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Clearcutting and. Natural Regeneration ... Management Implications for the Northern Sierra Nevada

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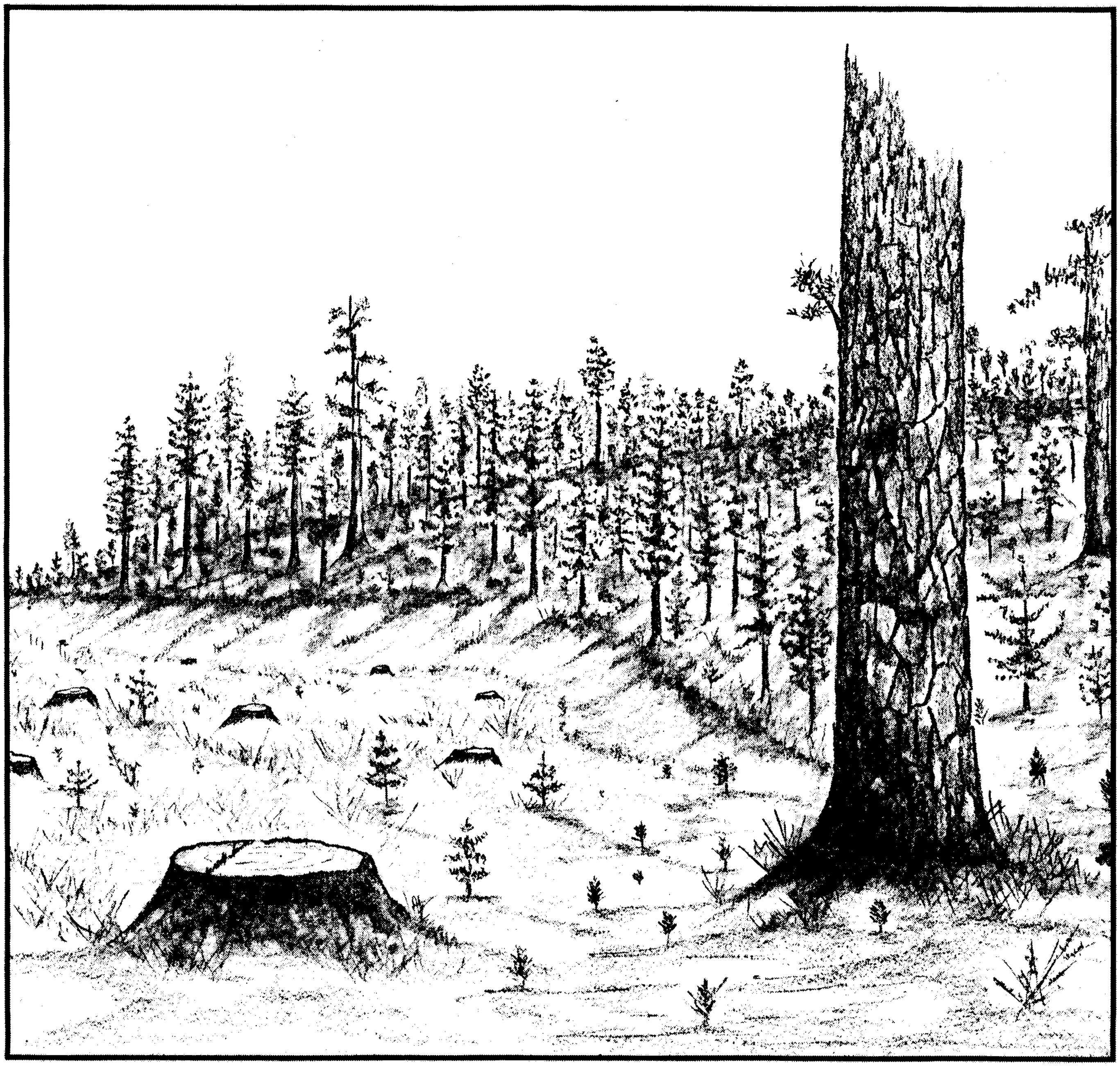

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Cover -- Conifer seedlings grow along the edge of a clearcutting in the northern Sierra Nevada, California. (Drawing by Bob Laacke)

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Clearcutting in stands of young-mature mixed-conifer and hardwood trees in north-central California is a relatively new method of silvicultural regeneration. It is increasingly practiced in the area because a biological basis for it exists. This basis is the persistent hardwood understory beneath the conifer canopy that adversely affects conifer regeneration and growth.

From 1963 to 1977, a series of clearcutting experiments were done on the Challenge Experimental Forest in Yuba County, California. The experiments were designed to test an approach to clearcutting in which 892 acres (361 ha) were cut in 41 compartments ranging from 7 to 60 acres (3 to 24 ha). More than 316 acres (128 ha) were designated for the study of natural regeneration. Slash disposal, site preparation, and rodent surveys, however, were done on acres that were regenerated by both artificial and natural techniques. Because artificial regeneration is discussed in another paper (Neal 1975) and not included here, the acreages expressed are not additive.

Broadcast burning, windrow and burning, rodent trapping, and seedfall surveys were done intermittently from 1964 through 1977. Broadcast burning was studied on 375 acres (152 ha) and windrow and burning on 576 acres (233 ha). Rodent populations were surveyed at various times on 440 acres (178 ha), natural seedfall was measured on 68 acres (27 ha), and natural regeneration was surveyed on 316 acres (128 ha). Surveys of clearcuttings having natural regeneration began in 1964 and ended in 1982.

This report is the product of 20 years of research on forest regeneration after clearcutting in the young-mature mixed-conifer and hardwood forests of north-central California. It describes an approach to clearcutting, suggests the management implications of this approach, and offers recommendations for reducing delays in regeneration.

CHALLENGE EXPERIMENTAL FOREST

Research done on the Experimental Forest applies to about 1.5 million acres (607,035 ha) of highly productive timberland along the west slopes of the Sierra Nevada. These young-mature mixed-conifer and hardwood forests at low- to mid-elevations form a transition zone between the chaparral and mixed hardwoods at lower elevations and the mixed-conifer forest at higher. Within this zone, and often in complex mixture, the California Black Oak, Douglas-fir-Tanoak-Pacific Madrone, Pacific Ponderosa Pine, and Pacific Ponderosa Pine-Douglas-fir forest cover types are found (Eyre 1980). A chaparral type also is present. Conversion of the mixed hardwood and conifer stands to conifers alone is both difficult and costly.

The hardwoods, often of sprout origin, compete vigorously with young conifers and must be controlled. Reducing sprout numbers by knocking down all remaining trees in conjunction with slash disposal generally is cheaper and more effective than girdling and poisoning trees or treating cut surfaces or sprouts with herbicides. Flattening unmerchantable trees puts a large amount of fuel near the ground and leads to broadcast burning.

A valuable attribute of the Experimental Forest is its high site. Soils often are more than 100 ft (30 m) deep, mean annual temperature is 55° F (13° C), and annual precipitation averages 68 inches (1727mm). These conditions ensure that vegetation is abundant and fast-growing. Indeed, the dominant species, ponderosa pine (*Pinus ponderosa* Doug]. ex Laws. var. *ponderosa*), will average 140 ft (43 m) in height in 100 years (Arvanitis and others 1964). Trees 170 ft (52 m) tall at this age are not unusual.

Other tree species on the Experimental Forest are Douglas-fir (*Pseudotsuga menziesii* [Mirb.1 Franco), sugar pine (*Pinus lambertiana* Dougl.), California white fir (*Abies concolor* var. *lowiana* [Gord.] Lemm.), and incense-cedar (*Libocedrus decurrens* Torr.). Hardwoods, principally California black oak (*Quercus kelloggii* Newb.), tanoak (*Lithocarpus densiflorus* [Hook. and Am.] Rehd.), and Pacific madrone (*Arbutus menziesii* Pursh), are scattered throughout as individual trees, clumps, or groves (*fig. 1*). Generally, trees larger than 3.5 inches (8.9 cm) in diameter-at-breast-height (d.b.h.) number 248 per acre (613/ha) and contain about 270 ft^2 (62 m^2) of basal area.

The stands are classified as young-mature. Dominant and codominant trees are about 120 years old. They number about 35 per acre, 70 percent of which are ponderosa pine. Trees in these crown classes produce more than 80 percent of the cones in a seed crop (McDonald 1973, 1976b).

Shrub species also grow on the Experimental Forest. The most abundant are whiteleaf manzanita (*Arctostaphylos viscida* Parry) and deerbrush (*Ceanothus integerrimus* Hook. and Am.). When logged, the clearcut compartments show no signs of manzanita and deerbrush. Killed long ago by the shady forest, the shrubs died and decayed until not a trace remained above ground. Below ground, however, thousands, if not millions of viable shrub seeds per acre awaited conditions that would stimulate germination (Quick 1956).

Figure 1--This young-mature stand on a high site on the Challenge Experimental Forest, Yuba County, California, typically has mostly ponderosa pine in the overstory with shade-tolerant conifers and hardwoods beneath.

CLEARCUTTING

Layout and Logging

In the summer of 1962, 12 circular units of 2, 5, and 10 acres (0.8, 2.0, and 4.0 ha) were cut on the Experimental Forest. Each size was replicated twice on a northeast aspect and twice on a southwest aspect. Slopes varied from 5 to 51 percent on the southerly aspect, and from 10 to 35 percent on the northerly aspect. Positions of the clearcuttings varied from near the top to near the bottom of the slopes. By adjusting slope measurements to horizontal distances, each cutting unit became a perfect circle.

Logging began in January 1963 and continued intermittently, as weather permitted, until mid-June. Other than in the small landings, which were located within the cutting units, soil compaction appeared to be negligible.

Clearcuttings after 1963 were more conventional in shape. Most were nearly rectangular and followed natural boundaries, such as streams or ridgelines and, occasionally, roads. They varied in size from 15 to 60 acres (6 to 24 ha). Each year several of various sizes were cut.

Slash Disposal and Site Preparation

After merchantable logs were skidded, remaining stems were flattened by a large tractor-dozer, usually in late spring. A few California black oaks, too large to be pushed over, had to be felled. The downed trees were not deliberately crushed after felling, although some crushing took place incidentally as skidding and pushing progressed. Pushing was accomplished at a rate of about 5 acres (2 ha) per tractor-day.

Slash Weight

The weight of residual slash and unmerchantable trees after logging in young-mature stands on high sites tended to be high (*fig. 2*). Once on the ground, the slash was sampled and dry weights were determined.

In clearcuttings on the southwest aspect, slash weights ranged from 53 to 89 tons per acre (119 to 200 t/ha), averaging 74 tons per acre (166 t/ha). Hardwoods made up 31 percent of the slash, conifers 45 percent, and litter and humus 24 percent (Sundahl 1966). On the northeast aspect, where more California white fir and sugar pine grow, residual weights ranged from 88 to 110 tons per acre (197 to 247 t/ha), averaging 97 (217 t/ha). Of this total, hardwoods constituted 29 percent, conifers 45 percent, and litter and humus 26 percent. Although the amount of residual material differed between the two aspects, the percentage makeup among hardwoods, conifers, and litter was similar. Conifer cull logs contributed only 5 percent to total slash weight. About 66 percent of the material on each aspect was fine fuel--less than 4 inches (10 cm) in diameter. The high percentage of fine fuel and low amount of large cull logs were conducive to broadcast burning.

Broadcast Burning

Altogether, 20 compartments ranging from 2 to 46 acres (0.8 to 18 ha) and totaling about 375 acres (152 ha) were broadcast-burned from 1963 through 1966. A prescription stating acceptable conditions of fuel moisture, temperature, and weather was formulated (McDonald and Schimke 1966) before slash was burned. When the prescribed conditions are

Figure 2--A typical clearcutting after logging and pushing on the Challenge Experimental Forest, Yuba County, California. Large amounts of evenly distributed material facilitate broadcast burning.

met, slash can be burned in spring, winter, or fall. Fall burns generally are favored over spring and winter burns because they remove the most fuel, consume more heavy fuel, and are soaked "dead out" by winter storms. Winter and spring burns consume fuels that have been wetted and at least partially dried. Heavy fuels remain wet, except for outer surfaces and, therefore, less of them burn.

The problem with fall bums is that the first rain of the season could last for a week or more, wet the fuels, and thereby result in impossible burning conditions.

A storm in mid-October 1963, which deposited 2.85 inches (72 mm) of precipitation, set the stage for the first broadcast burning trial. By October 22, fuel moisture sticks indicated that fuels in the clearcuttings were drying rapidly, while those on the forest floor were wet. All conditions in the prescription were met and burning was scheduled.

Slash was ignited by drip torches. Weather during the first day was suitable and 19 acres (8 ha) were burned without incident. Despite a favorable weather forecast, an unexpected storm arrived that night and halted burning. Another 10-acre (4.0-ha) clearcutting was successfully broadcast-burned several days later. Again, a storm curtailed burning operations, although most of the remaining cutting units were burned partially. Only 29 of 68 acres (5 units of 12), therefore, were broadcast-burned successfully in 1963. The remaining cutting units were unacceptably burned and the fuels that remained were bunched into piles and burned later.

For broadcast burning in the 1964-66 compartments, weather continued to be a critical factor. The fall 1964 burns were drowned out by the first storm of the season. The fuels became so wet that they never were dry enough to be burned in the fall. Long dry spells in February and April, however, permitted winter and spring burning. The broadcast burns planned for fall 1965 also were washed out by the first storm. These compartments and those cut in 1966 totaled 195 acres (79 ha). All were satisfactorily burned in the fall of 1966 when the weather was nearly ideal.

For the acceptable broadcast burns, between 70 and 90 percent of the fine fuels below 4 inches (10 cm) in diameter, and slightly less than 50 percent of the coarse fuels above 4 inches were consumed (Hall 1967) (*fig. 3*). The overall fuel reduction by compartments ranged from 68 to 84 percent (McDonald and Schimke 1966).

Proportion of area burned and intensity of burning also are noteworthy. Data from the successful burns on the Experimental Forest indicated that broadcast burning left about 42 percent

Figure 3--When the weather cooperates, broadcast burning on the Challenge Experimental Forest, Yuba County, California, removes most of the smaller fuels and much of the larger.

of the area unburned, 53 percent burned lightly, and only 5 percent burned sufficiently to remove the entire litter layer and alter the structure of the uppermost soil layers (Neat 1975). A highly variable seedbed was formed.

Broadcast burning generally has been found to have no consequential effect on physical properties of soils in the northern Rocky Mountains (Roe and others 1971). And it has statistically nonsignificant effects on both physical and chemical soil properties in the western Cascade Mountains of Oregon and Washington (Kraemer and Hermann 1979).

Erosion is not a problem on the Experimental Forest either. Even where bared, the deep clay-loam soils have high internal capacity for water storage, and precipitation infiltrates fairly rapidly. Needles, twigs, pieces of charcoal, holes and furrows resulting from pushing, and charred logs impede the flow of surface water. After the first year, woody pioneer species increasingly cover the area, thereby checking erosion even more.

The total cost of slash disposal and site preparation by broadcast burning depends upon the number, size, shape, and distance between the units to be burned. Topography also can increase costs in proportion to increases in slope and roughness of terrain. Weather always is a factor in determining costs. The amount of men and equipment on the job is predicated on the entire acreage to be burned. Should adverse weather cause only one-half of it to be burned, most of the costs remain. These are then spread over only one-half the acreage, increasing costs per acre.

The cost of broadcast burning (1966 rates) varied from $8.42 per acre ($20.81/ha) for 75 acres (30 ha) to $36.24 per acre ($89.55/ha) for 28.5 acres (12 ha) (Hall 1967). Current rates have increased greatly. A good job of broadcast burning in 1981 cost about $125 per acre ($309/ha).

Windrow and Burning

Windrow and burning is the slash disposal and site preparation technique most commonly used in the northern Sierra Nevada on other than steep ground. A heavy tractor, usually with brush rake, windrows the slash (*fig. 4*). Costs in 1981 were $80 to $90 per acre ($198 to $222/ha) for tractor piling, with a burning cost of $25 to $35 per acre ($62 to $86/ha).

Advantages of the windrow and burn method are that almost all of the slash is pushed into the windrow, leaving a mineral soil seedbed. After piling, the surface of the ground is rough. Thousands of little earthen dams and, indeed, the windrow itself, check surface erosion. A windrow and burn compartment is safer to burn than one with broadcast slash because the

Figure 4--After windrowing slash in the northern Sierra Nevada, a mineral soil seedbed is available for regeneration.

surrounding forest can be much wetter, and the windrows still readily burnable. On the Experimental Forest, the forest floor usually was soaking wet before the windrows were ignited. Once lit, fire tends to spread the length of the windrows, particularly if on sloping ground. Ignition costs are low, and because the chance of escape is almost nil, standby crews are small. And the concentrated slash burns hot, thereby reducing smoke and air pollution.

A possible disadvantage of windrow and burning is that the high temperatures from the concentrated fuels cause clay particles to fuse into larger particles. Water percolates rapidly through the spaces between the large particles and the effect on plants may be likened to that in a desert. No conifers and only a few herbaceous species grow in the portions of the windrows that are hot-burned. After 8 to 10 years, however, the clay particles break down and ponderosa pine seedlings can become established. Less than 10 percent of an area is burned hot enough for clay particle fusion to become serious. The area affected is long and narrow and, because pines often become abundant in the rich loose soil on either side, the amount of area lost to the growing of trees is small.

Seed fall

Natural seedfall of several of the more valuable conifer species in California has been studied for years (Barrett 1966, Curtis and Foiles 1961, Fowells and Schubert 1956, Roy 1960). In general, most sound seeds are dispersed within a distance of 1½ to 2 times the average height of the dominant and codominant trees. Foresters have observed, however, that natural regeneration is almost totally lacking in some clearcuttings, absent in portions of others, and abundant in still others. In some instances regeneration becomes established in locales with no apparent seed source. Obviously, seeds of some species are being distributed farther than anticipated. A basic need for information on seed flight distance of several young-mature conifer species in the northern Sierra Nevada was recognized.

To help fill this need, the eight compartments of 1963 that resembled perfect circles were clearcut (*fig. 5*). The circular shape facilitates measurements of distance from the seed source at the forest edge.

To quantify seedfall at various distances into the clearcuttings, each clearcut was divided into concentric zones. Each zone extended inward toward the plot center for 100 ft (30 m), except the centermost. The number of zones in each size of circular clearcutting (radius of cutting shown in parentheses) was: 2 acres (166 ft)--2 zones; 5 acres (263 ft)--3 zones; and 10 acres (372 ft)--4 zones.

Foot-square (0.09 m^2) seed traps were used to sample seedfall. They were located on scaled maps that showed their placement in each clearcutting. Cutting tests determined seed soundness.

Seedfall was studied for 4 years, from 1964 through 1967. During this time, ponderosa pine produced three seed crops that ranged from light to heavy. Douglas-fir yielded three light seed crops, incense-cedar two light crops, and California white fir two medium crops.

Most seeds were distributed in the fall on days when winds were from the northeast and the atmosphere was warm and dry. When warm temperature and low humidity combine to lower the moisture content of cones and scales, a shower of seeds takes place. If this weather continues, most of the seeds fall, often within a week. If it does not last long enough, remaining seeds dribble out in warm weather between storms from the southwest, or again under the influence of northeasterly winds.

Seedfall estimates varied from 76 to 40,691 sound seed per acre (188 to 100,547/ha) for a single species in a given year

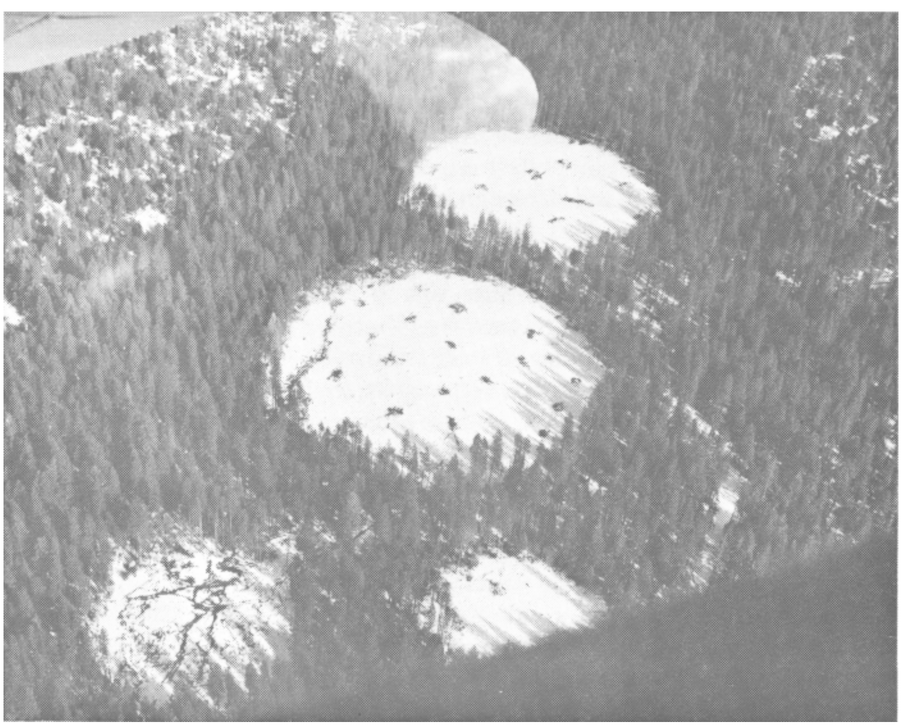

Figure 5--Aerial view of two 10-acre and two 2-acre circular clearcuttings on the Challenge Experimental Forest, Yuba County, California.

(McDonald 1980). Seedfall decreased successively in each zone with increased distance from the forest edge. The highest seedfall was 67,488 sound seed per acre (166,763/ha) in the outer zone of the 2-acre (0.8-ha) clearcutting, and the lowest 2520 per acre (6227/ha) in the innermost zone of the 5-acre (2.0-ha) opening. Douglas-fir seed carried up to 300 ft (92 m) into the 10-acre (4.0-ha) clearcuttings, incense-cedar reached 200 ft (61 m), and at least some seeds of California white fir and ponderosa pine were dispersed well into the innermost zone (350 ft or 107 m). Altogether, from 89 to 100 percent of each species' sound seed fell within a distance of 1 ½ times the height of the average dominant tree or 200 ft (61 m) into the clearcutting (McDonald 1980).

Rodent Control

The principal rodents on the Experimental Forest are deer mice (*Peromyscus maniculatus*). Nocturnal and inconspicuous, they seldom are seen and their effect on natural regeneration in clearcuttings in this area is not known. Deer mice in California feed largely on seeds (Jameson 1955), which often are coniferous. In Oregon, mice and shrews, but mostly deer mice, destroyed 40 percent of the Douglas-fir seed crop (Gashwiler 1970). In Montana, deer mice populations were affected by the previous year's ponderosa pine and Douglas-fir seed crops (Schmidt and Shearer 1971), implying that the conifer seeds were a significant portion of their diet.

Populations of deer mice in mature forests of the Sierra Nevada are relatively stable at about 5 mice per acre (12/ha) (Ingles 1965). Clearcuttings, however, produce environments favorable as mice habitats. Supplies of seeds and other foodstuffs become abundant and new areas for shelter and reproduction are provided. Under normal conditions, deer mice produce up to four litters of three to six young each year. As mice increasingly reproduce and immigrate into clearcuttings, populations rapidly expand.

Population Size

Before natural regeneration could be evaluated, information on the size of the rodent population and its potential for depredation was needed. In the newly made clearcuttings of 1963, for example, rodent surveys of March 10-13, 1964, averaged 9.2 mice per 100 trap-nights, a population large enough to mandate rodent control measures when direct seeding ponderosa pine (Wetherbee 1964). In the spring, warmer parts of clearcuttings probably are preferred habitats. Centers of clearcuttings and sunny edges are more desirable than cold frosty areas along southern edges that remain shaded by standing timber.

Potential for Damage

The potential for depredation of ponderosa pine seed by deer mice was evaluated in a study on the Experimental Forest with seed having radioactively labeled (Scandium 46) seedcoats. Some seeds were placed near the forested edge of clearcuttings and others near the center. Seeds were also positioned on the surface and others buried about' Y2 inch (1.8 cm) deep. Movement and fate of the seeds was traced with a scintillator (*fig. 6*). Even seeds that were eaten were detected easily because the radioactive seedcoats were left behind.

Figure 6--Movement of radio-tagged seeds is traced with a scintillator.

Movement of the seeds into and out of the soil was studied. Some buried seeds became uncovered and even a few became buried again. Likewise, some surface seeds were buried, a few even twice. Surface seeds were more vulnerable than buried seeds: 68 to 80 percent of surface seeds were destroyed compared with 35 to 70 percent of buried seeds. In one instance, a seed was moved a considerable distance and buried, then dug up and eaten on the spot several days later. Of the seeds moved (and usually destroyed) by rodents, 67 percent were within 1 ft (0.3 m) of their original position, 90 percent within 5 ft (1.5 m), and 98 percent within 8 ft (2.4 m). One seed was moved 17 ft (5.2 m). In general, depredation of seeds was greater in the interiors of clearcuttings than near the edges.[1]

That deer mice, and in some instances large numbers of them, were present and actively eating conifer seeds in the clearcuttings is a safe assumption. During the heavy California white fir and ponderosa pine seed years of 1965 and 1968, mice probably did not have as great an effect as in years of lighter crops. The effect of depredation by deer mice on the lower amounts of conifer regeneration near the center and westerly portions of most of the cutting units is not known. But the presence of deer mice should not be ignored.

[1] Unpublished data on file, Pacific Southwest Forest and Range Experiment Station, Redding, California.

NATURAL REGENERATION

Conifers

Adequacy of natural regeneration was evaluated periodically for 19 years. The evaluation was subjective and took into account numbers of conifer seedlings by species, distribution, and a general assessment of vigor. Number and distribution of hardwood trees and woody shrubs also were assessed. Twenty-four clearcut units ranging from 2 to 60 acres (0.8 to 24 ha) were surveyed annually for the first 2 to 4 years after cutting and periodically thereafter to age 15.

Regeneration categories and rating criteria were these:

Adequate or better--Seedlings no farther apart than 12 ft (3.7 m) and well distributed throughout the compartment.

Marginal--Spacing of seedlings near 12 ft (3.7 m) but distribution clumpy.

Failure--Large areas devoid of seedlings.

The marginal category was similar to a plantation not understocked enough to require starting over, but one that needed interplanting. Compartments rated adequate tended to be overstocked and to require precommercial thinning, those deemed failures to need new site preparation and artificial regeneration. Regeneration adequacy and number of clearcut units in each category were adequate 7, marginal 13, and failure 4. Acreage of adequately stocked clearcuttings ranged from 5 to 60 acres (2 to 24 ha), marginally stocked from 2 to 42 acres (0.8 to 17 ha), and failures from 2 to 10 acres (0.8 to 4 ha). Aspect, slope, or position of clearcutting on slope showed no trend as to why regeneration was adequate or inadequate in a given clearcutting.

Amount and distribution of natural regeneration followed the general pattern, as discussed earlier for seedfall. Regeneration was most abundant near the forest edge and least abundant near the center. It also was best in the northeast quadrant, extending in a pie-shaped wedge to near the clearcut center. In addition to the northeast quadrant, a shallow wedge of increased regeneration also was observed in the southwest quadrant in many clearcuttings. Westerly portions of most clearcuttings tended to have fewer conifer seedlings than other portions.

Adequately stocked clearcuttings, although having less conifer regeneration near the center and in westerly portions than elsewhere, nevertheless had seedlings distributed in adequate numbers throughout. One of these was a 60-acre (24-ha) unit that had well over a visually estimated 1000 seedlings per acre (2471/ha) along the eastern edge and about 500 seedlings per acre (1235/ha) near the center. Another clearcut unit had at least 3000 seedlings per acre (7413/ha) with fairly even distribution throughout.

Cutting units rated as failures generally had a few conifer seedlings near the forest edge and an occasional seedling elsewhere. Density was rated at less than 100 seedlings per acre (247/ha).

The adequacy rating in each clearcutting tended to be similar, in general, between the first and last surveys. On high sites such as those on the Experimental Forest, reinvasion of disturbed ground is rapid and complete, and only the first conifer seed crop stocks the ground. Seeds from subsequent crops fall into microsites already occupied by conifer seedlings or competing vegetation. In a case history of six clearcuttings intensively sampled to quantify plant succession, total plant species numbered 50 to 57 per acre (124 to 141/ha) and total number of plants 75,000 to 215,000 per acre (185,325 to 531,265/ha) 5 years after cutting and windrow and burn site preparation.[2] Mean number of plants was 142,721 per acre (352,664/ha) with standard error of 21,496 per acre (53,116/ha). Mortality of ponderosa pine and white fir seedlings is high the first growing season and decreases rapidly thereafter. After 2 to 3 years, early seedling losses from the principal causes--drought, damping-off fungi, cutworms, and birds-are mostly over. Should overtopping by competing vegetation take place, most conifer seedlings, including ponderosa pine, persist in partial shade and even live for a few years. For these reasons, regeneration counts did not change much during the 19 years of evaluation.

Mortality of ponderosa pine and California white fir seedlings followed the general pattern of large losses the first year and a rapid decrease in mortality in successive years. The few incense-cedar and Douglas-fir seedlings that got started in the clearcuttings generally survived well.

Browsing by deer, although of minor consequence overall, affected height growth of some ponderosa pine seedlings. After site preparation by either broadcast burning or windrow and burning, large amounts of nutrients that have accumulated in living and dead organic material are released. This flush of nutrients affects the woody and herbaceous vegetation for the first year and also the second to a lesser extent. The chief effect is that the tender shoots and new leaves of nearly *all* plants become palatable, including manzanita, tanoak, poison-oak, and others that usually are untouched. Not only is the new vegetation nutritious, it also is succulent. Evaporation of moisture from the soil and transpiration by vegetation are relatively low. Plants in the clearcuttings, especially in the first year, remain green in late fall when most other vegetation elsewhere is hard and dry.

Deer browsing in the clearcuttings increased as summer ended. By late October 1965, only nubbins of lesser vegetation remained, but pine seedlings were yet untouched. Browsing damage was noted first on November 24. By December 30, more than 80 percent of ponderosa pines in three units near the ridgetop on the northeast aspect were damaged. Apparently, the ridgetop was a travel route for deer moving to lower elevations. In some cutting units, damage was spotty, groups of seedlings were browsed in places; in others, single pines or a

[2]Unpublished data on file, Pacific Southwest Forest and Range Experiment Station, Redding, California.

line of pines were damaged. Few seedlings were killed by deer and nearly all developed a new leader the next year. By losing a year of height growth, browsed seedlings had one strike against them in the race for dominance with the woody shrubs.

Height growth of ponderosa pine seedlings ranged from good to poor depending on many variables, but mostly on the degree of competition from woody shrubs or other conifer seedlings. Fourteen-year-old pine seedlings, growing in dense manzanita, for example, ranged in height from 4 to 14 ft (1.2 to 4.3 m) with less leader growth each year as their general health and vigor declined.

Woody Shrubs

Stocking of whiteleaf manzanita and deerbrush was high initially and continued high throughout the study (*fig. 7*). For the compartments broadcast burned in 1965, density of whiteleaf manzanita and deerbrush averaged 6523 9-year-old plants per acre (16,118/ha) (McDonald 1976a). In all or portions of most other compartments, shrub density was high or even extremely high. In the compartments rated as adequately stocked with conifer seedlings, several contained solid masses

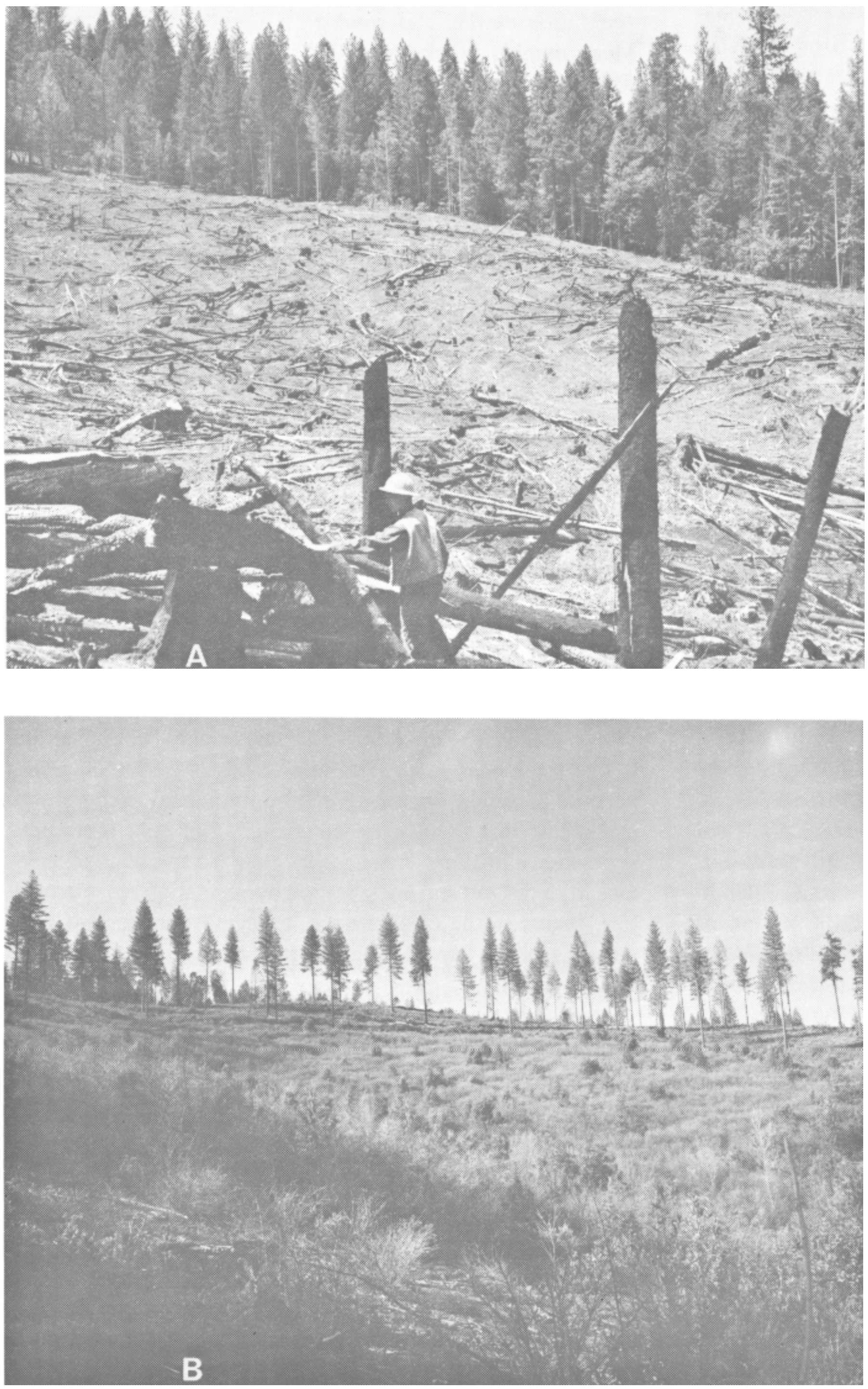

Figure 7--The western portion of a 10-acre clearcutting in 1964 (*A*) and 1977 (*B*) on the Challenge Experimental Forest, Yuba County, California. In *B* , a few clumps of hardwoods and occasional ponderosa pines grow among the shrubs. The uncut forest has become a seed-tree cutting.

of shrubs from which conifer saplings protruded. In portions of several other clearcuttings, pine seedling density was high and shrub density low. In one compartment, however, shrub density was uniformly low throughout.

Hardwoods

Hardwood regeneration consists of stump sprouts that number up to 100 per stump, seedling sprouts that average 1 to 4 per root crown, and seedlings that usually are single stems. Relative height growth potential is high for stump sprouts, moderately low for seedling-sprouts, and low for seedlings. Stocking of hardwood regeneration after clearcutting was spotty and density was low. Stump sprouts were scattered throughout and, where present, outgrew all other vegetation. Distribution of seedling sprouts was extremely clumpy and tended to be concentrated where a California black oak or tanoak seed tree had been before cutting. Hardwood seedlings were scanty, consisting of a few tanoak seedlings near the forest edge, and a few Pacific madrone seedlings scattered throughout. Birds apparently transported seeds and were responsible for the wider distribution of madrone.

MANAGEMENT IMPLICATIONS

Slash Disposal and Site Preparation

The condition of the seedbed has a major influence on regeneration. A detailed study of seedbeds formed in the broadcast-burned compartments showed that while broadcast burning improved a seedbed not otherwise disturbed, mechanical disturbance (windrowing) developed the best seedbed for establishment of ponderosa pine seedlings (Neal 1975).

One criterion of good seedbed condition is absence of competing vegetation. Seeds of woody shrubs stored in the duff and upper soil layers (Quick 1956) may number more than 2 million per acre (4,942,000/ha). Mechanical site preparation scoops much of these layers into windrows where they usually are burned. Broadcast burning, however, leaves substantially more of an area with at least some litter and duff and generates conditions that are near ideal for the breaking of dormancy of some shrub seeds. For varnishleaf ceanothus (*Ceanothus velutinus* var. *laevigatus*) in western Oregon, one study indicated that broadcast burning of logging slash stimulated a larger number of seeds to germinate (average, 8305/acre) than did burning of mechanically piled slash (average, 1568/acre) (Gratkowski 1962).

A disadvantage of broadcast burning is that it almost always takes place after the conifer seeds, which are intended to restock the land, have fallen. Consequently, a substantial amount of seeds, or even seedlings if the burn is delayed too long, are consumed. But if slash is windrowed, the area (seedbed) usually is prepared during the summer before seedfall begins. The only seeds burned are those in the windrows. Mechanical site preparation, moreover, destroys or disrupts almost all of the deer mouse habitat, especially breeding and resting areas. Although the windrows provide shelter, they lack food, and mice foraging in the open spaces between them are susceptible to predators. In broadcast burning, nearly all deer mouse habitat remains intact and the population is affected little. In some instances, therefore, an intact deer mouse population is forced to feed on a seed supply greatly reduced by burning.

Broadcast burning frequently affects the species of woody shrub that becomes most abundant. Noted visually in other compartments on the Experimental Forest and mentioned in the literature (Gibbens and Schultz 1963), ceanothus species are favored more by broadcast burning, and manzanita more by mechanical site preparation. Because manzanita grows slightly slower in height and crown width in the environment of the Experimental Forest, mechanical site preparation could give ponderosa pine seedlings a slight short-term advantage in the windrowed areas. Long-term gains are questionable, however, because manzanita is more severe in its competitive effect on height of pine reproduction than ceanothus (Dahms 1950).

Of the many variables in this silvicultural system, broadcast burning probably contributes most to the variation of natural regeneration in clearcuttings. This form of burning can be an effective technique for slash disposal. And, when the weather cooperates, direct costs can be low. Broadcast burning, however, does not modify the environment enough to adequately reduce the competitors and consumers common to the forest types in this study.

Regeneration

To be successful, natural regeneration of mixed-conifer and hardwood stands in clearcuttings in the northern Sierra Nevada depends on several interacting variables. Slash must be largely removed from the area and a large expanse of bare mineral soil present. Seedfall must be heavy, well distributed, and prompt, or favorable microsites will already be occupied by undesirable vegetation. Once on the ground, the seed must not be consumed by animals and birds nor destroyed by fire, frost, or other agents. Conifer seedlings need to become established and grow rapidly, free of severe competition from conifer counterparts or woody vegetation.

Different species of conifer seedlings fare differently in clearcuttings. The bright, warm, open environment favors the establishment of ponderosa pine, and California white fir to a lesser extent, but not Douglas-fir or incense-cedar. Few seedlings of the latter two species are present in the clearcuttings today, and then only near the shaded forest edge.

Although the initial clearcut environment is suited to establishment of California white fir seedlings, high mortality indicates that the subsequent environment is less than ideal. Part of the reason could be that white fir is not as competitive with the woody shrubs of the Experimental Forest as is ponderosa pine. Maximum daily water potential of 4-year-old white fir seedlings in a clearcutting having moderate shrub density was - 22 bars; for ponderosa pine of similar age, -- 17 bars.[3] This difference probably should be expected. California white fir cannot control stomatal aperture as well as ponderosa pine. Also, white fir is at the lower end of its elevational range.

As stated earlier, the seedbed produced by broadcast burning is highly variable. Seedfall, both in frequency and magnitude, also is variable. Both are mostly beyond the practical control of the silviculturist. Windrowing and burning slash gives more control over seedbed variability. Rodents, chiefly deer mice, can be more of a problem after broadcast burning than after windrowing. Rodenticides can be used, but population dynamics are such that control often is limited in duration and effectiveness. Seeds of woody shrubs are numerous after both broadcast burning and windrow and burning. These seeds and resultant plants plague the forester almost from the time the conifer seeds germinate.

The strong adverse effect of the woody shrubs continues after conifer seedlings have become established. The shrubs' many adaptations to a wide range of environments are expressed in their physiology and morphology (McDonald 1982). Shrubs tend to grow taller and wider than young pines, and often are better suited to attain dominance in early succession than are conifer seedlings.

Repeated observations have shown that the clumpy distribution of conifer seedlings in clearcuttings is partly a function of chance. Seedlings that survive to become crop trees become established in areas where woody shrubs are few or lacking. These areas often are large enough to allow several or even a group of trees to become established. Elsewhere, occasional seedlings grow tall enough to survive before shrub crowns coalesce. Where the woody shrubs are dense and vigorous, few conifer seedlings survive. Those that do, suffer from insects and drought and seldom achieve the productivity inherent in the site. Controlling the density and vigor of woody shrubs is one part of the clearcut and natural seed system that can be practical, although costly.

Recommendations

For the silvicultural package as a whole, many variables affect the successful establishment and early growth of conifer seedlings. Most cannot be controlled sufficiently to ensure regeneration success with the degree of timing and consistency demanded by foresters. Even with additional expenditures for rodent control and other measures, variation of natural regeneration likely will be high. Although the variation may not be beyond the control of the manager, knowledge of its presence is valuable.

To the forest manager, time is money. Delays in establishing a forest stand or in achieving a high growth rate are costly. A more reliable way to avoid these delays in regenerating clearcuttings and to gain better stocking control is to windrow and burn slash, plant conifer seedlings, and control woody shrubs at plantation age 2 and again at age 4, as necessary.

[3]Unpublished data on file, Pacific Southwest Forest and Range Experiment Station, Redding, California.

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In the young-mature mixed-conifer and hardwood forests of north-central California, a dense and persistent hardwood understory competes with the conifers for space, nutrients, and water. Clear-cutting with intensive site preparation often is the most appropriate silvicultural regeneration method. This report, the result of 20 years of research on the Challenge Experimental Forest in Yuba County, California, evaluates one approach to clearcutting. Topics discussed are broadcast burning, windrow and burning, seedfall, rodents, woody shrubs, seedling stocking, and early growth of conifers. Variation in seedbed and seedfall, uncertainty of amount of rodent damage, and competition from woody shrubs can result in inconsistent and unpredictable amounts of natural reproduction. Windrow and burning of slash and planting of conifer seedlings are recommended alternatives to broadcast burning and natural seeding.

Retrieval Terms: cutting methods, slash disposal, natural regeneration, ponderosa pine