, and seedling mortality generally was still low. Thus seedling abundance was at or near maximum at each survey.

Regeneration was evaluated by number of seedlings per acre and stocking percentage (percent of milacre plots having one or more seedlings). In this context, stocking percentage is a measure of how well the seedlings are distributed throughout the sampling area. High stocking percentages indicate good distribution; low percentages indicate either few seedlings or a clumpy distribution. Results were evaluated for individual species when possible, or for tolerant conifers (Douglas-fir, white fir, sugar pine, and incense-cedar as a group), hardwoods, and ponderosa pine.

The seed-to-seedling ratio often reflects the biological agents and environmental conditions that affect germination and early seedling survival. In this shelterwood cut, the ratio for ponderosa pine was 13:1–that is, for every 13 sound seeds that fell in the fall of 1960, one ponderosa pine seedling was tallied in the spring of 1961. In another study at the Challenge Experimental Forest where seedbeds were mostly bare mineral soil, and rodents were not controlled, 14 sound seeds produced one ponderosa pine seedling (McDonald 1966). Fowells and Schubert (1956) rated the seed-to-seedling ratio at 40:1 for ponderosa pine on seedbeds having a medium-to-heavy cover of vegetation, litter, or logging debris, and several hundred to one with no seedbed preparation or rodent control measures. Therefore, in the present shelterwood cutting, the ratio of ponderosa pine seed to seedlings was low.

Seed-to-seedling ratios for other seed crops during 1960 or as noted were:

Sugar pine	39:1
White fir	17:1
Douglas-fir	10:1
Douglas-fir (1962)	10:1
Incense-cedar	8:1
Incense-cedar (1962)	11:1

Initial ponderosa pine stocking was almost the same for all three slash disposal methods and no significant differences prevailed. Two years later, however, ponderosa pine seedling stocking was significantly worse ($p = 0.05$) where the lop-and-scatter method was employed. Delayed piling was best, but results did not differ significantly from those of the pile-after-logging treatment.

Initial stocking of tolerant conifer seedlings, 2 months old, was best for the delayed slash disposal treatment, and differed significantly ($p = 0.05$) from that of the after-logging treatment, but not significantly from stocking in the lop-and-scatter treatment. These relationships were found to be consistent for 26-month-old seedlings as well.

The effect of slash disposal treatment on hardwood regeneration also was examined. Numerous hardwood seedlings became established where the slash had been piled, but sprouts excelled where the slash was lopped and scattered.

Mineral soil seedbeds favor ponderosa pine (Curtis and Lynch 1957; Fowells and Stark 1965) more than other species. Ponderosa pine seeds readily germinate and large numbers of seedlings result, but many soon die from drought and overcrowding. On high sites, some seedlings quickly become dominant and suppress others (*fig. 2*). High mortality of young seedlings is part of the natural thinning process and is not deleterious; 3700 5-year-old seedlings per acre or 9139 per ha (*fig. 3*) are more than enough to satisfy the most ambitious management goals. In fact, seedling mortality in this instance may be considered beneficial as seedling numbers are reduced greatly without impairing distribution.

Early survival of tolerant conifer seedlings decreased less sharply than that of ponderosa pine, and after 5 years numbered 600 per acre (1482 per ha) (*fig. 3*). Survival for the second wave of seedlings was less than for the first, probably because vegetative competition had increased greatly. Of the tolerant conifers, survival of sugar pine and incense-cedar was best, white fir was intermediate, and Douglas-fir was poor.

Reproduction of California black oak, tanoak, and Pacific madrone is usually a combination of sprouts and seedlings. Logging and slash disposal eliminated

Figure 2—Some of these 3-year-old ponderosa pine seedlings on a mineral soil seedbed are already expressing dominance.

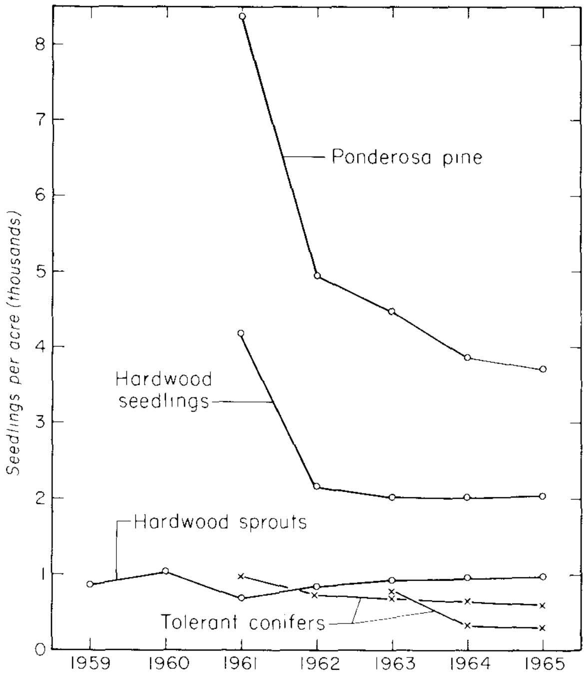

Figure 3—Variation between species is evident in seedling survival patterns for the composite shelterwood block.

many small hardwood trees, saplings, and seedlings. Others were broken off at ground line or severely damaged. These promptly sprouted from root crowns. Other small seedlings died back to the root crown after logging because of shock from increased sunlight. Most of these also sprouted. Together the sprouts numbered about 1000 per acre (2470 per ha; *fig. 3*).

Hardwood seedlings of one species or another became established nearly every year. The bumper seed crops of Pacific madrone and California black oak, plus the near-annual yield of tanoak acorns, resulted in many seedlings. Distribution of these seedlings was clumpy, ranging from as many as 70 per milacre plot to none. On some plots they decreased rapidly. When hardwood seedlings numbered 20 or more per milacre, the intense competition drastically reduced their numbers (*fig. 3*). On plots containing only 1 to 5 seedlings, almost none died. Altogether, hardwood seedlings averaged about 2000 per acre (4940 per ha) after 5 years and were second only to ponderosa pine.

Relative to the control, seedling establishment and survival favored the shelterwood cutting, both for number of seedlings and seedling distribution, as shown in the data for 1963 (1960 seed crop):

	Milacre stocking, (percent)		*Seedlings per acre*	
	Shelter-wood	*Control*	*Shelter-wood*	*Control*
Species:				
Ponderosa pine	76	10	4495	250
Sugar pine	8	0	120	0
Douglas-fir	3	3	25	60
White fir	7	0	85	0
Incense-cedar	11	0	500	0
Hardwoods	44	23	2025	560

Growth of Residual Stand

An important consideration in any partial cutting method is the growth of the residual trees. In this operation the 12 shelterwood trees per acre were ideally situated to maximize growth. The site is high, and they were the most vigorous trees in the stand– tall, full-crowned, and thrifty. They possessed the photosynthetic area necessary to respond quickly to their new environment. Cutting removed virtually all competition and allowed them almost unlimited growing space with increased available water, nutrients, and sunlight. The 63 trees per acre (156 per ha) in the small- and medium-size classes probably benefited from the cut, but not to the extent of the larger trees. First, their distribution was clumpy, as thickets of them were deliberately avoided by the bulldozer. Second, they needed time to develop and respond to their new environment.

Understory basal area growth generally was distributed according to the abundance of each species, as indicated in the stand table (*table 1*). Douglas-fir contributed most to total accretion, showing twice the growth of incense-cedar, the next largest contributor. Pacific madrone, which ranked third in abundance, also was third in growth. Ponderosa pine contributed less than any other conifer or hardwood in the understory. In the large tree size class, however, ponderosa pine was most abundant and contributed most to basal area growth. Sugar pine and Douglas-fir ranked second and third in abundance and held the same rank in their contribution to total accretion.

Ranking of growth rates over all diameter classes showed sugar pine best, followed by ponderosa pine and Douglas-fir, white fir, California black oak, and tanoak. Pacific madrone and incense-cedar grew slowest (*table 3*).

Ranking of growth rates over all diameter classes in the control indicated Douglas-fir best, followed by ponderosa pine, incense-cedar, and hardwoods, with sugar pine and white fir too few to be tested.

Table 3–*Comparative basal area growth rates in composite shelterwood (S) and control (C) blocks, by species and diameter classes, 1959-63, Challenge Experimental Forest, California*

Species	Tree growth[1] by diameter class (inches)											
	3.5 to 8.0		8.1 to 12.0		12.1 to 16.0		16.1 to 20.0		20.1 to 30.0		30.1+	
	S	C	S	C	S	C	S	C	S	C	S	C
	Square feet per tree											
Conifers:												
Ponderosa pine	–	0.01	0.04	0.02	0.11	0.07	–	0.17	0.46	0.27	0.58	0.42
Sugar pine	–	–	.17	–	–	–	–	–	.74	–	1.15	.92
Douglas-fir	0.06	.03	.12	.08	.17	.16	–	.26	.40	.45	.58	.60
White fir	.04	.03	.09	.12	–	–	–	–	.38	.42	–	–
Incense-cedar	.02	.01	.08	.04	.11	.06	–	.12	–	–	–	–
All conifers	.04	.02	.10	.06	.16	.11	–	.18	.49	.29	.64	.46
Hardwoods:												
California black oak	.03	.02	.07	.04	.11	.09	–	.08	.32	.10	–	–
Tanoak	.06	.03	.09	.07	.10	.07	.11	.11	–	–	–	–
Pacific madrone	.05	.02	.08	.06	.06	.05	–	.05	–	–	–	–
All hardwoods	.04	.02	.08	.06	.09	.07	.11	.08	.32	.10	–	–
All species	.04	.02	.09	.06	.13	.09	.11	.16	.45	.29	.64	.46

[1] Dash indicates no trees present.

Analysis of variance showed significant differences ($p = 0.05$) in the overall growth rate between the composite cut block and control. Individual ponderosa pines, incense-cedars, and hardwoods in the cut blocks outgrew their counterparts in the control in nearly all diameter classes. Notably, Douglas-fir grew at about the same rate in both the shelterwood cut and control and thus was relatively insensitive to release, at least during the study period.

In the composite shelterwood block, accretion during the study period amounted to 4.60 ft^2 of basal area per acre for trees 3.5 to 20.0 inches in diameter. In the control, it was 10.43 ft^2 /acre for trees of similar size. Obviously, trees in the cut blocks grew faster than trees in the control, as the control contained 3½ times as many trees (63 against 220 per acre). And trees over 20.0 inches in diameter outgrew their counterparts in the control (13 trees per acre and 5.52 ft^2 of basal area per acre in the cut against 23 trees and 7.32 ft^2 /acre in the control).

In heavy partial cuts such as this shelterwood cutting, leave trees are subjected to a sudden and drastic "opening up" of the stand, and an increased risk of mortality from sun, wind, and insects. Trees that die after logging seldom are salvaged before the shelterwood is removed, and the entire basal area of each is lost. Increment accruing between the time of initial measurement and the tree's death also is lost.

In the cut area, nearly 2.45 ft^2 of basal area per acre was lost to natural causes, half in the small- and half in the medium-sized tree classes. About 5.76 ft^2 were lost in the control. Accretion on trees that died in the cut and control amounted to 0.03- and 0.1-ft^2 per acre, respectively, during the 1959-63 period.

When a tree becomes ingrowth, its initial basal area plus any growth from time of entry to end of the measurement period are recorded. Accretion on ingrowth into the 3.5- to 8-inch diameter class in the control was over twice that of the cut blocks (1.35 ft^2/acre against 0.55 ft^2/acre), which is logical, as there were 2½ times as many ingrowth trees in the control.

Net growth for all species, consisting of ingrowth plus accretion minus mortality, for the 5-year period was:

	Cut	Control
	——*ft^2/acre*——	
Net growth:		
Accretion	+10.12	+17.75
Accretion on trees that died	+.03	+.09
Ingrowth	+.55	+1.35
Mortality	-2.45	-5.76
Accretion on trees that died	-.03	-.09
Net	8.22 (1.9 m^2 /ha)	13.34 (3.1 m^2 /ha)

DISCUSSION AND CONCLUSIONS

The typical young-growth forest on sites of high quality often contains too many trees, growing too slowly. Also, it often contains a disproportionate number of small trees of less desirable species. In fact, 66 percent of the trees in the small tree size class on the Experimental Forest are hardwoods and incense-cedars. The Forest also contains the more desirable sugar pine, Douglas-fir, and white fir, which in this size class number 2, 46, and 9 per acre, respectively (5, 114, and 22 per ha). Although, in the shelterwood block, some of these desirable trees, particularly Douglas-fir, were older suppressed trees of low growth potential, many were younger and had a high potential for increased growth.

Logically, a forest manager would want to reduce the number of less valuable hardwoods and incense-cedars and proportionally increase the more valuable pines and firs. Because these desirable species serve as a potential interim monetary return after the shelterwood is removed and before the reproduction grows to maturity, the manager also wants to know what the species proportions will be after logging, and the potential for survival and growth.

To increase the numbers of these desirable species, then, and because it is expensive to remove and dispose of this size of tree, 24 sugar pine, white fir, and Douglas-fir per acre (59 per ha) remained after logging. They represented a slight proportional gain in relation to other species in this size class. Only two of these trees per acre (five per ha) died from natural causes in the next 5 years. Two incense-cedars and one ponderosa pine per acre also died. The combined loss was less than that gained from ingrowth.

The only other natural mortality was that of ponderosa pine in the overstory shelterwood, and this was minimal. Of a total of 192 overstory trees, only 3 were lost in 5 years. Therefore, if the landowner wants to retain his shelterwood for some time, losses from natural mortality need not keep him from doing so.

Overall, the effect of shelterwood cutting and slash disposal on stand structure and species composition was to eliminate the 14- to 20-inch d.b.h. conifer component of the stand. A secondary effect was to reduce greatly the number of trees in both the largest and smallest tree size classes while only slightly changing the species composition of either.

In the control block, both the ponderosa pine overstory and the hardwood and tolerant conifer understory remained essentially intact. In this environment, natural mortality was decidedly different. Different species died from different causes. Suppression was the primary cause of death to sun-loving California black oak and ponderosa pine.

Ingrowth is of special interest because it indicates the trend of species composition. Shade tolerant tanoak, Pacific madrone, Douglas-fir, incense-cedar, and white fir compose fully 98 percent of ingrowth. Ponderosa pine and sugar pine amount to only 2 percent. In the undisturbed control, the forest of the future will be much different from the present one. It will consist of increasing proportions of shade-loving conifers and hardwoods. But in the cut blocks, the new environment created by cutting assures that the future forest will closely resemble the present one.

The discrepancy between estimates of seed production, which were lower from traps than from cone counts, has several probable causes. Douglas-fir, for example, is capable of producing viable seed as early as age 20, and young trees frequently bear a few cones. In these young trees, many seeds reach full size but are undeveloped internally because of lack of pollen (Allen 1942). Roy (1960) noted that larger trees also produce many apparently fully developed, but empty seed, owing to lack of fertilization. Differences between trap and cone counts also are caused by insects, chiefly the cone moth larvae (*Barbara colfaxiana* [Kearf.]) and the gall midge (*Contarinia* spp.), which either destroy seeds or cause them to adhere to the cone scales.

The discrepancy between counts applies to a lesser extent for white fir (Keen 1958) and other species, and is well illustrated in this study by the 1961 Douglas-fir and 1962 white fir seed crops. Estimates of 2100 and 9250 sound seeds were made from the two cone counts, respectively, but no seeds appeared in seed traps nor were any seedlings counted in regeneration surveys. Sound seeds from seed trap catches obviously give the best estimate of conifer seed production.

Overall, the proportion of sound seed was low. Even on this high site with near-ideal growing conditions, the young-growth trees in the shelterwood blocks produced only 49 percent sound seed. Ponderosa pine was highest in percentage of sound seed, but even in a bumper year this was only 58 percent.

The comparison of sound seed in the cut blocks and control emphasized the reproductive potential of the shelterwood method, not only for quantity of seed, but also for the larger number of species that produced it. In 3 years (1960-62), seven of the nine seed crops yielded by various conifer species resulted in sound seed in the shelterwood cutting, whereas only two species (ponderosa pine and Douglas-fir in 1960) produced sound seed in the control (as estimated from seed traps). The sound seed ratio of shelterwood to control was 9.2:1.

The probability that cone and seed production were stimulated by the shelterwood cut (a phenomenon noted by Williamson [1973] for Douglas-fir in the Oregon Cascades) is important: trees that would otherwise produce medium or even light seed crops of the various species could suffice for establishing adequate regeneration on prepared ground. Also, the short interval between adequate seed crops increases the applicability of the shelterwood method.

Ultimately, the success of a cutting method depends on establishing enough well-distributed seedlings of the desired species to meet management goals. This result is usually assured by proper choice of cutting method, adequate preparatory steps before the regeneration phase, and a certain amount of good luck.

Seed-to-seedling ratios are a good index to the success or failure of establishing a new crop of trees. In this trial, seed-to-seedling ratios in the shelterwood ranged from 8:1 for incense-cedar to 39:1 for sugar pine, and relative to other studies, demonstrated high seed efficiency for all conifer species. Of course, the slash-disposal-site-preparation operations greatly influenced seedling survival. Other reasons for the high seed efficiencies could have been favorable weather and low deer mice (*Peromyscus maniculatus*) populations. During the critical months of February through May 1960, precipitation was 10.5 inches more than Challenge's 30-year average, and temperatures were below normal. A rodent survey in the spring of 1961 indicated only 1.5 mice per acre (3.7 per ha) in shelterwood and nearby compartments.

The slash - disposal-site - preparation treatments helped immeasurably to reduce slash, bare the soil, lessen vegetative competition, and disturb the habitat of seed-eating rodents. Where the piling was delayed until late summer, the just-loosened soil not only helped cover the seeds, but facilitated faster and deeper root penetration by seedlings.

The initial stocking in the delayed-piling treatment was best for tolerant conifers and hardwood seedlings, and later for ponderosa pines. Tolerant conifer stocking consistently was poorest for the pile-immediately-after-logging treatment. In blocks where slash was piled in 1958 and seed germinated in spring 1961, this delay, and perhaps the crusting or recompaction of the soil, apparently was deleterious to root penetration by the tolerant conifers. Lack of scarification in the lop-and-scatter treatment left hardwood rootstocks intact. This favored hardwood sprouts–not enough were eliminated. Under such a treatment, Douglas-fir, incense-cedar, and other conifer seedlings are likely to be overtopped by the burgeoning hardwood sprouts.

Of the three slash-disposal treatments tested, piling just before a major seedcrop is best if the maximum number of seedlings is desired. Lop-and-scatter treatment, however, is 10 to 15 times less expensive.

The environment in the shelterwood strikingly favored regeneration, except for Douglas-fir, which regenerated better in the dense shaded control block (the seed-to-seedling ratio in the control was 9:1). In contrast, the seed-to-seedling ratio for ponderosa pine in the control (28:1) was more than twice that of the shelterwood. Also, ponderosa pine seedling mortality was 96 percent higher in the control.

Survival is only half the regeneration story. The other half is seedling height growth. Hardwood seedlings grow slowly; sprouts have a much faster rate of height growth. In the shelterwood, sprouts and white fir seedlings are tallest, followed by ponderosa pine and sugar pine. With time, some of the slower-growing Douglas-fir and incense-cedar seedlings may fall behind, but because of their shade tolerance, they will persist and may even prosper.

Growth of the merchantable shelterwood types and their response after cutting is often of major interest because it can determine the number of trees that should be left in subsequent applications of the method„ Without exception, the shelterwood trees were tall, full-crowned, and seemingly vigorous.

Nearly every species of most sizes responded to the shelterwood cut, and in basal area growth for the first 5 years after cutting, surpassed their counterparts in the control. Large Douglas-firs and white firs were exceptions, however, as they grew slightly better in the control. Of the larger shelterwood trees, sugar pine had the best basal area growth rate and responded more to cutting than any other species. Ponderosa pine rated next best, followed by Douglas-fir. As a whole, accretion was small, however, and was gained at the expense of the established seedlings. For this reason, and because small seedlings are least susceptible to logging damage, the shelterwood overstory should be removed early.

The shelterwood can be removed efficiently and with minor seedling losses. When 2 to 10 seed trees per acre (5 to 25 per ha) were removed carefully at Challenge, stocking of 29-month old seedlings fell by only 3.8 percent and density by 212 seedlings per acre (524 per ha; McDonald 1969a). Skidding production increased by 38 percent or 1247 board feet per hour over that in the original seedtree cutting (McDonald 1969b).

By 1965, revegetation of the shelterwood compartments was nearly complete and the forest of the future could be predicted. Ponderosa pine regeneration was abundant and well distributed; so were hardwood sprouts and seedlings. Throughout, an admixture of tolerant sugar pine, incense-cedar, white fir, and Douglas-fir seedlings stocked the ground. Also, residual saplings and poles, mostly Douglas-fir and incense-cedar, bolstered the tolerant conifer component of the stand.

The new timber stand will differ relatively little from the old. Ponderosa pine will be most abundant and again will dominate in the overstory. Tolerant conifers also will be present. A few hardwoods, especially California black oak, will reach into the overstory as well. Most hardwoods, however, will again be relegated to understory positions. Before the shelterwood cut, the forest was progressing toward the more tolerant mixed-conifer climax in which ponderosa pine is a lesser component (*table 1*). Ponderosa pine was not reproducing itself and the species composition of the stand was tending toward more and more tolerant conifers and hardwoods. Cutting interrupted this process, and allowed succession to begin anew with ponderosa pine. Thus the forest our children will enjoy will closely resemble that of our fathers.

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Oxford: 231:187x466(794):221.23
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