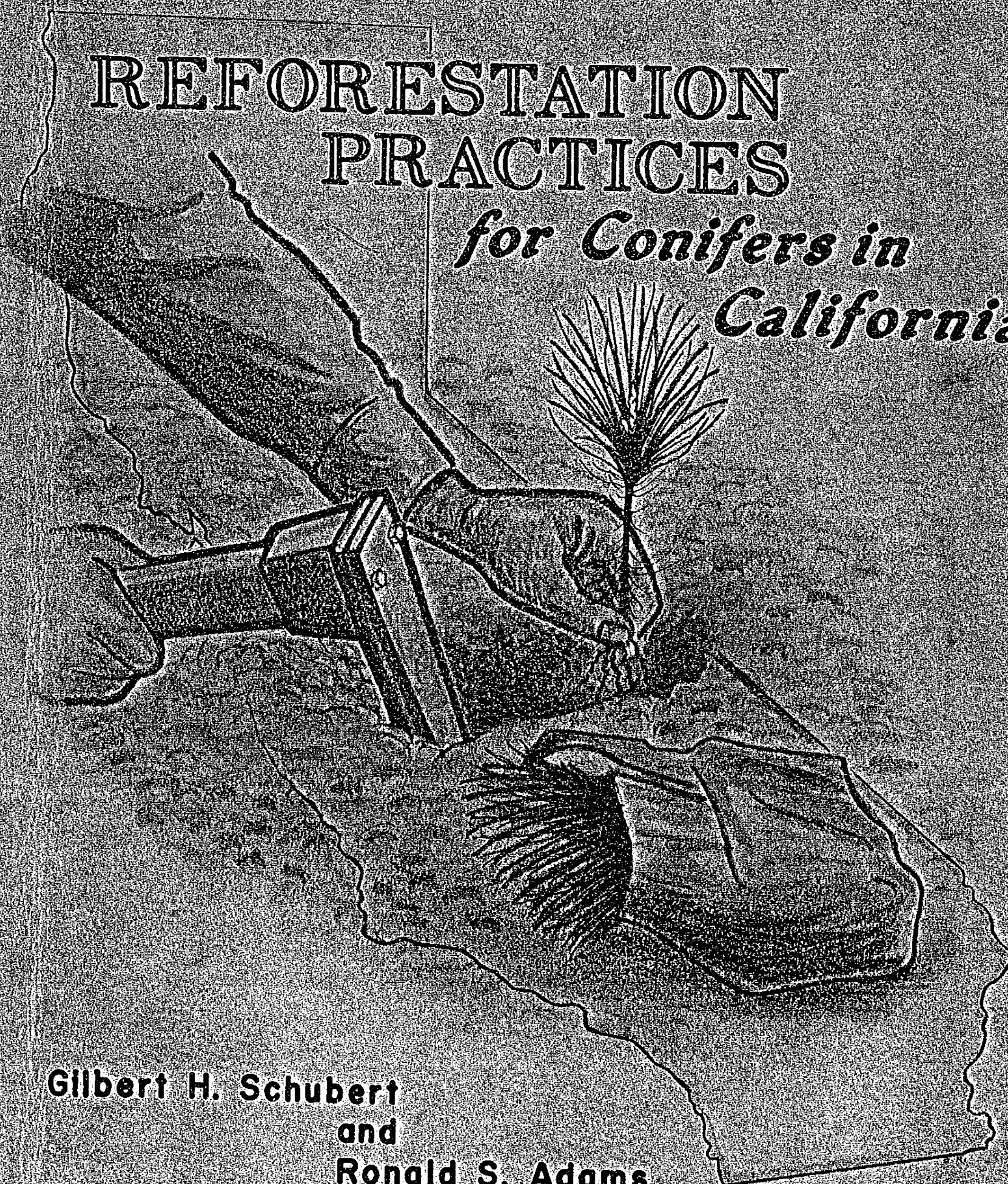
REFORESTATION PRACTICES *for Conifers in California*



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REFORESTATION PRACTICES FOR CONIFERS IN CALIFORNIA

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The pesticides reported on and recommended in this publication were registered for the use described at the time this report was prepared. Since the registration of pesticides is under constant review by State and Federal agencies, a responsible State agency should be consulted as to the current status of these pesticides.

ACKNOWLEDGEMENTS

Reforestation practices for conifers in California have been developed through the work of personnel in Federal and State agencies and in private industry. During the past 65 years, numerous individuals have contributed substantially to the material assembled in this report. We deeply appreciate their contributions.

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I INTRODUCTION

Foresters in California have noticeably shifted their attitude toward reforestation within the past 10 years. Until the early 1950's, they had generally regarded tree planting as an unrewarding gamble. And until recently, their hesitancy to do any planting regardless of size was amply justified. Failures were more frequent than successes. Before 1953, only 31 percent of the plantings in the State became established–the national average was 76 percent (Zillgitt, 1958). In recent years, the number of successful plantations has been on the upswing. Since 1957, for example, 85 percent of the plantings on National Forests in California have succeeded (Buck, 1959). And so, foresters are now generally convinced that reforestation can be done successfully--and at reasonable costs.

Any aggressive planting program in the past has been discouraged by high planting costs and frequent failures. The small, widely dispersed plantings contributed to the high costs. Recent improvements in production of planting stock and in planting machines both, however, have helped to lower the per acre planting costs. In addition, larger plantations have helped to spread high fixed costs over a greater acreage.

Most failures in reforestation have been blamed on climatic and biological difficulties. Among the obstacles to successful planting are the physiological condition of the planting stock, lack of proper site preparation, planting at the wrong time, careless planting by inexperienced planters, and biotic and other agents. The wet winters and dry summers that characterize parts of California also may have contributed to the difficulty of establishing plantations.

To find answers to these problems, studies in artificial regeneration have taken two approaches: (1) by acquiring a better understanding of the fundamental processes that occur within seeds and small plants, and determining their relationship to environmental factors; and (2) by trying to solve immediate problems but not necessarily probing into their causes. Much information has been developed, but many obstacles must still be hurdled before failures in some areas can be reduced to an acceptable minimum.

The U. S. Forest Service (1965) estimates that California has about 3.8 million acres of non-stocked commercial forest land--about equally divided between public and private ownership. 1/ Both public and private land managers have called for greater effort to restock nonproductive land. Not only is there a backlog of nonproducing land from old burns and past poor logging practices, but annual burns and clean-logged areas require large amounts of continuous reforestation.

As long ago as 1887 there was a concern for the need to reforest State and private lands in California. In that year the California Board of Forestry established two nurseries and planting stations; Santa Monica and Chico (Clar, 1959). Since these nurseries produced trees primarily for experimental planting, however, they contributed little to the immediate reforestation needs. They were turned over to the University of California in 1893.

A State forest nursery was again authorized by the 1917 Legislature. Tree production began in 1922. However, this nursery contributed little to reforestation needs since trees were grown primarily for highway and roadside plantings.

There also was an early interest in reforesting federal lands, although nothing was accomplished on a large scale. About 200 acres a year were planted on Forest Service lands between 1910 and 1920 (Baker, 1955). Figure 1 indicates how the interest in reforestation fluctuated on California National Forests between 1930 and early 1950's.

More recent recognition of the need to restock land came in 1945 when the California Legislature enacted the Forest Practice Act. This statute pointed out:

> The existence of a public interest in the forest resources and timberlands of this State; the necessity of good forest practices

1/ The California Reforestation Advisory Committee believes this estimate may be too high, but accepts the fact that the reforestation job is a large one. See Findings and Recommendations to the Reforestation Advisory Committee, Dec. 1, 1965. (Unpublished report to the State Forester.)

> ... to conserve and maintain the productivity of timberlands in the interests of the economic welfare of the State and the continuance of the forest industry (Public Resources Code, Div. 4, Chapter 2, Sec. 4541, 4571).

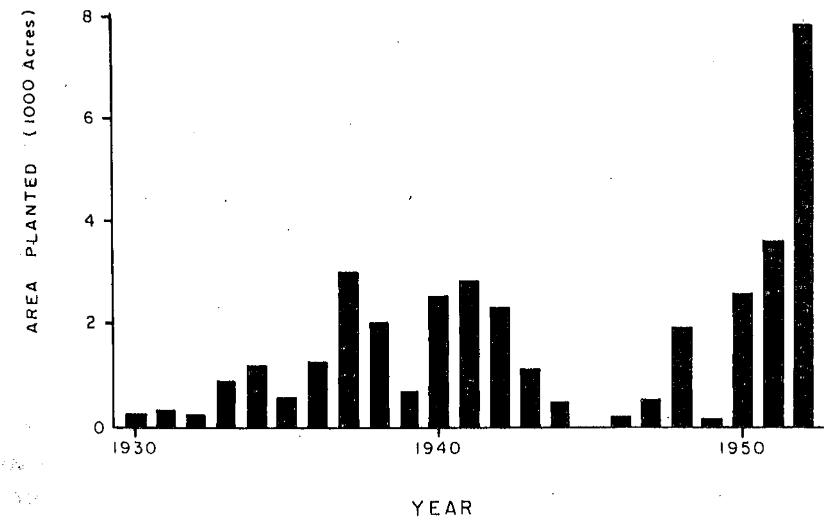

Figure 1. Annual planting by the Forest Service in California since 1930 showing the rise in CCC period merging with brush-stripping period followed by World War II decline period and present expansion due to heavy utilization demands. (Baker, 1955.)

It provided that Forest Practice Rules were to be adopted. These measures were to assure continuing productivity, including restocking.

The adoption of the Forest Practice Rules did not entirely fill the need. In 1952, the State Board of Forestry noted that:

> Failure to secure adequate reproduction following cutting or fire has caused thousands of acres of good timber cropland to become idle and an economic loss. While California's forest practice regulations are specifically planned for the purpose of securing the reproduction of a good stand of trees, there is still much to learn about natural forest regeneration and much more to learn about artificial reforestion (Baker, 1955).

The State Legislature eventually followed up by authorizing the State Forester to conduct reforestation studies and to appoint a 10-man Reforestation Advisory Committee. The Committee, first appointed in fall 1957, represents the various geographical areas and forest interests in California. Its job is (a) to recommend to the State Forester reforestation methods and procedures, (b) to assist in guiding the Division of Forestry in its reforestation field studies, and (c) to act as a medium of exchange for reforestation information.

The Forest Service has developed plans for reforesting about 900,000 acres--the amount of nonstocked National Forest land that it considers plantable in California.[2/] Between 1949 and 1968, it increased the number of acres reforested annually from 200 to 27,000. Less than half of the 27,000 acres planted is from the backlog of nonstocked land; the remainder is in fresh burns and clean-logged areas.

Private land owners have also concentrated on reforesting fresh burns. But they have also tried to keep in production land recently logged. A few owners have worked on the backlog to some extent, but the acreage has been small. As the need for more intensive young-growth timber management becomes apparent, greater effort probably will be made in restocking the backlog.

This publication summarizes technical information on reforestation practices for California conifers that is now available in many separate reports, including some hitherto unpublished data. Information was gathered from many sources, including the Pacific Southwest Forest and Range Experiment Station, Pacific Northwest Forest and Range Experiment Station, and California Region of the Forest Service, U. S. Department of Agriculture; California Division of Forestry, and the forest industry.

We have organized this information in the normal sequence that various steps are usually carried out in practice. Chapter II concerns cone and seed handling practices; III covers nursery practices that affect the production of planting stock; IV describes site preparation for both planting and direct seeding; V covers planting; and VI explains direct seeding. Together, the five chapters tell the story of how nursery and planting techniques have been improved so that reforestation is no longer an unnecessary gamble. For the land manager, they illustrate the pitfalls that they should avoid and the methods they can use in doing a better job of reforestation.

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II CONE and SEED HANDLING PRACTICES

As in other regions, past experience in California has demonstrated that in the production of planting stock, certain requirements must be met and procedures followed for successful reforestation. These requirements necessarily begin with the quality of seed used and end with the quality of planting stock produced.

Much high quality seed is needed to restore and keep commercial forest land fully productive. To obtain and maintain an adequate seed supply requires a thorough understanding of the effect of seed origin, production, collection, and processing on reforestation and timber production.

SEED ORIGIN

General

The importance of seed origin was recognized by European foresters almost a century ago. Many of their plantations from imported seed had failed to meet expectations. Some plantations were lost during the initial period of establishment; others, after a period of excellent growth, became severely damaged or were destroyed by a sudden adverse climatic change that caused little or no damage to native stock. These failures with imported seed led European foresters to conduct seed origin studies and to conclude that local seed should be used (Roeser, 1926).

The importance of seed source also has been recognized for many years in the United States (for examples Bates and Rudolf, 1938; Isaac, 1949, 1952, 1955; McCall, 1939; Munger and Morris, 1936; Roeser, 1926; Society of American Foresters, 1963; Wakeley, 1954). Bates and Rudolf (1938) stated that the "most fundamental of all items in reforestation is the source of seed used. Long-lived plants must be thoroughly adapted to the climate where they are planted." The Woody-Plant Seed Manual (U. S. Forest Service, 1948) includes this statement: "Seed source is second in importance only to choice of species in reforestation practices." Since many species have extensive geographical ranges, however, Wakeley (1954) stated that, "Choosing seed from wrong geographic source, even though it is of the right species for the planting site, may result in plantation failure."

Striking differences in productivity have been found to be attributable to seed origin (Isaac, 1952; Rudolf, 1951; Wakeley, 1954). Among conifers native to California, geographic variations have been reported for ponderosa pine (Bates and Rudolf, 1938; Callaham, 1960; Callaham and Hasel, 1958; Callaham and Liddicoet, 1961; Callaham and Metcalf, 1959; Mirov, *et al.*, 1952; Munger, 1947; Squillace and Silen, 1962). Other species studied have been lodgepole pine (Critchfield, 1957) and Douglas-fir (Isaac, 1949; Munger and Morris, 1936; Silen, 1966). With these species, as well as sugar pine, redwood, incense-cedar and the true firs, seed collected in different parts of their range may be as unsuited to the local planting site conditions as introduced species.

Not all introduced species have failed, nor have all local species escaped undamaged. Introduced trees from certain seed sources have outgrown native stock, whereas stock of the local species at times were stunted or of poor form (Munger and Morris, 1936; Roeser, 1926). A classical example is Monterey pine *(Pinus radiata* D. Don) which in part of its local environment has poor form but as an introduced species in Australia, New Zealand, Chile and South Africa, it has developed into a valuable timber species. Native trees at times are damaged but seldom killed by sudden unusually severe climatic conditions. Late spring freezes have injured both sugar pines and true firs in many parts of their natural ranges. Douglas-firs have been reported damaged by a severe fall freeze, with damage to young trees more severe than to older ones (Duffield, 1956).

Silen (1966) reevaluated an Oregon and Washington Douglas-fir provenance study originally reported on by Munger and Morris (1936). He hypothesized that planting-site exposures were more important than elevation because of climatic extremes affected by the exposures. Thus, race differences in a plantation at age 50 years may not be the same as when they were age 20 years or less. Climatic extremes, particularly in sheltered sites, might not have taken effect at the earlier age. Silen concluded that local seed sources were favored in the most severe site, whereas in the most sheltered one where survival was good, nonlocal sources outgrew local ones. However, local Douglas-fir sources on most sites generally will out-survive and out-grow nonlocal ones after a number of decades.

Seed Origin of Early California Plantings

Nothing was mentioned specifically in early reports of the importance of seed origin in California plantings (Person, 1937; Show, 1924, 1930). Show (1930) reported that seeds of native species were used in the direct seeding projects. Since ponderosa and Jeffrey pines were the main species used, the term "native" may have no particular significance as to the geographic source other than seeds normally were collected near the base of operation. Often seed-use in the Pine Region was predicated on availability rather than seed source. Since many of the early planting and seeding projects were done in brushfields without local seed trees, we can assume that seed from another source was used. But in the Redwood Region, planting stock may have been from the right seed origin, as one of the advantages of planting redwood was "an adequate local seed supply obtainable at reasonable costs" (Person, 1937).

Seed Collection Zones

Recognition of the importance of seed source in the United States was demonstrated in 1939 when the U. S. Department of Agriculture adopted a forest tree seed policy (McCall, 1939). This seed policy (see Woody-Plant Seed Manual [U. S. Forest Service, 1948]) covers seed use, seed verification, seed records, geographic limits, provenance tests, establishment of seed zones, and a request to accept and adhere to the seed policy.

Definite progress has been made in California to meet the requirements of the forest seed policy. In 1946, the forested area of the State was subdivided into 13 forest tree seed collection zones (Fowells, 1946). The two main purposes of these seed collection zones were: first, to insure that planting stock grown from any specific seed lots was planted in the area with an environment comparable to that from which the seeds were collected; and second, to simplify record keeping by grouping many of the seed lots which had been kept separate by individual collections.

The 13 seed collection zones established by Fowells (1946) were based on a vegetation map of the State and the composition of coniferous tree species, site quality, and latitude. In 1955, the limits of the northern seed zones were extended to Oregon (Roy, 1955).

The original 13 seed zones exceed the limitations of 100 miles and 1,000 feet in elevation set in the forest seed policy. Our present knowledge of geographic variation in ponderosa pine, one of the major species used in reforestation, indicates that the original 13 seed zones should be subdivided into smaller units. Nursery studies support this conclusion. They show consistent differences in planting stock from several seed zones grown at the Federal and State nurseries (Baron and Schubert, 1963; Schubert and Baron, 1965; Stone and Bensler, 1962).

Because many foresters have recognized the need for refined local seed zones, the Tree Improvement Committee of the Northern California Section of the Society of American Foresters developed a new seed zone map and zone numbering system (fig. 2). Also developed was a collection reporting system (Buck, *et al.*, 1970). The map and numbering system are similar to one adopted by foresters in the Northwest.[3] Boundaries of zones common to Oregon and California were adjusted to coincide at the California-Oregon border.

Zones are delineated on the basis of forest seed policy collection criteria (McCall, 1939). The State is divided into six physiographic and climatic regions, 32 subregions within regions and 85 seed collection zones. Seed collection zones are limited to appoximately 50 miles in latitude. Where possible boundaries follow natural features such as crests of mountain ranges, ridge tops and rivers, or physical features such as highways, canals, and railroads.

Zones are numbered in three digits so that seed collection information may be handled by electronic data processing. The first digit denotes the physiographic and climatic region, the second the physiographic and climatic subregion, and the third the seed collection zone.

[3] Soule, Lloyd. Oregon and Washington tree seed zones. (Personal communication, November 4, 1968).

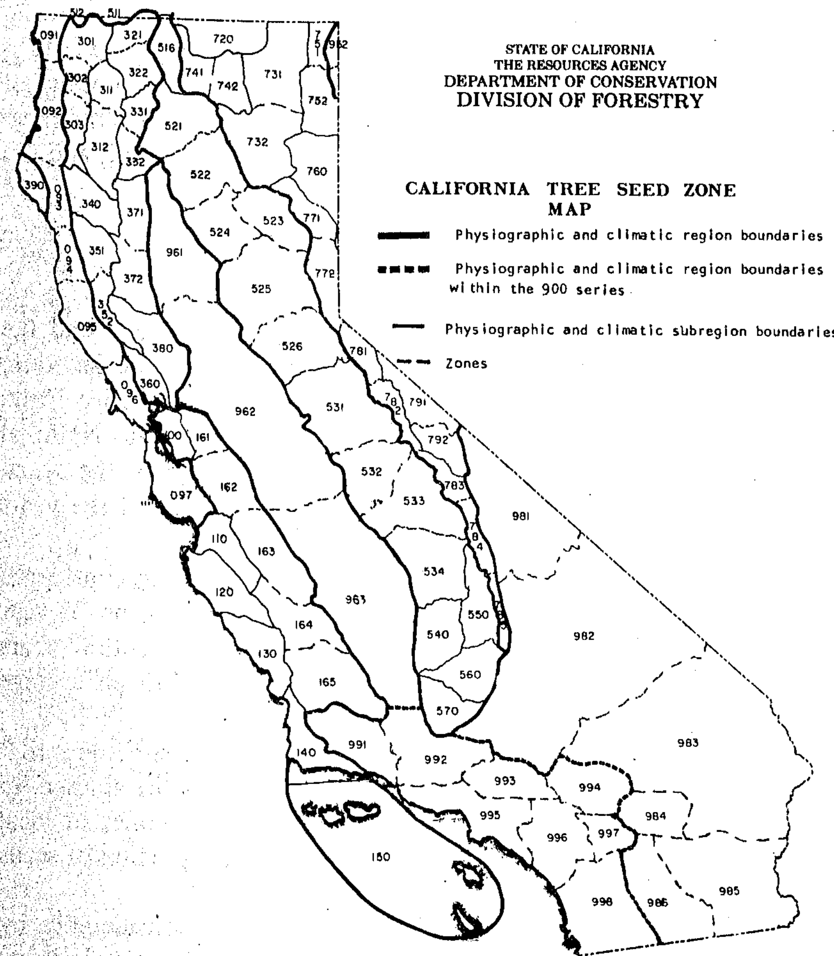


Figure 2. California tree seed zones. (Buck, *et al.*, 1970).

SEED PRODUCTION

To maintain an active expanding reforestation program, it is necessary to know: (1) frequency of good seed crops; (2) amount of seed produced; (3) types of good quality trees that produce the most seed; (4) ways in which seed production can be increased; and (5) estimated size of potential seed crops.

Size and Frequency of Cone Crops

Records of annual cone production since 1926 suggest that the cone crop size varies considerably by species, geographic location, years, and individual trees [4] (Fowells and Schubert, 1956; Fritz, 1947; Roy, 1960). During a 35-year period on Stanislaus National Forest, heavy seed crops occurred in about one-fourth of the years; whereas, a light or no crop occurred in more than half of the years (table 1).

Generally only crops of medium or heavier size are considered good seed years for collection purposes. During this same 35-year period on Stanislaus National Forest, good seed collection years occurred at intervals ranging from 1 to 7 years, with an average interval of 2 to 3 years.

Heavy crops occurred even less frequently -- ranging from 2 to 9 years, with an average of 4 to 5 years for the four species studied. In some light seed years, trees may produce sufficient cones in local areas to augment seed supplies, however, a higher proportion of seeds may be infested with insects.

The size of the annual cone crop has varied considerably by geographic location. On Stanislaus National Forest, the heaviest ponderosa pine cone crops occurred in 1926, 1933, 1936, 1952, and 1958 (fig. 3). A heavy sugar pine cone crop coincided four out of nine times with a heavy ponderosa pine cone crop. A heavy white fir cone crop coincided four times with a heavy sugar pine and only twice with ponderosa pine.

4/ Based on annual California Cone Crop Reports 1955-1970.

Table 1. Size of cone crops on Stanislaus National Forest by Species -- 1926 to 1960.

Cone crop rating index	Ponderosa pine	Sugar pine	White fir	Incense-cedar
	Number			
None	2	2	2	0
Light	18	16	21	17
Medium	7	9	3	11
Heavy	4	5	3	4
Very Heavy	4	3	6	3
Total	35	35	35	35

Cone crops reported on a statewide basis by the Pacific Southwest Forest & Range Experiment Station and the California Division of Forestry since 1955 have shown that 1956 and 1960 were best for Douglas-fir, ponderosa, Jeffrey and sugar pine (table 2). Sugar pine crops were heavy in 1962 and 1964.

Types of Trees Bearing Cones

Fowells and Schubert (1956) reported that cone production of ponderosa pine, sugar pine, and white fir varied considerably with crown position, tree class and vigor, and tree size. Dominant trees were by far the best cone producers (table 3). More than 98 percent of the cones on the two pines and about 88 percent of the cones on white firs grew on dominant trees. Except for white fir, few cones were produced on codominant trees. And intermediate and suppressed trees generally produced no cones.

A strong correlation was found between Dunning's (1928) tree classes (fig. 4, table 4) and cone production (Fowells and Schubert, 1956). For the pines, class 1, 3, and 5 trees were the most productive, whereas, class 1 firs were the best (table 5). Class 5 ponderosa pines and white firs were less desirable for cone production than the younger age classes. The heaviest cone crops were borne by trees of moderate or good vigor and with a crown of moderate or better length and width.

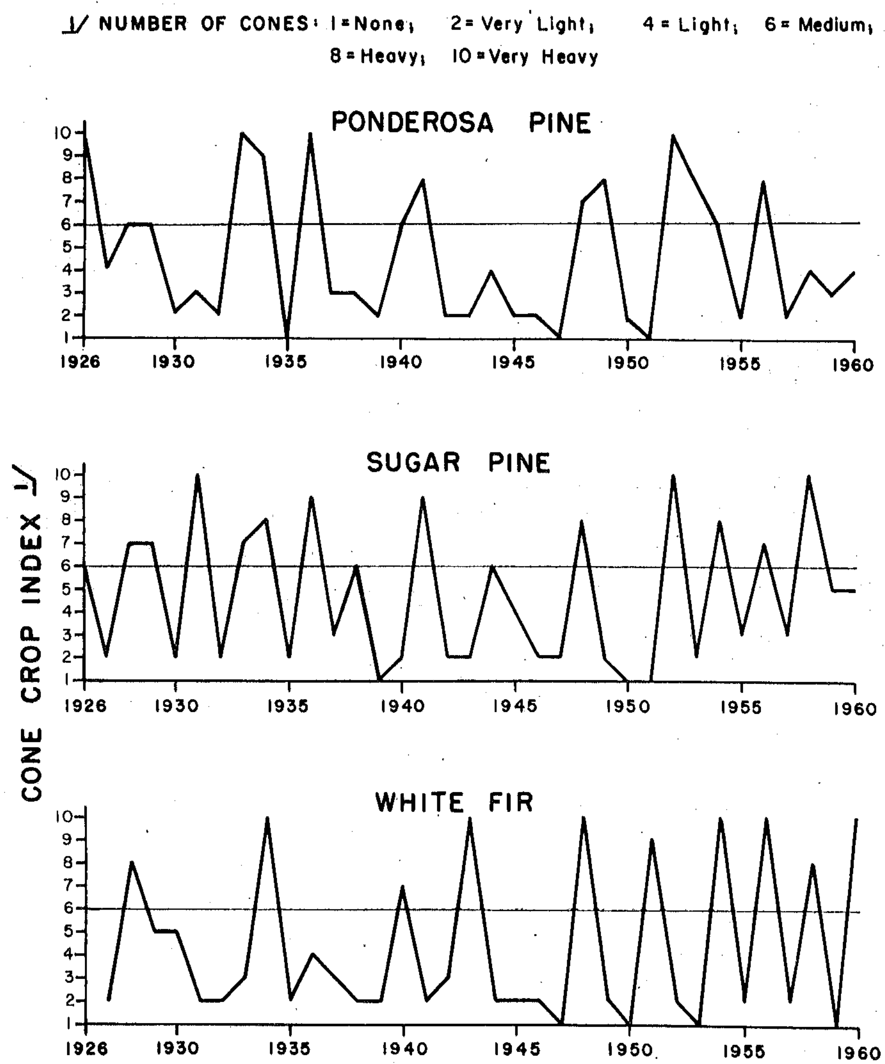


Figure 3. Average Cone Crop Index For Dominant Trees Larger Than 19.5" dbh Stanislaus National Forest 1926 - 1960.

Table 2. Average size of cone crops produced in California by 12 conifer species 1956 - 1966.

Species	Cone crop produced during - - -										
	1956	1957	1958	1959	1960	1961	1962	1963	1964	1965	1966
	Size class 1/										
White fir	7	4	5	2	4	2	2	2	3	2	2
California red fir	5	5	3	3	4	3	2	2	3	2	2
Incense-cedar	2	3	3	2	5	2	2	2	-	2	2
Knobcone pine	-	7	5	7	7	8	4	2	-	-	1
Lodgepole pine	6	5	3	2	5	2	3	2	3	3	2
Jeffrey pine	6	3	3	4	6	2	3	2	3	2	2
Sugar pine	7	4	4	4	6	2	4	2	4	2	3
Ponderosa pine	7	3	3	3	5	2	2	2	3	2	2
Monterey pine	4	8	4	6	6	8	-	3	3	3	5
Douglas-fir	7	3	4	3	4	3	3	2	3	2	2
Sierra redwood	3	4	4	4	5	3	3	3	3	3	3
Coast redwood	5	4	4	4	5	5	5	3	2	3	3

1/ Size class from 1956-1961: 1 = none; 2 = very light; 3 = very light to light; 4 = light; 5 = light to medium; 6 = medium; 7 = medium to heavy; 8 = heavy; 9 = heavy to very heavy; 10 = very heavy. Size classes 1961-1966: 1 = none; 2 = very light; 3 = light; 4 = medium; 5 = heavy.

Table 3. Cones produced on ponderosa pine, sugar pine, and white fir trees, by crown classes, Stanislaus National Forest, 1934-1940.

Crown class	Ponderosa pine	Sugar pine	White fir
	Percent		
Dominant	99.03	98.46	87.56
Codominant	.92	1.51	11.81
Intermediate and suppressed	.05	.03	.63

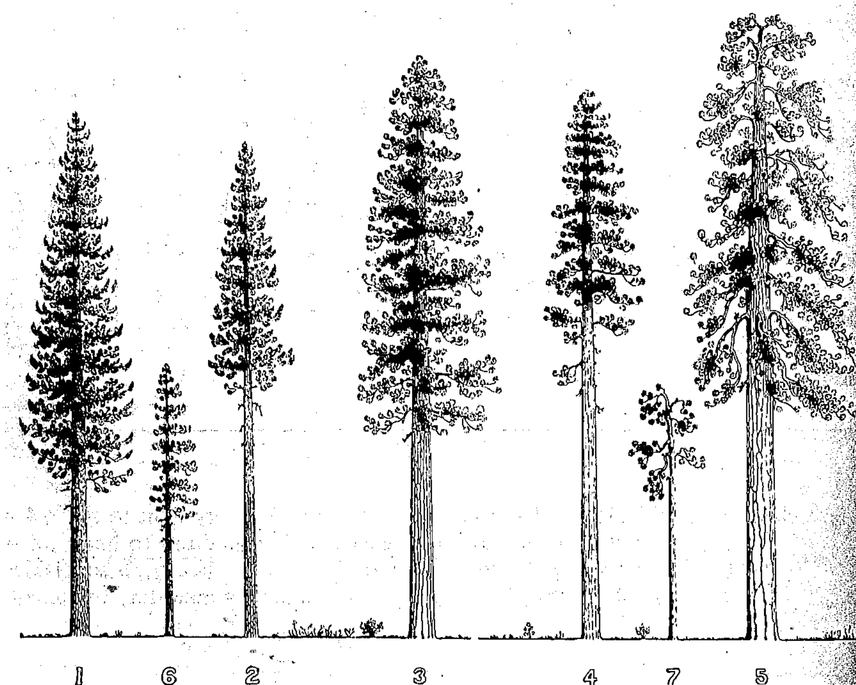


Figure 4. Dunning tree classes, selection stands, ponderosa pine (Dunning, 1928).

Table 4. Description of Dunning tree classes

Tree class	Age class	Position	Crown length	Crown width	Form of top	Vigor
1	Young or thrifty mature.	Isolated or dominant; rarely codominant.	At least 65 percent of total height.	Average or wider.	Pointed	Good
2	do	Usually codominant; rarely isolated or dominant.	Less than 65 percent of total height.	Average or narrower.	do	Good or moderate.
3	Mature	Isolated or dominant; rarely codominant.	At least 65 percent of total height.	Average or wider.	Round	Moderate
4	do	Usually codominant; rarely isolated or dominant.	Less than 65 percent of total height.	Average or narrower.	do	Moderate or poor.
5	Overmature	Isolated or dominant; rarely codominant.	Any size	Any size	Flat	Poor
6	Young or thrifty mature.	Intermediate or suppressed.	Any size but usually small.	Any size but usually small.	Round or pointed.	Moderate or poor.
7	Mature or over mature.	do	do	do	Flat	Poor

Source: DUNNING, Duncan. A Tree Classification for the Selection Forests of the Sierra Nevada. Jour. Agr. Res. 36: 755-771, illus. 1928.

Table 5. Proportion of cones produced between 1934 and 1940 by Dunning tree classes, Stanislaus National Forest.

Dunning tree class	Ponderosa pine	Sugar pine	White fir
	- - - - - - - - - - - Percent	- - - - - - - - -	
1	30	21	68
2	1	1	10
3	51	51	11
4	0	0	2
5	18	27	8
6	0	0	1
7	0	0	0
Total	100	100	100

Source: Dunning (1928).

Small white fir and ponderosa pine trees were found to bear larger cone crops than small sugar pines (fig. 5) (Fowells and Schubert, 1956). Sugar pines, except for occasional small trees which are prolific cone bearers, generally do not produce heavy crops until they reach about 30 inches in diameter. Good cone crops are produced by ponderosa pine less than 30 inches diameter and white firs less than 20 inches in diameter. The decline in cone production by ponderosa pine more than 50 inches and white firs more than 30 inches diameter was associated with a decline in vigor. Young open-grown Douglas-firs produced 151 to 6,000 cones, with the greatest numbers in the upper and middle south portions of the crown (Winjum and Johnson, 1964).

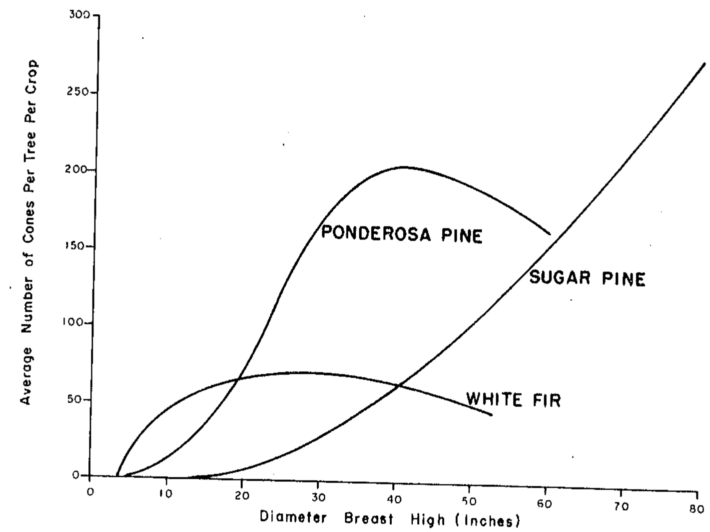


Figure 5. Average number of cones per tree per crop by diameter classes for ponderosa pine, sugar pine and white fir on Stanislaus National Forest.

Annual Seed Production

The amount of good seed produced per cone has generally been highest during heavy seed years. In general the ratio of good seed to total seed is highest in the pines and lowest in the true firs, redwood, and Douglas-air. Fowells and Schubert (1956) found that the number of good seeds per cone varied from 209 to 219 for sugar pine and from 69 to 73 for ponderosa pine. Jeffrey pine had from 120 to 180 good seeds per cone. Roy (1960) reported that Douglas-fir had a sound to total seed quotient varying from 0 to 53 percent during a 7-year period (table 6). White fir had as many as 185 good seeds per cone, but often a high percentage of the cones had few good seeds. No data are available for the other species except that suggested by germination tests.

Table 6. Sound Douglas-fir seed falling on clearcut blocks, Slate Creek Unit, Trinity National Forest, 1951-1957.

Year	Amount per acre	Sound seed to total seed quotient	Basis: seed traps
	Number	Percent	Number
1951	283	53	150
1952	35	3	150
1953	1,308	17	138
1954	18,969	38	88
1955	531	2	30
1956	30,760	18	29
1957	0	0	30
Total	51,886	25	605

Stimulation of Cone Production

Several methods to stimulate cone production have been tried in various parts of the world. Trees have been girdled, banded, and watered. The soil around seed trees has been cultivated and fertilized. And stands have been thinned and competing vegetation eradicated. Seed tree release and eradication of understory vegetation have shown promise. Banding and girdling treatments have not been effective. Fertilizer application to the soil seems to offer the best possibilities.

The first known attempt in California to increase cone production by soil fertilization was made in 1951 on Stanislaus National Forest (Schubert, 1956c). Three applications of ammonium phosphate (16-20-0) at the rate of 100 pounds per tree in each of three consecutive years resulted in a 2.3-fold increase in cone production on mature dominant sugar pines ranging from 27 to 52 inches in diameter (table 7). On a per acre basis, these application rates were equivalent to about 2,000 pounds of fertilizer.

Table 7. Cones produced on fertilized and unfertilized sugar pine seed trees, Stanislaus Experimental Forest, 1952-1960.

Tree Number	1952	1953	1954	1955	1956	1957	1958	1959	1960	Total 1953–1960
FERTILIZED										
1	848	13	48	131	762	7	546	177	148	1,832
2	104	10	89	2	64	15	40	58	1	279
3	12	53	74	0	4	10	74	5	12	232
4	156	3	128	1	8	0	84	6	12	242
5	158	0	122	2	154	0	84	0	10	372
6	398	17	145	26	52	3	187	0	30	460
7	321	4	313	0	340	0	180	31	147	1,014
8	76	0	64	0	69	0	33	27	1	194
Total	2,073	100	983	162	1,453	35	1,228	304	361	4,626
UNFERTILIZED										
1	309	3	9	0	70	6	116	36	2	242
2	72	2	23	0	14	14	69	2	20	144
3	152	3	34	0	14	1	63	19	24	158
4	160	10	46	0	165	8	118	0	41	388
5	185	3	182	1	73	1	88	19	8	375
6	9	26	2	0	5	0	45	18	9	105
7	273	3	26	0	161	0	300	12	42	544
8	106	4	15	0	10	0	14	14	9	66
Total	1,266	54	337	1	512	30	813	120	155	2,022

In the Pacific Northwest, 20-year old Douglas-firs treated with ammonium nitrate and superphosphate showed a large increase in cone production (Steinbrenner, Duffield, and Campbell, 1960). During the first year, sound seed was produced at a rate of 1.2 pounds per acre on unfertilized plots; 4.5 pounds on plots treated with 100 pounds per acre each of nitrogen and phosphorus; and 10.3 pounds of seeds on plots receiving 200 pounds of each fertilizer per acre. During the second year after treatment, 3.7 percent of the trees on unfertilized plots, 56 percent of those on plots with 100 pounds of each fertilizer, and 75 percent of those with the 200 pounds of each fertilizer produced flowers.

Ten seed production areas have been established on National Forests in California (Fowler, 1963). These specially designated and treated areas offer the best opportunity to produce maximum seed of known origin. They should be operated as fruit orchards to include cultivation, irrigation, fertilization, of thinned stands of known origin. The cones and seed must be protected against insects and squirrels.

Annual Cone Crop Forecasts

From August 1955 to August 1963, Pacific Southwest Forest and Range Experiment Station issued an annual cone crop forecast report (Baron, 1962, 1963; Baron and Schubert, 1961; Schubert, 1955b, 1956b, 1957, 1958; Schubert and Baron, 1959, 1960). In August 1964 the California Division of Forestry (Eden, 1964-1970) began publication. The data are collected in July by field crews from National Forests, California Division of Forestry, Pacific Southwest Station, and several timber companies.

These annual forecasts supplement the information published in the comprehensive cone production report by Fowells and Schubert (1956). In addition, they provide the following additional benefits:

1. Give an early warning of good crops and crop failures.

2. Provide a basis to formulate seed collection plans.

3. Make it possible to integrate cone collection with timber harvest.

4. Serve as a guide for seed collectors to locate areas of potentially good cone crops.

5. Provide a record of cone and seed losses.

6. Provide a basis to rate cone production by species for specific areas and for the entire state.

7. Provide a means of comparing annual cone crops.

8. Provide a cone production record that may have specific value to correlate climate and cone production.

9. May lead to a cone prediction method to forecast cone crops two or more years in advance.

The Forest Service, California Region, and the Experiment Station devised a 5-unit classification system to evaluate cone crops (Schubert and Baron, 1960). Estimates are based on seed production on dominant, vigorous trees more than 12 inches d.b.h. The California Division of Forestry has used this system since 1962. The five designations are:

1. None--no cones on any seed trees.

2. Very light--few cones on less than one-fourth of the seed trees.

3. Light--few cones on more than one-fourth of the seed trees.

4. Medium--many cones on one-fourth to one-half of the seed trees.

5. Heavy--many cones on more than one-half of the seed trees.

To reap the most benefits from an annual cone crop report, it is necessary to sample the cone crop in several locations within each seed collection zone. Gordon (1962) suggested taking photo slides of cone crop indicator trees so that they could be projected on a screen to enable more accurate cone counts.

The crop rating should be shown for all species at the sampling point, with a separate form filled out for each location. In addition to the crop rating, the report should indicate the seed zone and condition of the crop. Reporting cone damage from insects, birds, and squirrels and frost injury is important. If possible, the same locations should be sampled each year to provide a reliable base for seed crop frequency and correlation with climatic factors.

Cone crops possibly may be predicted by analyzing combinations of weather factors before cone crop maturation. From an analysis of more than 40 years of California temperature records and sizes of ponderosa pine cone crops, Maguire (1956, 1968) has suggested a correlation between temperatures and crops. From U. S. Weather Bureau records he used summations of maximum temperatures for 10-day periods for April, May and June. He compared 10-day period's maximum temperature sums within these three months with the average 43-year summation for the corresponding 10-day period. He suggests that a heavy cone crop will be produced 26 months hence when the following combinations of temperatures occur:

(1) In at least the second or third 10-day period of April, the maximum temperature sum equals or is above its corresponding average.

(2) In May, at least two 10-day periods have sums that are above average sums, and the total amount above the averages is at least 54 degrees.

As an example, maximum temperature sums in 1958 that produced the 1960 heavy ponderosa pine crop were as follows:

	April			May			
	1-10	11-20	21-30	1-10	11-20	21-31	Total
1958	513	784	758	851	829	929	
43-Yr. Average	697	737	739	776	820	921	
Difference		+	+	75	9	8	92

However, other factors such as late spring freezes during the conelet stage may override the April-May temperature effect.

In Oregon, Lowry (1966) studied the relationship between a 48-year record of Douglas-fir cone crops, mean monthly temperatures, and total monthly precipitation. He found that an abundant cone crop in a given October requires a warm January in the same year, a March-April with abundant rainfall 1½ years before the cone crop, and a cool July two years before the crop.

CONE AND SEED LOSSES

Forest seed crops may be destroyed in part or completely by insects, fungi, squirrels, birds, or adverse weather. Losses by these agents are often unpredictable and may seriously disrupt collection programs.

Insects

Almost all of the serious damage to cones and seeds are caused by four classes of insects: cone beetles, cone worms, seed chalcids, and maggots (Miller, 1914). The insects infest seed or cones of most conifers, but losses vary considerably among species (Keen 1952, 1958). Heavy losses have occurred in sugar, ponderosa, and Jeffrey pines, red and white firs, and Douglas-fir (Fowells and Schubert, 1956; Hall, 1955; Koerber, 1960; Miller, 1914; Stevens, 1959).

One major pest has been the sugar pine cone beetle. This insect overwinters in the current year's twig tip and in aborted cones (fig. 6), which drop to the ground (Ruckes, 1957). In some years cone beetles have destroyed 25 to 50 percent of the sugar pine cone crop over large areas (Miller, 1914). In other years, damage may be quite spotty ranging from very light in some areas to very heavy in others (Hall, 1955). Heavy losses are most likely to occur the year following a heavy cone crop, often precluding the occurrence of two successive good seed years. In 1949, almost all sugar pine cones on Stanislaus Experimental Forest were destroyed by the sugar pine cone beetles after the heavy cone crop in 1948 (Fowells and Schubert, 1956).

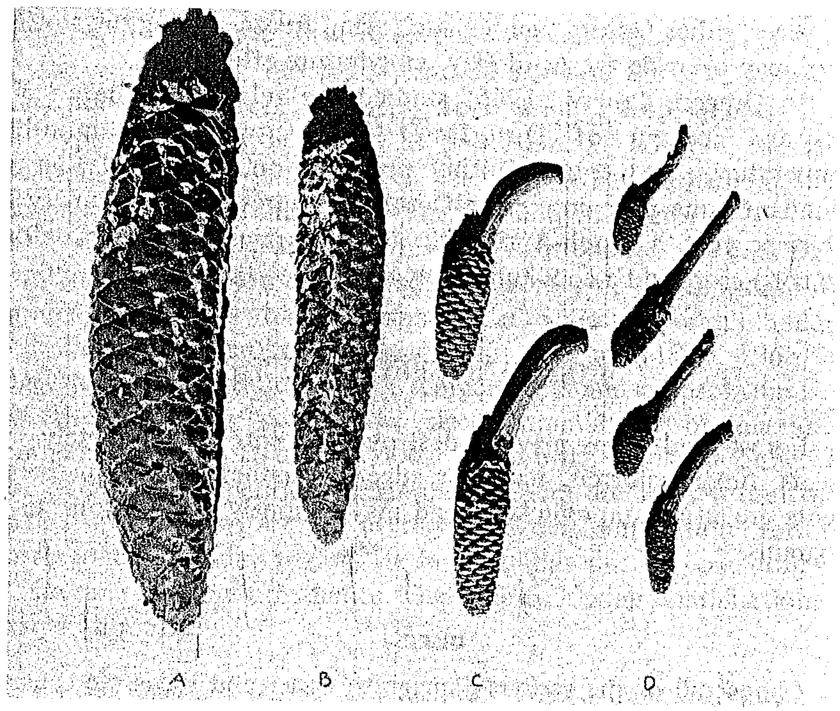


Figure 6. Normal sugar pine cones (A) compared to aborted (B, C, and D) cones. The cone (B) was infested with sugar pine cone beetles during late summer of the second year and the cones (C) during late spring of the second year of cone development. The four aborted cones in (D) were killed by an early severe fall frost during the first year of development or a late spring frost at the beginning of the second year.

Insect damage to ponderosa and Jeffrey pine cones and seeds has usually been light (Fowells and Schubert, 1956); however, during some years 50 to 90 percent of the cones were damaged (Miller, 1914). The cones damaged by ponderosa pine cone beetles often contain good seeds, but some years, chalcids may destroy 70 to 90 percent of the seed (Miller, 1914). Often damage by insects is not detected. In 1958, for example, Ruckes (1958) reported that 17 percent of the Jeffrey pine seeds had been infested with the deathwatch beetle. In what was otherwise an excellent cone crop year, no indication of insect damage was reported.

Fir cone maggots and chalcids have destroyed up to 95 percent of the red and white fir seed crop (Fowells and Schubert, 1956; Koerber, 1960). In 1951, all red fir seed collected on Stanislaus Experimental Forest had been destroyed by seed chalcids.

Douglas-fir seed crops during some years have been almost completely destroyed by insects. In 1954, losses varied from 53 to 98 percent (Hall, 1955; Stevens, 1959). Stevens (1959) reported the following losses during a 5-year period:

	Cones Infested By		
Year	Moth	Chalcid	Both Insects
	- - - - - -	Percent	- - - - - -
1954	--	82.2 1/	82.2 1/
1955	--	9.9	9.9
1956	16.5	.4	16.9
1957	47.3	6.4	53.7
1958	73.3	7.1	80.4

1/ Includes hollow seeds.

Fungi

Various fungi have caused serious damage to coniferous seeds (Schubert, 1950, 1961; Shea, 1960); however, very little is known about when or how best to treat seeds to prevent these losses. Molds have been found on fresh and stored cones, on seeds before and during storage, and on seeds during germination. Bloomberg (1966) reported that surface-sterilized Douglas-fir seed taken from dry cold storage produced several species of fungi when placed in a malt agar culture medium. Hyphae could be detected in seed coat cells. Most of the damage seems to occur during seed storage and germination. Fungi have completely destroyed sugar pine seed stored at 32 and 41° F. in 2 to 5 years (Schubert, 1961). Proper seed processing and storage at 0° F. have reduced losses.

Squirrels

The nearly complete destruction of pine cone crops in some years by squirrels has been documented (Berry, 1914; Jotter, 1914). Squirrels are particularly destructive on ponderosa and Jeffrey pine cones, in some years cutting over 90 percent of the cones before the seed matured (Fowells and Schubert, 1956; Schubert, 1953). In 1938, squirrels cut over 56 percent of the sugar pine cone crop on Stanislaus Experimental Forest (Fowells and Schubert, 1956). In 1951, 54 percent of the sugar pine cones on tagged trees near Lake Almanor were cut by squirrels (Tevis, 1953a). White fir cones also are cut by squirrels, but heavy losses have not been reported (Fowells and Schubert, 1956). In seed production areas, broad aluminum bands (fig. 7) around the trunk of each tree can help protect cones. The bands should: (a) be at least 18 inches wide, (b) expand as the tree grows, and (c) be smooth (Krugman and Echols, 1963).

Figure 7. Trees in a seed production area with broad aluminum bands can prevent squirrels from climbing to cut cones.

Birds

Many species of birds eat coniferous seeds. Some birds, such as the white-headed woodpeckers, Lewis woodpeckers, Clark's nutcrackers, and the Stellar's jays feed on seed while the cones are still attached to the trees (Fowells and Schubert, 1956; Tevis, 1953b). Other birds, such as the white-breasted nuthatches, red-breasted nuthatches, and mountain chickadees, have been observed removing seeds from cones cut by squirrels after the cones opened on the ground (Tackle and Roy, 1953). Eastman (1960) found that crops of seven bird species in central Oregon contained ponderosa pine seed. They included, in addition to Clark's nutcracker and Stellar's jay, the crossbill, mourning dove, pinon jay and evening grossbeak, all found in California forests. Other unreported species probably eat many seeds too, from cones on trees or that shed on the ground.

The birds of primary interest in artifical reforestation are those that destroy seed crops on trees. In some years white-headed and Lewis woodpeckers have completely riddled many sugar pine cones (fig. 8) on Stanislaus National Forest (Fowells and Schubert, 1956) and other Sierra Nevada areas. Tevis (1953b) reported that white-headed woodpeckers destroyed 34 percent of the 1,656 sugar pine cones counted on 20 trees near Lake Almanor in Plumas County. He also reported that Clark's nutcrackers and Stellar's jays extracted sugar pine seeds from partly opened cones. The exact impact these and other birds have on seed production has never been fully evaluated. However, the dependence of certain birds on coniferous seed for food was indicated by large migrations of Clark's nutcrackers from the Sierra to the lowlands during years of seed crop failures (Davis and Williams, 1957).

Weather

Immature cones are sometimes killed by severe late spring or early fall freezes. And prolonged storms during pollination can cause low seed quality during some years. A comparison of cone crop and weather records since 1926 on Stanislaus National Forest showed that a number of seed crop failures coincided with a severe late spring freeze (Fowells and Schubert, 1956).

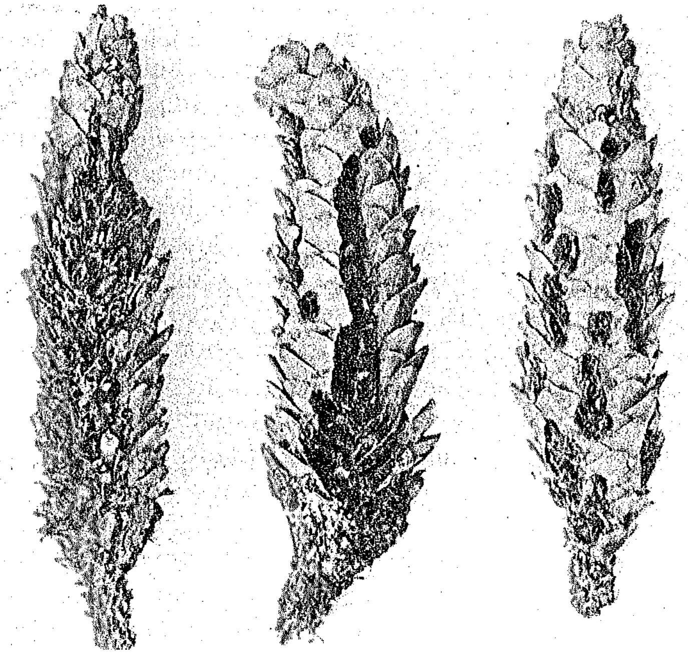


Figure 8. Sugar pine cones riddled by white-headed woodpeckers.

The killing effect of low temperatures depends on the stage of growth of the conelets and the duration of the freezing temperature. In 1936, a minimum air temperature of 23 ° F. on May 20 killed most of the white fir conelets (Fowells and Schubert, 1956). Based on the temperature profile reported by Fowells (1948) the temperature in the crowns of the trees would have been about 26.5 ° F. None of the sugar pine or ponderosa pine conelets were killed by the 1936 freeze. Since pine conelets start growth several weeks later than true fir conelets, they evidently had not started to grow when the freeze occurred.

White fir trees have borne large cone crops during some years when a freeze occurred after the middle of May; however, heavier crops are more likely to occur when the temperature does not drop below freezing in the crowns (Fowells and Schubert, 1956). For example, heavy fir cone crops occurred in 1948 when the minimum air temperature at 4.5 feet was 27 ° F. on May 22, and in 1951 when

the temperature dropped to 24°F. in the middle of May. In 1950 and 1952, almost no cones were produced after temperatures of 24 and 25 ° F. occurred the first week in June.

A late April freeze severely damaged knobcone pine conelets in the Forest Service's Badger Hill Breeding Orchard (Krugman, 1966). During a 3-day period, freezing temperatures prevailed for periods up to 16 hours, with the minimum reaching 21 ° F. in the tree crowns.

Cones of ponderosa, Jeffrey, and sugar pines and Douglas-fir also have been killed by a sudden freeze. In western Washington, a sudden drop in temperature to 7 ° F. in November 1955 caused widespread damage to Douglas-fir and several other coniferous species (Duffield, 1956). In 1954, immature sugar pine cones were killed (fig. 6) on 35 percent of the trees on Stanislaus National Forest when the temperature dropped to 20° F. on June 6 (Schubert, 1955a). And a late spring freeze in 1962 killed many ponderosa and Jeffrey pine and white fir cones (Baron, 1963).

Rainy weather has had little effect on the Douglas-fir seed set in the Pacific Northwest (Silen and Krueger, 1962). For example, although an unusual amount of rain occurred during 1959, seed set was not reduced.

SEED COLLECTING AND PROCESSING

Seed collecting and processing are major phases of California's reforestation program. They affect financially all succeeding operations to the final harvest of the product. Of no small importance is the direct expenditures in labor and money for the collecting and processing alone. Therefore, it is of great significance that the seed (a) is collected from desirable parent trees, (b) is fully ripe when collected, and (c) is properly processed whether for immediate or future use.

Desirable Parent Stock

Since there is some chance that the progeny will be like the mother tree, it is important to pick cones from trees that have the desired characteristics for the intended product. For reforestation of the commercial timber lands, the cones must come from trees with good form and vigor. For ornamental or Christmas tree production, seed collections should be made from trees with dense symmetrical crowns.

Seed collections should be made only from stands composed of trees with desirable phenotypic characteristics to avoid the possibility of producing future stands of inferior quality. The importance of this requirement has been adequately stressed but not always strictly enforced.

Except under a controlled pollination program, only the characteristics of the mother tree are known. The father may be the same tree or any one of the trees within pollen flight, so the characteristics of each new progeny are the product of its environment and the genes it inherited from both parents. Therefore, the probability of producing good quality trees is enhanced if stands that contain poorly formed or excessively limby, or diseased trees are avoided as the stock for the new forest.

Isolated trees and squirrel cone caches have been used as an easy source of seeds by cone collectors; however, this practice is not always recommended. Neither of these two sources may yield seed of desirable quality. Unless the isolated tree is within a few hundred feet of a desirable pollen supply for adequate cross-pollination, it should not be used for cone collecting. Squirrels harvest cones from all trees -- good and bad. Unless the cone cache is located in or near a stand with desirable phenotypic characteristics, it would be advisable to leave the cones for the squirrels.

Some plantations in California have reached, and others soon will reach, cone-bearing size. However, unless the original seed source is known and is of the desired location, cones from these should not be harvested. Some plantations may appear to be well adapted and grow vigorously up to cone bearing age and older, and then be affected by some factor that reduces growth or causes malformation of trees. Cones from plantations of known seed origin should be labeled with the original seed zone designation.

Cone Maturity and Seed Quality

When is the best time to harvest cones? If only a small quantity of seed is needed, the best time to collect cones is when the cones begin to open on the tree. Seeds then are fully ripe and at peak quality. Once the cones start to open, however, they may shed most of their seeds within a few days. Even at best, the time interval between the date the cones reach maturity and the date the cones

open may be only a few weeks (Fowells, 1949). Therefore, to fill large cone quotas, seed collectors must be able to start cone harvest at the earliest date that cones are mature enough to yield high-quality seeds.

One of the main difficulties has been that all cones do not mature at the same time. The maturation date of cones has been found to vary for cones on the same tree (Ching, 1960; Fowells, 1949; Maki, 1940) to vary from stand to stand in the same year (Fowells, 1949), and to vary from one year to the next (Allen, 1958; Fowells, 1949). On Stanislaus Experimental Forest, as sugar pine cones matured, the seed viability increased from 23 percent collected on September 8, 1948, to 88 percent for those collected on October 7 (fig. 9) (Fowells, 1949). In 1952, the viability of sugar pine seed was 35 percent during the second week in September and more than 98 percent during the first week in October (Schubert, 1956a). In Canada, the viability of Douglas-fir seed during their usual collection period increased from 33 percent on August 15 to 94 percent on October 10 when the cones started to open (Allen, 1958). These comparisons of viability indicate the high probability of collecting low quality seed when the cones are picked too early.

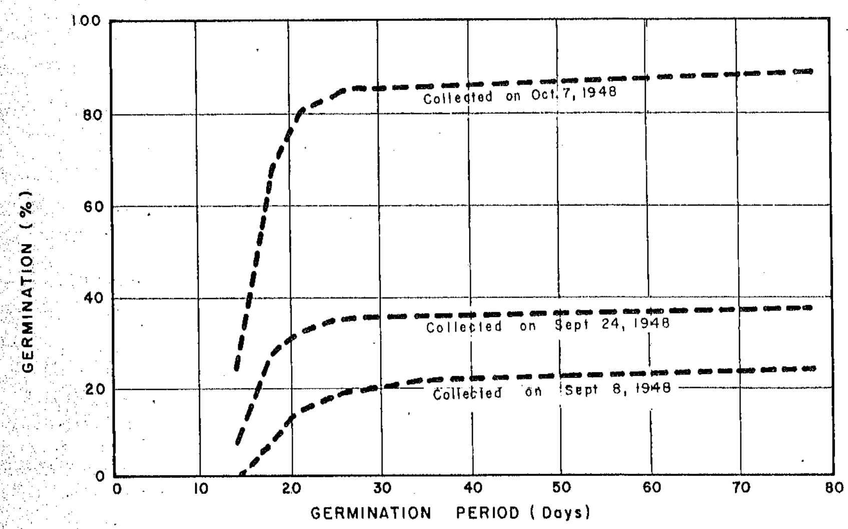


Figure 9. Germination of sugar pine seed collected at three different times on Stanislaus National Forest.

Since cones lose weight when they start to mature, floatation tests have been developed to determine when cones are ripe enough to yield high quality seeds (Fowells, 1949; Maki, 1940; Wakeley, 1954). Immature cones with a specific gravity slightly more than 1.00 will sink in water. As these cones ripen and lose weight they will begin to float in water. Water is a poor test medium, however, since the viability of seed from any of the cones that would float in water would be far too low (Maki, 1940). Fowells (1949) reported that specific gravity alone accounted for 56 percent of variation in the germination of sugar pine seeds.

The specific gravity index of mature cones has been determined for ponderosa, Jeffrey, and sugar pines (table 8). Ponderosa pine cones are mature enough to pick when the specific gravity drops to 0.84 (Fowells and Schubert, 1956). This figure agrees closely with the specific gravity index of 0.86 reported for ponderosa pine in the northern Rocky Mountains (Maki, 1940) and may be the same for this species throughout its range. Sugar pine cones on Stanislaus National Forest were not mature enough to collect until the specific gravity had dropped to 0.80, whereas, the specific gravity for mature Jeffrey pine cones was found to be about the same as for ponderosa pine (Schubert, 1956a).

Table 8. *Specific gravity and recommended test medium for mature ponderosa, Jeffrey, and sugar pine cones.*

Species	Specific gravity	Test medium
Ponderosa pine	0.84 to 0.86	Motor oil (SAE-30)
Jeffrey pine	.86	Motor oil (SAE-30)
Sugar pine	.80	Kerosene

The specific gravity of mature cones of other species may be similar to those reported for the three pines. Until cone maturity indices are available for other species, we suggest that kerosene be used to test cones of the other white pines and SAE- 30 motor oil for all other species.

Cones are sufficiently mature to harvest from a tree when at least three cones from a sample of five freshly picked cones float in a test medium (Fowells, 1949). The cone maturity check must be made within a half hour after the cones are collected from the tree. If cones are collected from felled trees, they must be tested for maturity within 1 day after the trees are cut.

The cone maturity sampling will vary during the collection season. At the beginning of the collection season, the cones for each tree should be tested. Later in the season, if the cones on at least four out of five trees at each location are found to be mature, further sampling is not required. However, a maturity check should be made at each new location that has a different environment.

The specific gravity of cones at the time they begin to open on the tree varies by species. Sugar and ponderosa pine cones started to open on the tree when the specific gravity was 0.62 (Schubert, 1956a). Jeffrey pine cones were still closed at a specific gravity of 0.61 (Schubert, 1956a). Douglas-fir cones were reported to open when the specific gravity was about 0.69 (Ching and Ching, 1962).

Other criteria than specific gravity have been used as seed maturity guides, including cone color, seed coat color, plumpness and firmness of seeds, absence of milky fluid in the endosperm, and cone cutting by squirrels. These guides have resulted in high quality as well as low quality seed collections.

These subjective guides all have certain shortcomings: (a) cones often mature on trees without an appreciable change in color; (b) insect infested cones may change from green to brown long before the seeds are mature; (c) light-colored seeds have at times a higher viability than dark-colored ones; (d) the endosperm of a mature seed is full, firm, and without a milky fluid, but immature seeds may also seem to possess these same characteristics; and (e) squirrels start to cut cones in June – about 3 to 4 months before the seeds are ripe. However, squirrels may not begin to store cones for winter use until late summer or early fall. The earliest cone caches will usually contain a mixture of mature and immature cones, whereas latest caches may contain a high proportion of mature cones.

Failure to test cones and seeds properly has often resulted in problems in seed extraction and assessment of seed quality. Immature cones require more time to open than mature cones. At times they do not open even after considerable extra handling, and then yield only a small quantity of seed. The low seed quality often may not be apparent until a germination test is made some months or years later. Seeds from immature cones may appear to be good by cutting tests, but the viability is usually low or many seedlings are abnormal and worthless (table 9, fig. 10) (Schubert, 1956a).

Table 9. Seedling development of sugar, Jeffrey, and ponderosa pines from seed of four specific gravity cone classes.

Species and cone specific gravity class	Seedling development		
	Normal	Abnormal	Total
	Percent		
Sugar pine:			
0.58-0.69	98	0	98
.70- .79	100	0	100
.80- .87	35	17	52
.88- .95	35	50	85
Jeffrey pine:			
0.61-0.80	71	0	71
.81- .86	72	0	72
.87- .92	61	18	79
.93-1.00	48	32	80
Ponderosa pine:			
0.60-0.80	76	0	76
.81- .86	73	0	73
.87- .92	39	0	39
.93-1.00	29	0	29

A sample of cones that is ripe enough to harvest should be cut to determine the number of good seeds per cone. The test of cone specific gravity gives an indication of seed maturity but not seed quantity. To determine the quantity of good seeds, the cones must be sliced lengthwise and the good seeds counted on one of the sliced surfaces. This count of good seed does not include the seeds at the base or top of the cones which are often undeveloped. Cones of the pines, hemlocks, and Douglas-fir are cut through the center core. The

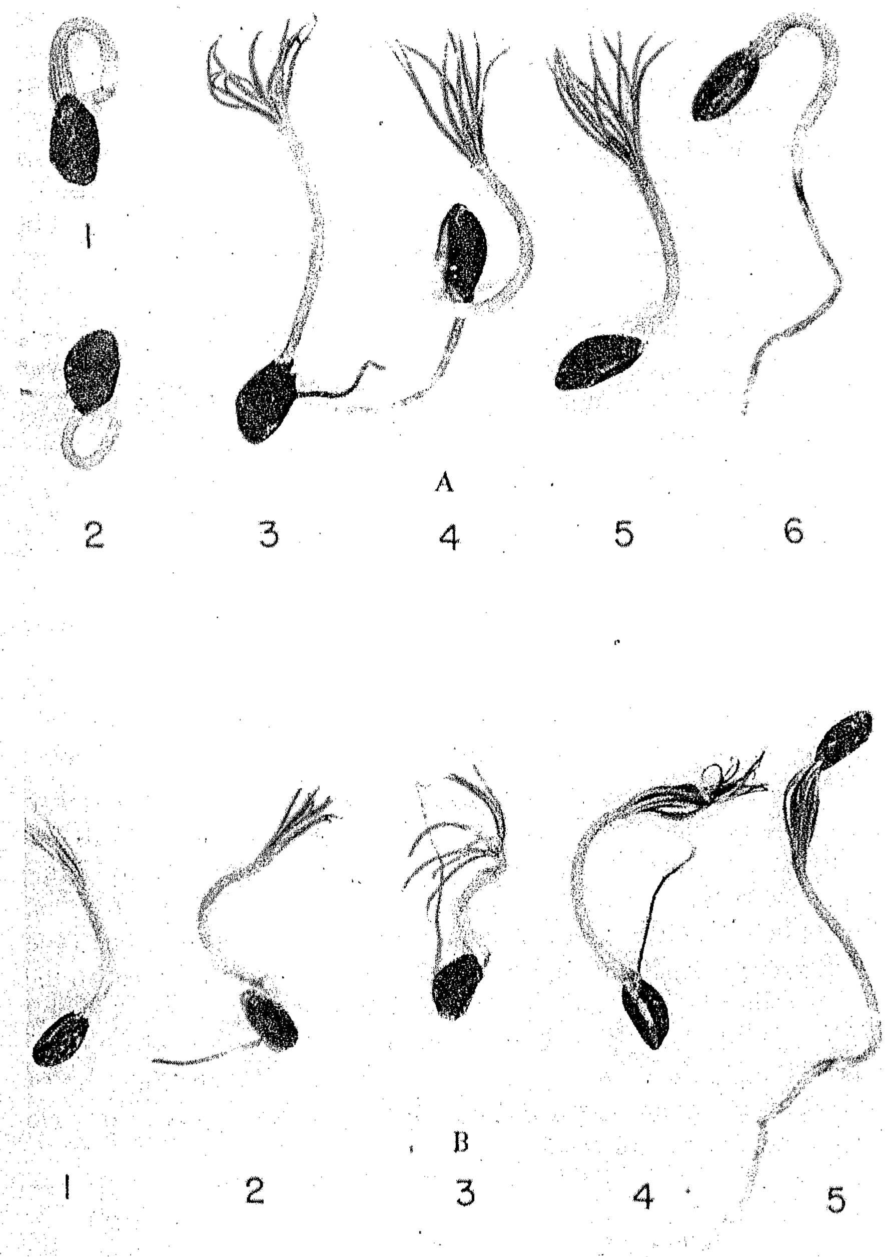


Figure 10. Abnormal sugar pine (A1-A5) and Jeffrey pine (B1-B4) seedlings associated with immature seed.

spruces and true firs are sliced about ¼ to ½ inch to either side of the center core. For the cones to be acceptable, at least 75 percent of the exposed pine seeds and 50 percent of the exposed seeds of the other species should be good. Incense-cedar cones can be tested by cutting across the axis about ¼ inch above the base of the cone to expose the four seeds with at least two being sound.

Average counts of good seed on the cut surface of each cone for the Pacific Northwest were made by Douglass (1960):

Species:	No. of good seeds per cut surface
Douglas-fir	6
Hemlock	8
Ponderosa pine	10
Sitka spruce	14

For noble fir and other true firs, 50% or more exposed seeds were good.

Methods of Cone Collection

Cones may be collected from standing or felled trees or rodent caches (Weyerhaeuser Timber Company, [1960]). Many different methods and types of equipment have been described for collecting cones. No attempt will be made to list or evaluate all the different ways used to collect cones. Each system has its own advantages and disadvantages depending upon tree size, location of the cones on the tree, terrain features, the size of the cone collection operation, and the availability of special equipment. Each, in turn, is affected by personal preference. Whichever method is used, safety must be of prime consideration. Cone pickers must operate in pairs to provide prompt help in case of accidents.

Most cones are collected from standing trees. Cones on the true firs occur almost exclusively in the tops of trees. In other species, most cones occur in the top half of the crown. For small trees, the cones may be within hand reach from the ground or be reached with a sharp-bladed hook on a pole. For large trees, the cones can be

reached by climbing with or without the aid of climbers, depending on tree size and branch structure, or with the aid of a rope. Special tree ladders are available that can be chained to the trunks of trees for climbing into the lower crowns (Miles and Hoekstra, 1954). The cones may be reached from a ladder or scaffolding set on the ground or mounted on a truck (Petersen, 1962). Special truck-mounted ladders or hydraulic devices are limited by terrain and tree spacing, and therefore most commonly suited to seed orchards or seed production areas. Whatever method is used to gain access to the tree the picker should consider using a cone cutter on a long handled pole or a hook welded to 6 to 8 feet of number 9 wire to aid in pulling cone bearing branches within reach for hand picking. Safety belts are a **must** when working in trees on long ladders or scaffolding.

Mechanical tree shakers designed for shaking fruit from orchard trees are being used to shake cones from trees. Shakers are gaining acceptance in Southern States' seed orchards and seed production areas (Kmecza, 1970) and have been tried in California. [5]

At times cones may be picked from felled trees. Trees should not be cut solely for their cone crop. During fall harvest cutting, trees with a heavy cone crop should be felled when the cones are mature. The cones then can be picked easily by hand. Pickers must not follow fallers too closely and should be on the lookout for broken branches and tree tops that may have lodged in residual trees after falling operations.

As indicated earlier, collect cones from rodent caches only in areas surrounded by high quality trees. Cones of some species, such as Sierra and coast redwood, are difficult to obtain from standing trees, and rodent caches may be the only readily available source. Rodent caches also have been robbed for pine and Douglas-fir cones. Squirrels generally locate their caches in moist, shady spots along stream banks, in hollow stumps or logs, or in holes under stumps or rocks. However, a cone cutting test should be made before harvesting cones from rodent caches.

Some cones, such as those from Sierra redwood, knobcone pine, and Bishop pine may remain unopened on the tree for several years. As long as these cones remain closed the seed will remain viable.

[5] Knight, Michel. Unpublished report on file. U. S. Forest Serv., California Region, October 9, 1968.

Cone Collection Schedules

Knowing when cones mature, by species, in different locations would be quite helpful in scheduling cone harvests. Unfortunately data on ripening dates are limited. Considerable time and expense could be saved by setting up cone collection periods, by species, for the main collection areas. Each year's record will increase the value of this information. The earliest maturation dates would serve as a general guide to start sampling cones for ripeness.

At best the cone collection period is short, but careful scheduling, by species and location, can extend this period. For example, on Stanislaus National Forest, the cones opened in the following order: first, Jeffrey pine cones; then sugar; and last, ponderosa pine (Schubert, 1956a). Other species within the same area may be fitted into this or an extension of this sequence. In general, cones ripen first at lower elevations, on south and west exposures and last at higher elevations and on north and east exposures. In the Pacific Northwest, the collection season was extended by "post harvest ripening" techniques (Lavender, 1958; Silen, 1958); but this procedure needs to be adequately tested in California before adoption. In this procedure, Douglas-fir cones were collected before they matured on the trees and then placed in a running stream to complete ripening.

Cone and Seed Processing

Cone and seed processing includes all the operations from cone collection until the seeds are ready for immediate use or storage. Special care is required during this period to prevent injury to the seeds and to maintain proper seed identity.

At the collection location, cones are normally placed in burlap sacks and the sacks properly tagged. No matter what the system used, tags must identify each sack so that there will be no danger of mixing species or lots during transportation and processing. A cone buyer may require such information as species name, seed zone, section, township and range, county, elevation, collection date, and name of collector on each tag. The California Division of Forestry

requires only the pre-assigned lot number be entered on each tag. Complete information on the lot is filled in by the collecting supervisor on a press numbered seed collection card (fig. 11) that is mailed to the processing plant. This method reduces the time required to fill out complete information on tags. Cones to be used in tree improvement work may require labeling with still additional information, such as site index, aspect, slope, soil type, stand condition, and tree characteristics.

The cones should be transported to the seed extractory the same day collected or within a day or two at most. The sacks should be stacked loosely on the transport to permit air circulation. If cones must be held for a few days at the collection station, the sacks should be placed on storage racks with adequate space around each sack to permit the cones to dry and to prevent overheating or molding. Coast redwood, true fir and Douglas-fir cones should be removed from sacks and spread on a tarp or floor and stirred occasionally. Cones of most species from the earliest collections, squirrel caches, and those that have been wet are most likely to overheat and become moldy. These moist cones must be surface dried before shipment to or immediately after arrival at the seed extractory.

Upon arrival at the extractory, the cones may be processed immediately, or placed on drying racks for storage until processing. Cones should never be piled or stacked in sacks without provisions for adequate ventilation. Storage racks may be outdoors or in a building. If outdoors, cones must be protected from rain and losses from birds and rodents. Cones indoors also require protection from rodents, particularly mice.

Some seed processors predry cones to reduce the time required for seed extraction. Predrying may be done in any heated, ventilated shed.

Cones may be opened to extract seed by several methods. Three that take advantage of natural heat are: (1) spreading cones in a thin layer in the sun on canvas, wood platform or cemented area; (2) placing cones on cone-drying racks either out of doors or under cover; and (3) hanging loosely filled cone sacks from an overhead rack. These three methods generally require a warm dry climate during processing. Cones opened by natural heat should be stirred or turned occasionally to get uniform opening of scales.

No 807

DIVISION OF FORESTRY
REPORT
of
CONE COLLECTION

Species:________
Location of Collection:
County:________
T:____ R:____ Sec.____
Elevation:________
Dates of Collection:________

No. Sacks Cones Collected:________
No. sacks rough cleaned seed processed:________
Condition of Crop:
Good____ Fair____ Poor____
Remarks: (Access, directions, owner, etc.)________

Collected by:________
Title____ Unit____

FORM No. FM 44 69367 7-62 1M TRIP ② SPO

Figure 11. Cone collection card used by the California Division of Forestry.

If a more rapid method is desired, artificial heat is used in extracting cones (fig. 12). This technique is suitable in any climate.

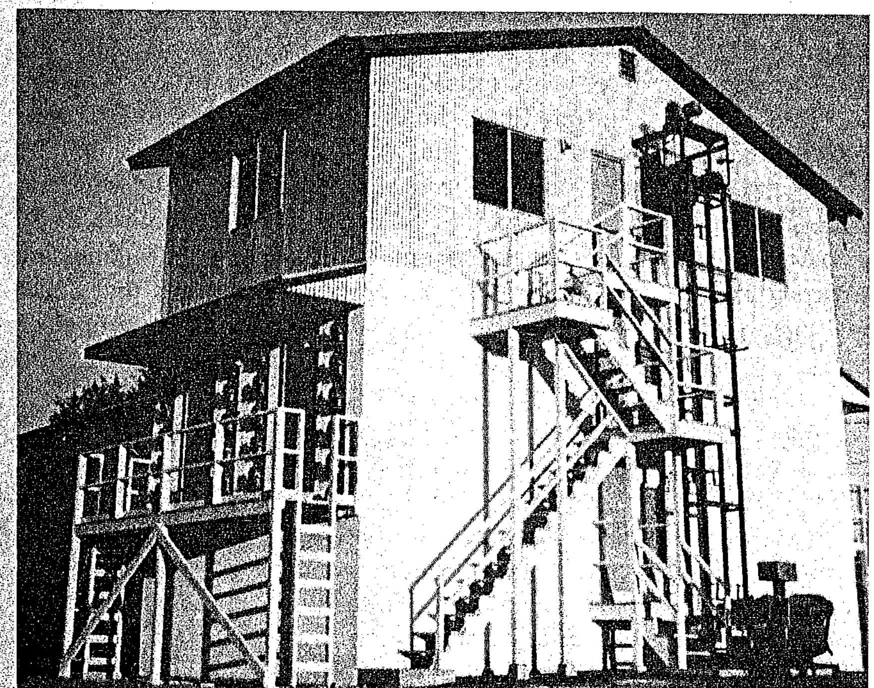


Figure 12. Modern seed extraction plant at California Division of Forestry, Davis Headquarters Nursery.

Cones dry slower at air temperatures with less chance for seed damage than at cone kiln temperatures. Generally, no special precautions are needed to prevent overheating at air temperatures, if adequate ventilation is provided. Cone kilns require careful regulation of heat and humidity to keep them below levels injurious to the seeds. Successful seed extraction in cone kilns depends on a sufficient volume of hot air (fig. 13A) to raise the cone temperature to the safe maximum within about an hour. It also depends on rapid circulation of air to dry and open all cones as quickly as possible.

The maximum safe kiln temperature will vary by species and the amount of moisture in the cones. In general, the maximum temperature in the cone kiln should not exceed 130 °F. for most species, except for the closed cone pines, which should not exceed 140 ° to 160 °F. Lower temperatures are preferable, if they are sufficient to open the cones. Extractories processing Douglas-fir and ponderosa pine generally operate at 110 °F. to 120 ° F. The temperatures for moist cones should be about 20 to 30 °F., lower than for dry cones. At many extractories, cones that have not been precured are placed in the kiln at the temperature for moist cones for about 10 to 15 hours and then the temperature raised to complete cone opening. All seeds should be removed from the kiln when the cones have opened completely.

Most seed will be released from open cones if the cones are turned during drying. However, most processing requires that cones be transferred to a cone tumbler (fig. 13B). The tumbler should be turned slowly to prevent damage to the seeds. Cones dried in a kiln with a tumbler or shaking trays may not require extra tumbling.

After the seeds are extracted from the cones, they are passed over a screen to remove sharp cone scales which may damage the seeds during final processing. Often this screening or scalping is combined with the seed extraction process.

Seeds of most species, except Sierra and coast redwood, are then processed through a dewinger and fanning mill. Removing seed wings may be done by hand rubbing or rubbing with brushes in a dewinger as the one designed by Lanquist (1954). Seeds are seldom damaged by hand rubbing, but may be by the stiff bristled brushes of a dewinger. The brushes and rotation speed should be set to remove or break off the seed wings without cracking the seed coats. Since true firs and incense-cedar seeds are easily damaged by dewingers with stiff brushes, they usually are not processed through this kind of equipment. All species in relatively large lots may be dewinged effectively by passing through a grain mixer with the r.p.m. reduced to between 30 and 60 (fig. 13C). The seed wings, empty seeds, and other debris are removed by a fanning mill (fig. 13D) as a separate operation or combined with the dewinging. The cleaning and upgrading may be refined still further by the use of such equipment

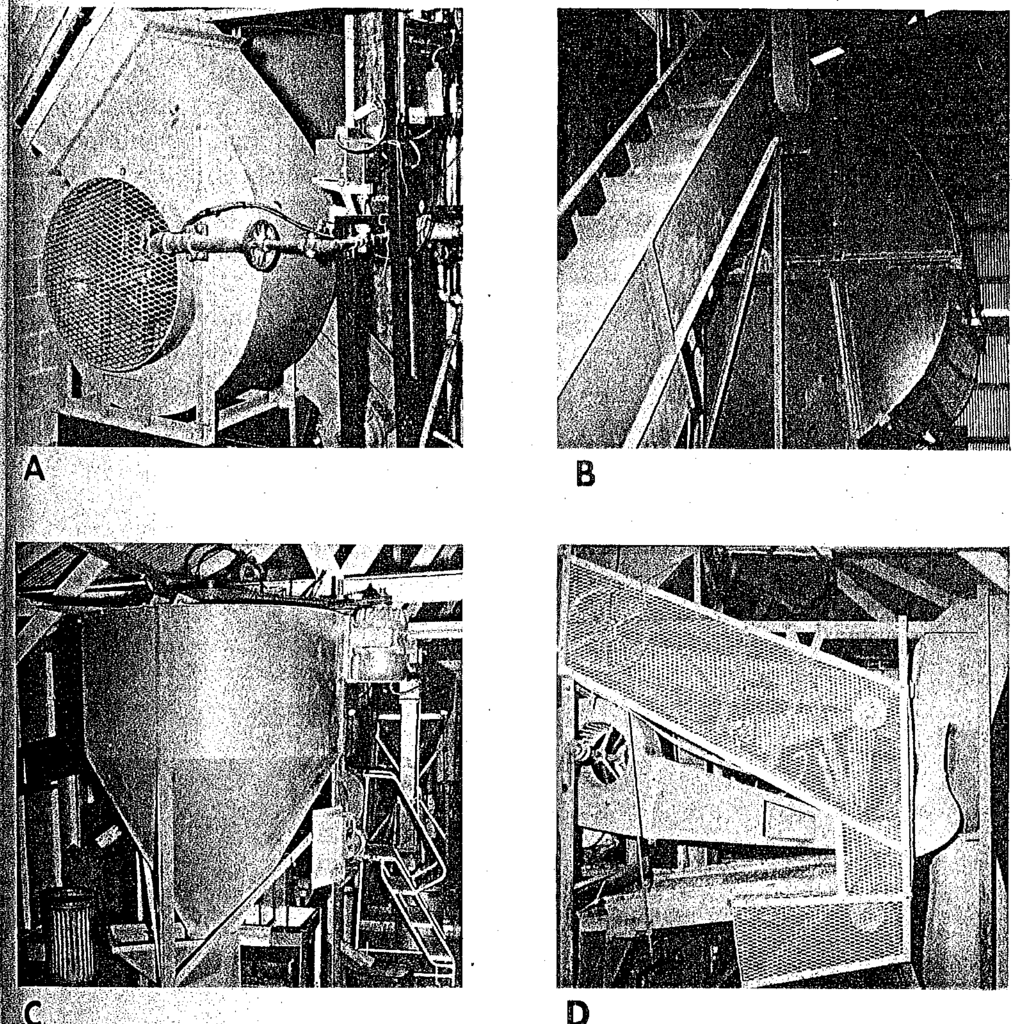
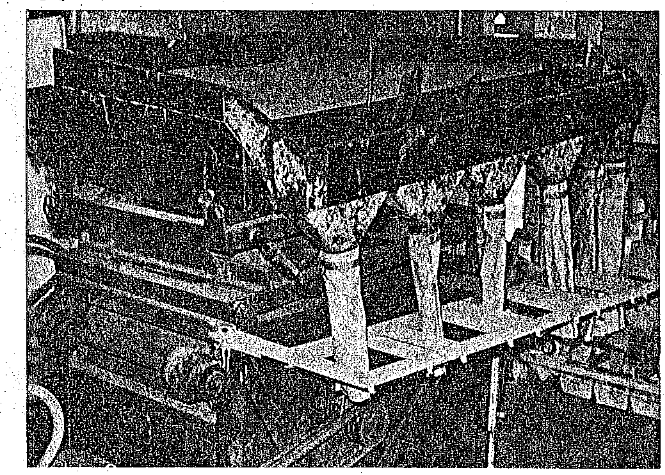


Figure 13. Examples of some seed processing equipment used by California Division of Forestry at Davis Headquarters Nursery and by the U. S. Forest Service at Placerville Nursery. (A) 700,000 b.t.u. natural gas burner and 8,000 cu. ft./min. blower to heat the kiln. (B) Continuous flow cone tumbler. (C) 1,200 lb. capacity grain mixer for dewinging. (D) Scalper and fanning mill.

as a pneumatic separator and gravity separating table (figs. 14A and B). After each lot of seed has been processed, it should be thoroughly mixed for homogeneity.

A



B

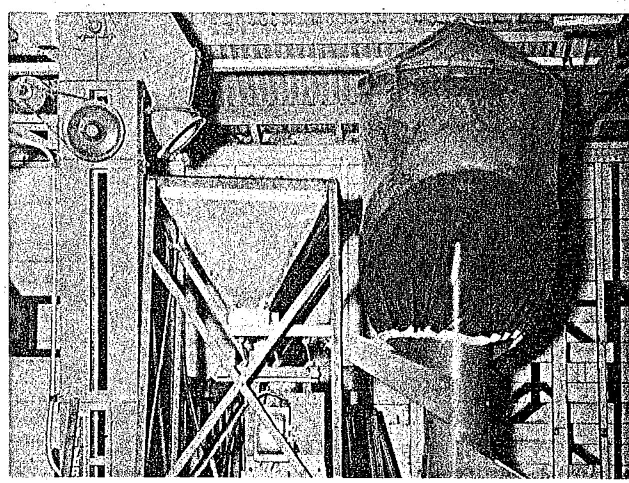
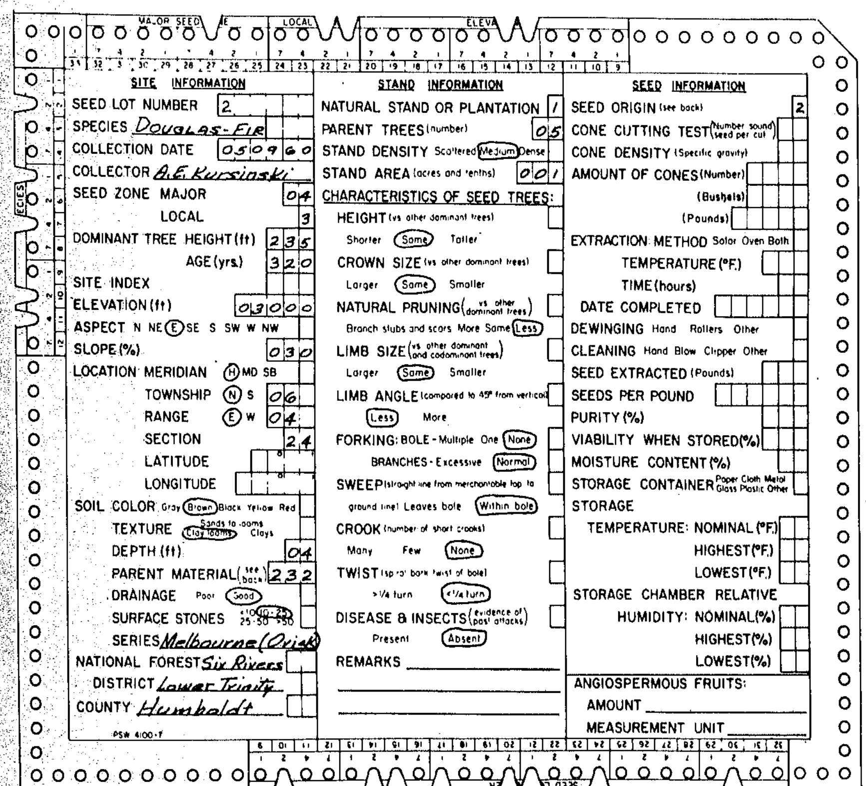


Figure 14A and 14B. Equipment to further refine the seed cleaning process. (A) Gravity separating table. (B) Pneumatic separator.

The seeds are then dried, if necessary, and poured into storage containers that have been properly identified by a tag. A cone collection tag also should be placed on top of the seed in each container. A seed-lot record card, of the type proposed by Roy (1963 a,b) for research collections (fig. 15), or by California Division of Forestry for large scale collections (fig. 16) should be prepared for the entire seed lot. Part of the data for the seed-lot record card are taken from the cone collection tag or collection card and the remainder from information taken after collection and during seed extraction. Inventory data are recorded on the reverse side of the card proposed by Roy (fig. 17) and on the face of the California Division of Forestry card (fig. 16).



SITE INFORMATION
SEED LOT NUMBER 2
SPECIES Douglas-Fir
COLLECTION DATE 05 09 60
COLLECTOR A.E. Kursinski
SEED ZONE MAJOR 04
LOCAL 3
DOMINANT TREE HEIGHT (ft) 235
AGE (yrs.) 320
SITE INDEX
ELEVATION (ft) 03000
ASPECT N NE (E) SE S SW W NW
SLOPE (%) 030
LOCATION MERIDIAN (H) MD SB
TOWNSHIP (N) S 06
RANGE (E) W 04
SECTION 24
LATITUDE
LONGITUDE
SOIL COLOR Gray (Brown) Black Yellow Red
TEXTURE Sands to loams (Clay loams) Clays
DEPTH (ft) 04
PARENT MATERIAL (see back) 232
DRAINAGE Poor (Good)
SURFACE STONES <10 (10-25) 25-50 >50
SERIES Melbourne (Orick)
NATIONAL FOREST Six Rivers
DISTRICT Lower Trinity
COUNTY Humboldt
PSW 4100-7

STAND INFORMATION
NATURAL STAND OR PLANTATION 1
PARENT TREES (number) 05
STAND DENSITY Scattered (Medium) Dense
STAND AREA (acres and tenths) 001
CHARACTERISTICS OF SEED TREES:
HEIGHT (vs other dominant trees)
Shorter (Same) Taller
CROWN SIZE (vs other dominant trees)
Larger (Same) Smaller
NATURAL PRUNING (vs other dominant trees)
Branch stubs and scars More Same (Less)
LIMB SIZE (vs other dominant and codominant trees)
Larger (Same) Smaller
LIMB ANGLE (compared to 45° from vertical)
(Less) More
FORKING: BOLE - Multiple One (None)
BRANCHES - Excessive (Normal)
SWEEP (straight line from merchantable top to ground line) Leaves bole (Within bole)
CROOK (number of short crooks)
Many Few (None)
TWIST (spiral bark twist of bole)
>1/4 turn (<1/4 turn)
DISEASE & INSECTS (evidence of past attacks)
Present (Absent)
REMARKS

SEED INFORMATION
SEED ORIGIN (see back) 2
CONE CUTTING TEST (Number sound seed per cut)
CONE DENSITY (Specific gravity)
AMOUNT OF CONES (Number)
(Bushels)
(Pounds)
EXTRACTION METHOD Solar Oven Both
TEMPERATURE (°F.)
TIME (hours)
DATE COMPLETED
DEWINGING Hand Rollers Other
CLEANING Hand Blow Clipper Other
SEED EXTRACTED (Pounds)
SEEDS PER POUND
PURITY (%)
VIABILITY WHEN STORED (%)
MOISTURE CONTENT (%)
STORAGE CONTAINER Paper Cloth Metal Glass Plastic Other
STORAGE
TEMPERATURE: NOMINAL (°F.)
HIGHEST (°F.)
LOWEST (°F.)
STORAGE CHAMBER RELATIVE
HUMIDITY: NOMINAL (%)
HIGHEST (%)
LOWEST (%)
ANGIOSPERMOUS FRUITS:
AMOUNT
MEASUREMENT UNIT

Figure 15. Seed-lot record card as marked by seed collector in field.

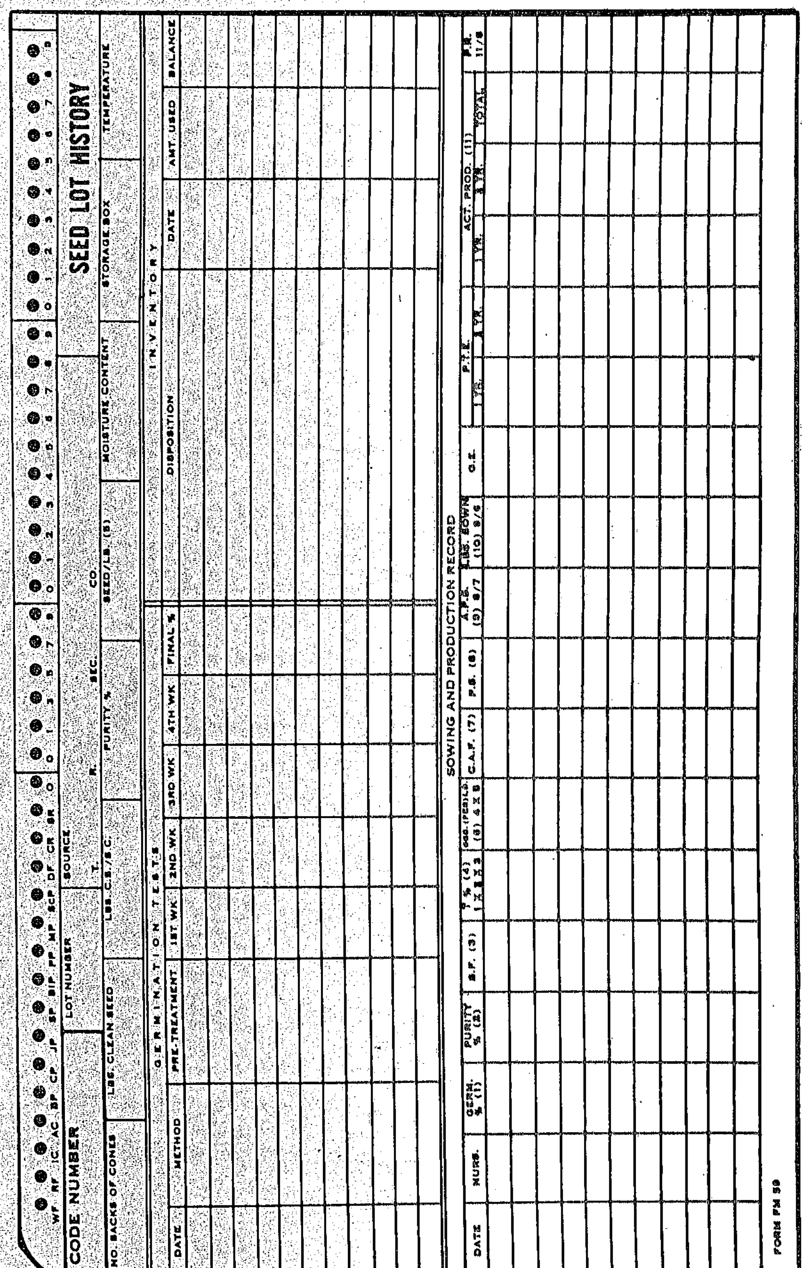


Figure 16. Seed record card used by California Division of Forestry which may be punched for needle sort.

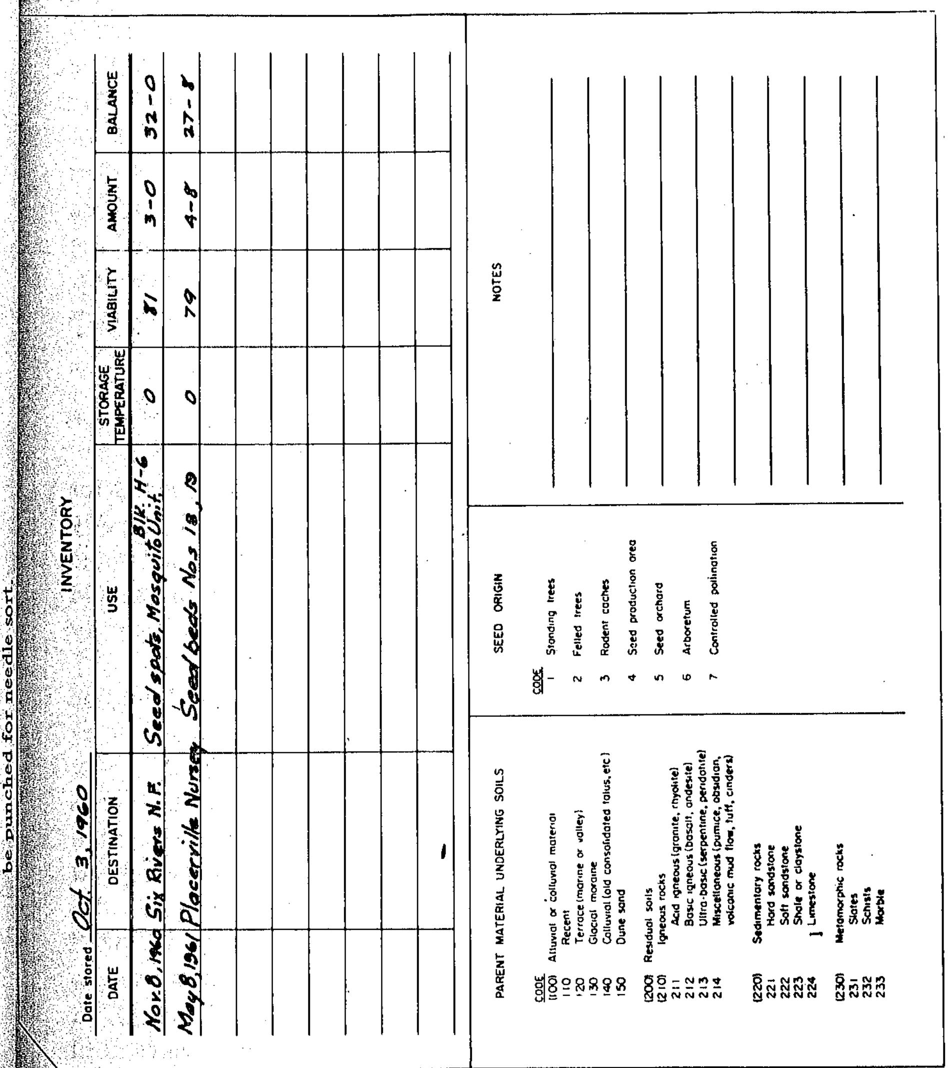


Figure 17. Seed-lot inventory record printed on back of seed lot record card proposed by Roy (1963a, b).

SEED STORAGE

All seeds of California conifers that are used in artificial reforestation must be stored. Some seeds may be stored for only two or three months; others must be stored for several years to meet the demand when there are no seed crops. Technically, seeds can be considered in storage from the time they reach maturity until they are placed in an environment conducive to germination. Seeds of almost all conifers can be kept viable for the required periods if they are properly handled in storage. Seed moisture content and storage temperature are the two most important considerations–provided the seed is mature when harvested and undamaged during processing. Usually immature or damaged seed will not retain its viability even under the best storage conditions.

Moisture Content

The seed moisture content is generally at acceptable levels for most species of seeds that are fully ripe when collected and properly processed (Schubert, 1956a). If these conditions are not met, some additional drying may be necessary. The moisture content should range from 4 to 8 percent for all California conifers requiring dry cold storage.

If the moisture content is above 8 percent, the seeds should be dried to below that amount. Seeds may be dried by sunlight or by artificial heat in a kiln or oven. Of the two, direct sunlight is safer and cheaper. Under direct sunlight, spread the seeds in shallow layers in trays or place them in loosely woven sacks that hold about 20 to 25 pounds. Stir the seeds or turn the sacks often during the day. At night replace them in moisture-proof containers. Repeat this procedure each day until the moisture content drops below 8 percent. If seeds are dried by artifical heat, spread them in shallow layers in trays in a well ventilated kiln or oven set at 90 to 100 °F. As with outdoor drying stir seeds often and allow them to dry until the moisture content drops below 8 percent, but not less than 4 percent.

Successful storage has been reported for seeds with moisture contents as low as: 4 percent for ponderosa pine (Schubert, 1956a);

5 percent for Jeffrey pine (Schubert, 1956a); 6 percent for white fir (Allen, 1957), Douglas-fir (Barton, 1954a,b) and sugar pine (Schubert, 1956a); and 7 percent for Sitka spruce and western hemlock (Allen, 1957). The moisture content of all other California coniferous seeds can be reduced to 4 to 8 percent without damage to the seeds. The lower moisture content gives a greater flexibility in choice of storage temperatures and a lower probability of mold contamination (Schubert, 1961).

Several methods have been used to determine seed moisture content, the most frequently used and recommended is the oven-drying method. The procedure is as follows:

1. Thoroughly mix all seeds in the population to be sampled. This may be an entire seed lot or the contents of one or more containers.

2. Draw three representative seed samples of about 20 grams each. Smaller samples may be used if total quantity of seeds is small.

3. Weigh seeds on an accurate balance to obtain "fresh weight" to nearest 0.1 gram.

4. Place seeds in oven at about 180 to 190° F. Temperatures higher than 190° F. may drive off volatile hydrocarbons.

5. Dry seeds until they reach a constant weight. The seeds should be weighed periodically until there is no further loss in weight. Drying time is usually from 2 to 24 hours, but may take up to 48 hours.

6. Record weight of seeds at each weighing.

7. Calculate moisture content as a percent of oven-dry weight as follows:

$$\text{Moisture content percent } \left(\frac{\text{Original weight} - \text{oven-dry weight}}{\text{Oven-dry weight}} \times 100 \right)$$

8. Determine average moisture content of the three samples to nearest 0.1 percent.

Although somewhat expensive, moisture determination equipment is available that will give relatively accurate direct readings.

Storage Temperature

All seeds of coniferous species retain viability best when stored at low temperatures. Both temperature and moisture affect the respiration rate of live seeds. Some respiration is needed to keep the seeds alive, but the rate should be reduced to safe minumum levels to extend the seed's life.

Most storage temperatures in the past ranged from 23 ° F. to 41° F., at which some species retained viability (Heidmann, 1962; Schubert, 1952, 1954). Today, however, below-freezing temperatures are generally being recommended. Even when stored at the "best" storage temperature, a given species has often shown extremely variable germination results (Schubert, 1961; Wakeley, 1954). Where results have been variable, it appears that: (1) the moisture content was usually too high--above 10 percent, or (2) seed fungi destroyed the seed--particularly sugar pine, or (3) the seed was immature, or (4) the seed was damaged during processing, or (5) storage temperature was too high--usually with uncontrolled temperature conditions. The exact cause for viability losses even in "controlled experiments" is often unknown. The drop in viability may have been the result of any one or a combination of factors.

Seed storage tests have shown that Jeffrey and ponderosa pine have retained high viability at 0°, 23°, 32°, and 41° F., but sugar pine did not at the higher temperatures (table 10). One seed lot of sugar pine stored at 41° F. had a viability of 95 percent after 7 years of storage (Mirov and Kraebel, 1937) and 50 percent at the end of 15 years (Schubert, 1952). However, some seed lots of sugar pine have lost all viability in 2 to 5 years at this temperature (Schubert, 1954, 1961). Some species, such as white fir, grand fir, red fir, and incense-cedar, lose all viability within a few years when stored at 41° F., but retain high viability when stored at 0 ° F. (Schubert, 1952).

Since viability is least affected at low temperatures, dry seed can be stored successfully at 0 ° to 5 ° F. (Allen, 1957; Barton, 1954a,b; Schubert, 1955c, 1961; Stone, 1957a,b,c). We have found no references indicating that 0 ° F. was too cold to store any coniferous seed. Seeds remain viable over winter on the ground even though the air temperature dropped to below -40 ° F.

Table 10. Viability of sugar, Jeffrey, and ponderosa pine seed stored at four temperatures by length of storage.

Species and years in storage	Storage temperatures 0°F.	23°F.	32°F.	41°F.
	Percent			
Sugar pine 1/				
0	98	98	98	98
2	94	84	77	6
5	78	8	0	0
8	60	0	0	0
Jeffrey pine				
0	93	93	93	93
2	91	93	85	84
5	89	89	2/	85
8	83	88	83	81
Ponderosa pine				
0	86	86	86	86
2	76	78	85	76
5	65	80	2/	66
8	64	70	2/	66

1/ Seed infected with fungi.
2/ Seed misplaced.

Storage Container

For seeds requiring dry cold storage, use a container with a tight-fitting top, although it probably need not be sealed (Holmes and Buszewicz, 1958a,b). Seeds of some species, for which sealed containers have been recommended, have been successfully stored in sacks or canvas bags at subfreezing temperatures when the seed moisture content had been reduced to the lower recommended limits. Actually, seed with a high moisture content may deteriorate rapidly in airtight containers because of anaerobic respiration. Similar seeds stored in open or porous containers are not so likely to deteriorate rapidly because excess moisture and heat can escape.

Containers should be chosen for their effects on seed moisture content (Wakeley, 1954) – particularly when seeds are to be stored at above-freezing temperatures and humidity is uncontrolled. Seeds stored at or above 32 ° F. should be in airtight containers – either cans, jars, or polyethylene bags.

The type, size, and shape of the container may vary by individual requirements and preferences. Cans, fibre drums, and polethylene bags have all been found to be satisfactory. Since equipment failures may occur, it is advisable to use containers with tight-fitting covers. Polyethylene bags should be closed at the top and preferably used as a liner in cans or fibre drums since bags are subject to damage. The size of the container should not be too large to handle when full. They also should be kept relatively small to reduce the possibility of heavy losses if seeds are or become contaminated. A 15½-inch diameter by 21-inch high fibre drum is a convenient size (fig. 18).

Seed Longevity

Coniferous seeds differ considerably in how long they can remain viable. Some species remain viable for 20 or more years; others only 1 year or so. If the seeds retain their viability in storage, then a supply may be collected during good seed years to last through poor seed years. If they do not retain viability, then only sufficient seeds should be collected to satisfy current needs.

In 1945 and 1951, seed viability of most California conifers was checked after 2 to 24 years of storage (Mirov, 1946; Schubert, 1952, 1954). These studies indicated that seed of all conifers (except the true firs, incense-cedar, and redwood) could be stored for at least 10 years in airtight containers at 41 ° F. (table 11). Seed viability, by species, varied widely. There probably would have been less variability and higher viability for all species had the seed been uniformly good and stored at 0 ° F.

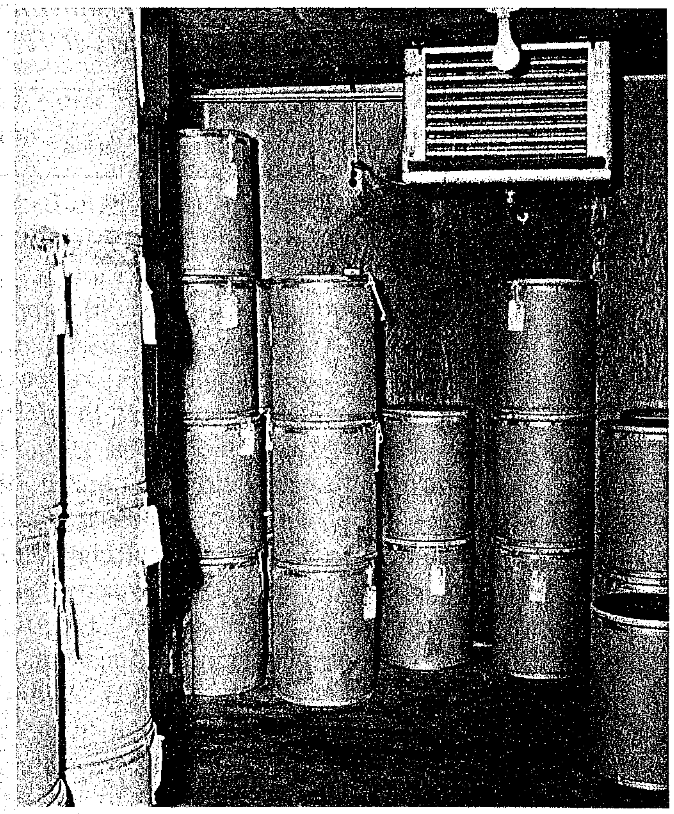


Figure 18. Fibre drums 15½ inches in diameter by 21 inches high used for tree seed storage.

SEED GERMINATION

The chief objective of storing seeds is to prolong life by reducing respiration and other biochemical activity to a minimum. To induce germination, seeds are sown under conditions of higher moisture, temperature, and oxygen than prevailed during storage.

Respiration and biochemical activity are increased. The rate at which the embryo grows and develops into a seedling is affected by such factors as seed dormancy, age of the seed, maturity, geographic origin, soil and air temperature, and moisture supply.

Table 11. Viability of some common California coniferous seed stored at least 2 years in airtight containers at 41° F.

Species 1/	Viability	Storage period
	Percent	Years
White fir	53 6	3 21
California red fir	24 8	6 16
Incense-cedar	98 74	2 3
Knobcone pine	87 76	16 17
Lodgepole pine	77 47	11 17
Jeffrey pine	88 62	10 18
Sugar pine	56 50	16 15
Ponderosa pine	94 75	18 17
Monterey pine	86 81	21 14
Douglas-fir	66 31	6 16
Sierra redwood	68 46	12 13
Coast redwood	14 1	3 17

Source: Mirov (1946); Schubert (1952, 1954).

1/ Two best seed lots of each species.

Seed Dormancy

Dormancy in seeds may be caused by one or more different factors. Some seeds have a seed coat dormancy--the seed coat may be impermeable to water or oxygen, or it may contain inhibitors. Other seeds have embryo dormancy--the embryo may not be fully developed or, if fully developed, may not be physiologically capable of immediate resumption of growth. Some seeds may have both types of dormancy. Temperature-controlled dormancy may be a third type. In the Southwest, ponderosa pine seed will not germinate until exposed to a temperature of 55 to 60° F.; however, it germinates rapidly without a pretreatment under favorable conditions of temperature and moisture (Pearson, 1950). Dormancy is perhaps a safety feature to prevent seed germination before field conditions are favorable for seedling growth.

Seeds of some species may have any type of dormancy, or they may vary significantly in the degree of dormancy. For example, sugar pine has been noted for its poor germination without some pretreatment (Jacobs, 1925; Mirov, 1936; Swensen, 1933); whereas, seeds from many sources of ponderosa and Jeffrey pine, Douglas-fir, and others will germinate without a pretreatment. However, a pretreatment has increased the rate and amount of seed germination of ponderosa pine (Lanquist, 1946), Jeffrey pine (Stone, 1957b), and Douglas-fir (Allen, 1960; Richardson, 1959).

Dormancy of sugar pine seed was reported to be both seed coat and embryo (Stone and Duffield, 1950) and that of Jeffrey pine seed to be seed coat (Stone, 1957b). Germination of sugar pine (Stone, 1957a) and Jeffrey pine seed was improved by removal of the seed coat and the papery membrane. Stone (1957b) attributed the dormancy of the Jeffrey pine seed to impermeability of the seed coat to oxygen. The seed coat of sugar pine retards but does not prevent intake of water (Swensen, 1933) so the seed coat dormancy may have been caused by an inhibitor on the seed coat or by impermeability to oxygen. Saponin, which inhibits germination of bitter-brush seed (Nord and Van Atta, 1960; Pearson, 1957), also is found on sugar pine seed. Saponin, as well as other inhibitors, is hydrolyzed when the seeds are placed in moist cold stratification.

polyethylene bags, (4) close top of bag with string or rubber band, and (5) store in a cold room at 32° to 36° F. for the required stratification period. This method has been referred to as "naked stratification." The polyethylene bags retain moisture, but permit exchange of gases. Pines generally can be treated by this method as a substitute for the moist sand, vermiculite or sponge rock method. Kozlowski (1960) found moist-cold stratification superior to the polyethylene method for balsam fir, therefore it would be advisable to check seeds of each true fir species by both methods to determine the best method to use to break dormancy. Stratification in the polyethylene bags has these advantages over the conventional method:

1. Requires less space for stratification.
2. Simplifies handling of small batches of seeds.
3. Eliminates need to separate seeds from stratifying medium.
4. Makes it easier to use seeds in drill-seeding because they are clean after the surface is dry.
5. Reduces chances of lost seeds where exact numbers of seed are needed for germination tests.
6. Simplifies control of harmful fungi.
7. Reduces need for rewetting the seeds.

The time required to break seed dormancy by either stratification method will vary by species, type of dormancy, age of the seed, and germination temperature. Under natural conditions, coniferous seed may lie on the ground from October until it germinates the following spring. During this period of 6 to 9 months, the seed may be subjected to many fluctuations in temperature and moisture--some favorable and others unfavorable to break dormancy. Therefore, the time seeds lie on the ground in nature does not always indicate how long seeds can be held safely in moist-cold stratification.

Under controlled conditions of favorable moisture, Schubert (1955c) found that many sugar and Jeffrey pine seeds broke dormancy and germinated in less than 5 months at 36° F; whereas, very few ponderosa pine seeds germinated in stratification (table 12). Allen (1960) reported that true fir seed would germinate at 36° F. if held in moist-cold stratification more than 80 days. Thus, if seeds are kept in stratification too long, the seeds may germinate at the stratification temperature or may decrease in viability. Either of these two events can be used to set limits of maximum stratification periods. For example, Stone, (1957a) found that no sugar pine seed germinated during the first 100 days at 41° F., but during the next 30 days, 90 percent germinated.

Table 12. Germination of sugar, Jeffrey, and ponderosa pine seed in 5 months while in stratification at 36° F.

Storage temperature	Sugar pine	Jeffrey pine	Ponderosa pine
	- - - - - - - - - - Percent 1/	- - - - - - - - - -	- - - - - - - - - -
0° F.	86(94)	21(91)	4(76)
23° F.	80(84)	22(93)	1(78)
32° F.	66(77)	20(85)	1(85)
41° F.	3(6)	21(84)	2(76)

Source: Schubert (1955c)

1/ Percents enclosed in parentheses are final germination percentages at 80° F.

Allen (1960) reported that the maximum period Douglas-fir seed could be stratified without loss of viability varied by seed origin. Seed from some origins could be stratified for 150 days without loss of viability; others showed a loss if stratified more than 40 days. These differences by seed origin may account for some of the variation in recommended storage periods by different investigators.

Seeds of all California conifers, except sugar, western white, lodgepole, and Torrey pines, will break dormancy in 30 to 60 days in moist-cold stratification. Seeds of the other species should be stratified for 60 to 90 days. Although lodgepole pine will not break dormancy in a 90-day stratification, 30 days are enough. In general, fresh seed will break dormancy and germinate sooner than seeds stored dry for several years at low temperatures (Stone, 1957a). Seed of the same species may vary in degree of dormancy, some seed lots having rapid and complete germination at shorter stratification periods than those indicated above. For example, Allen (1962b) reported good germination for Douglas-fir seed that had been stratified for only 10 days.

The starting date for moist-cold stratification is governed by (a) the time needed to break seed dormancy, and (b) the date desired for germination. Nurserymen usually plan a sowing date as early in spring as the ground can be worked. This date, with a few exceptions, does not vary by more than a week or two from year to year. Thus, dates to place seed in stratification can be determined with a fair degree of confidence.

Pretreated seed that are not sown immediately should be returned to the cold room. The clean seed should be remoistened if necessary and stored in polyethylene bags. Allen (1962a,b) reported that treated Douglas-fir seeds could be returned to stratification without loss of viability--provided the seeds are kept moist to prevent secondary dormancy. If they are kept moist and cold, most coniferous seeds may be held for an additional 2 to 3 weeks without germinating prematurely or other harmful effects, except possibly for sugar and Jeffrey pines and true firs.

Allen (1962b) reported that stratified Douglas-fir seed could be redried and returned to storage for at least 1 year without much loss in viability. Adams [6] suggested that similar results could be obtained with white fir. However, the practice of redrying and storing stratified seeds is not recommended unless it is unavoidable. If done, the seeds should be restratified and used at the earliest possible date. In no event should these seeds be held in storage for more than 1 year. Stratified seeds of other species should be checked to determine what effect redrying and storing has on viability.

6/ Personal communication.

Germination Temperatures

Coniferous seeds will germinate most readily when the temperature averages about 68 to 77° F. Some investigators seem to prefer a fluctuating temperature between 68 and 86° F. (U. S. Forest Service, 1948; Western Tree Seed Council, 1966). Except under controlled laboratory conditions, the seed germination temperature for California conifers has seldom been measured or reported. Stone (1957a) reported excellent results for sugar pine seed at 59 and 77° F. Richardson (1959) had better results with Douglas-fir at 68 and 78° F. than at 58° F. His findings agree with data reported by Allen (1962b). Seeds will germinate at temperatures below 60° F., but the rate is generally slower except when seeds have been stratified for a longer period.

Relation of Seed Viability in Laboratory to Nursery

Each nurseryman must determine the seed quality of each batch of seeds before he sows the seed beds. Without this information, he has no basis to determine sowing rates to obtain specific seedling densities. Oversowing the seedbeds wastes seeds and leads to laborious, time-consuming hand thinning to the desired density. Undersowing wastes bed space and will not provide the prescribed number of seedlings.

Several methods have been tried to estimate seed quality. Some nurserymen use cutting tests, or staining techniques; others make germination tests. Of these methods, germination tests have been the most reliable. Relatively reliable results have been obtained germinating seed in a 1% solution of hydrogen peroxide (Ching and Parker, 1958). Results can be obtained from five to nine days.

For best germination test results, use a qualified seed laboratory experienced in working with tree seed. Standardized testing procedures for western conifer seed have been recommended by the Western Forest Tree Seed Council (1966) and adopted by the Association of Official Seed Analysts. The procedures specify test substrata materials, lengths of moist-cold stratification periods, germination temperatures, periods of light and lengths of tests.

Cutting tests in general are unreliable as a measure of viability. Seeds that appear sound may have dead embryos. To compensate, nurserymen may arrive at a "conversion factor." At times this practice has given reasonably good results, but it also has grossly overestimated the true viability.

Lanquist (1958) reported that the tetrazolium staining test has provided reliable estimates at Mt. Shasta Nursery for sugar, Jeffrey, and ponderosa pines and Douglas-fir. The success of this method depends on the ability of the individual to distinguish the difference in shades of red to determine the live embryos. The x-ray technique offers possibilities for determining viability (Baron, 1967; Belcher 1967; Belcher and Benson, 1968; Eden 1965; Hansen and Muelder, 1963; Simak, 1960; Stark and Adams, 1963). Radiographs differentiate between empty and filled seed, and indicate healthy tissues. Evaluation of quality from radiographs closely correlates with laboratory germination for fresh seed, but techniques need to be developed yet to provide better evaluation for stored seed. Other nurserymen have used "experience factors" as a guide for seed quality. Of these four methods, the staining test and radiographs probably give the best estimate of seed quality, but none is as reliable as an actual germination test.

Even results from a germination test must be converted to expected seed germination in the nursery. Laboratory germination tests almost always indicate a higher viability than the germination in a nursery. The Woody-Plant Seed Manual (U. S. Forest Service, 1948) indicated that germination in the nursery was 75 percent for ponderosa pine, 78 percent for Jeffrey pine, and 60 percent for lodgepole pine of the viability based on laboratory results. Show (1930) reported that germination in the nursery was only slightly lower than the germination in the greenhouse and both were lower than that indicated by a cutting test (table 13). Czabator (1962) has suggested "germination value" to correlate more closely laboratory results with nursery germination. He developed the formula GV=MDG x PV to obtain germination value, in which GV is germination value, MDG is mean daily germination, and PV peak value.

The difference between the laboratory results and the actual germination in the nursery reflects the effect of uncontrolled factors in the nursery. These factors vary by nurseries and nursery practices from year to year, therefore, each nurseryman should determine a reliable conversion factor based on an average over a period of years for each species.

Table 13. Comparative viability based on cutting tests and germination in greenhouse and nursery.

Species	Cutting	Greenhouse	Nursery
	Percent		
Ponderosa pine:			
Average	84	67	64
Maximum	94	83	78
Minimum	74	53	50
Jeffrey pine:			
Average	79	66	62
Maximum	94	82	80
Minimum	63	45	45

Source: Show (1930).

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III NURSERY PRACTICES

Forest managers require large quantities of nursery stock each year to meet the demands of reforestation. To produce the type of high quality stock needed, they should (1) select the best location for new nurseries; (2) make constant improvements in watering schedules, seed treatment, seeding densities, and other techniques to produce better trees; (3) control fungi, insects, birds, rodents, stock storage, stock shipment, and other factors that may cause losses; and (4) manage the soil properly to maintain nursery fertility.

Present production of planting stock in California comes from three U. S. Forest Service nurseries, three State nurseries, and several small commercial nurseries. Since the late 1940's and early 1950's, when the nurseries were established, the production of stock has increased substantially (table 14).

Table 14. Capacities of California nurseries in 1970.

Nursery	No. of Seedlings
U. S. Forest Service: 1/	
Placerville, El Dorado County	12,000,000
Humboldt, Hunboldt County	15,000,000
State 2/	
Davis Headquarters, Yolo County 3/	240,000
Magalia, Butte County	4,000,000
Ben Lomond, Santa Cruz County	5,000,000
Commercial	2,000,000
Total	38,240,000

1/U. S. Forest Service, California Region, 1970. Report on file.
2/California Division of Forestry, 1970. Report on file.
3/Production is in small tar paper containers for planting in droughty, difficult valley and foothill sites.

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3/Production is in small tar paper containers for planting in droughty, difficult valley and foothill sites.

SEEDLING PHYSIOLOGICAL CONDITION

Greatest concern in nursery practices is the condition of the seedling when it is planted in the field. To produce the best quality seedling possible requires a thorough knowledge of how nursery environment and cultural practices affect the seedling's physiological condition. This knowledge is used to determine criteria for selecting new nursery sites, best seed bed cultural treatments, and storage and shipping practices.

At times the physiological condition of nursery stock is apparent from morphological characteristics, but often no evidence is visible (Stone, 1955a). Wakeley (1954) reported that the presence of winter buds indicated the physiological condition of southern pines. Inconsistencies in survival of ponderosa and Jeffrey pines experienced by early California forest planters were believed to be related to differences in the development of the terminal buds. A field test of 1-1 [7]stock, however, indicated that differences in winter bud development had slight effect on survival (Fowells and Schubert, 1953).

The root regenerating potential (RRP) has been found to be a good index of the physiological condition of planting stock (Stone, *et al.*,1962, Stone and Schubert, 1956, 1959c, 1959d; Stone *et al.*, 1963). Poor survival of stock lifted from nursery beds in fall and planted where soil moisture was plentiful suggests that the trees may have been physiologically dead when planted (Stone, 1955a,b). The plants that failed to produce new roots were morphologically similar to those that produced new roots.

The aerial portion of plants is known to go through periods of growth and rest. But the root system, on undisturbed plants may continue growth throughout the year, although at different rates. Root growth on ponderosa pines lifted at different times during fall, winter, and spring has been found to vary with the season and to

[7]The figure to the left of the hyphen indicates the number of years stock has been in a seed bed, and to the right of the hyphen the years in a transplant bed.

have a different pattern depending on the local nursery climate[8] (Paul and Todd, 1965; Stone and Schubert, 1959a,b,c,d). Studies of Douglas-fir (Stone, *et al.*, 1962; Todd, 1964) and Monterey pine seedlings (Krugman, Stone and Bega, 1965) generally indicate seasonal root growth patterns similar to those for ponderosa pine.

The effect of nursery environment, particularly climate, must be considered in selecting a new nursery site or in scheduling operations in nurseries. One of the most important climatic factors is temperature. The relationship of night and day temperatures has a particularly strong influence on seedling development (Krugman and Stone, 1966).

How temperatures are related to the physiological condition of seedlings of all commercial timber species in nurseries has not been determined yet, but some answers are available for ponderosa pine.

Low Night Temperatures

Reactivation of rapid root growth after the regular growing season seems to depend on exposure of the seedlings to low night temperatures. Krugman and Stone (1966) found that an exposure of 90 days, at a night temperature of 6 degrees C, was required to produce a significant increase in number of new root tips $\geq$ 1.25 cm on seedlings that had been grown in an environmental growth chamber (fig. 19). For total length of new roots $\geq$ 2.5 cm to increase significantly required an exposure of about 120 days (fig. 20). Number and length of new roots continued to increase with additional exposure to low night temperature up to 150 days, the maximum period tested. Similar trends have been reported for 1-1 ponderosa pine (fig. 21A) grown at Placerville Nursery and 1-0 ponderosa pine (fig. 21B) at Ben Lomond Nursery (Krugman and Stone, 1966; Stone, 1967).

[8]Schubert, Gilbert H., and Frank J. Baron. Nursery sites determine planting stock storage schedules, 1965. Report on file at Pacific Southwest Forest & Range Experiment Station, U. S. Forest Service, Berkeley, Calif.

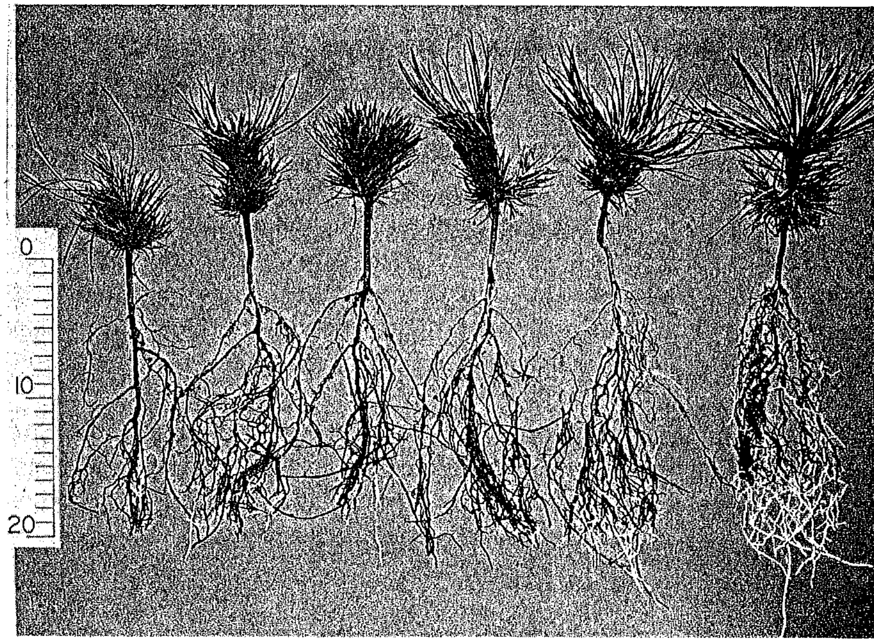

Figure 19. Ponderosa pine seedlings after 30 days growth in the greenhouse following exposure to different numbers of cold nights (6 degrees C). From left to right, seedlings exposed to 0, 30, 60, 90, 120, and 150 consecutive cold nights. (From Krugman and Stone, 1966).

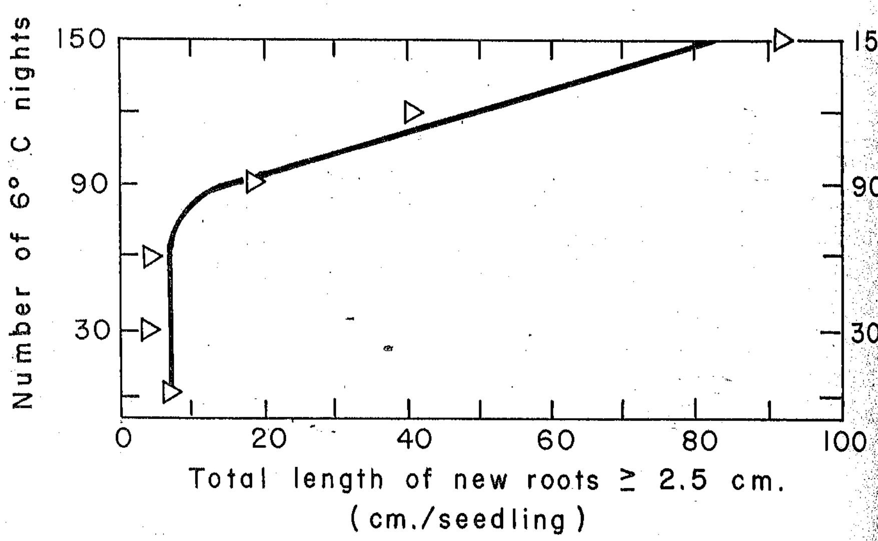

Figure 20. Root regenerating potential of 360 day-old ponderosa pine seedlings, evaluated after 30 days growth in the greenhouse at a

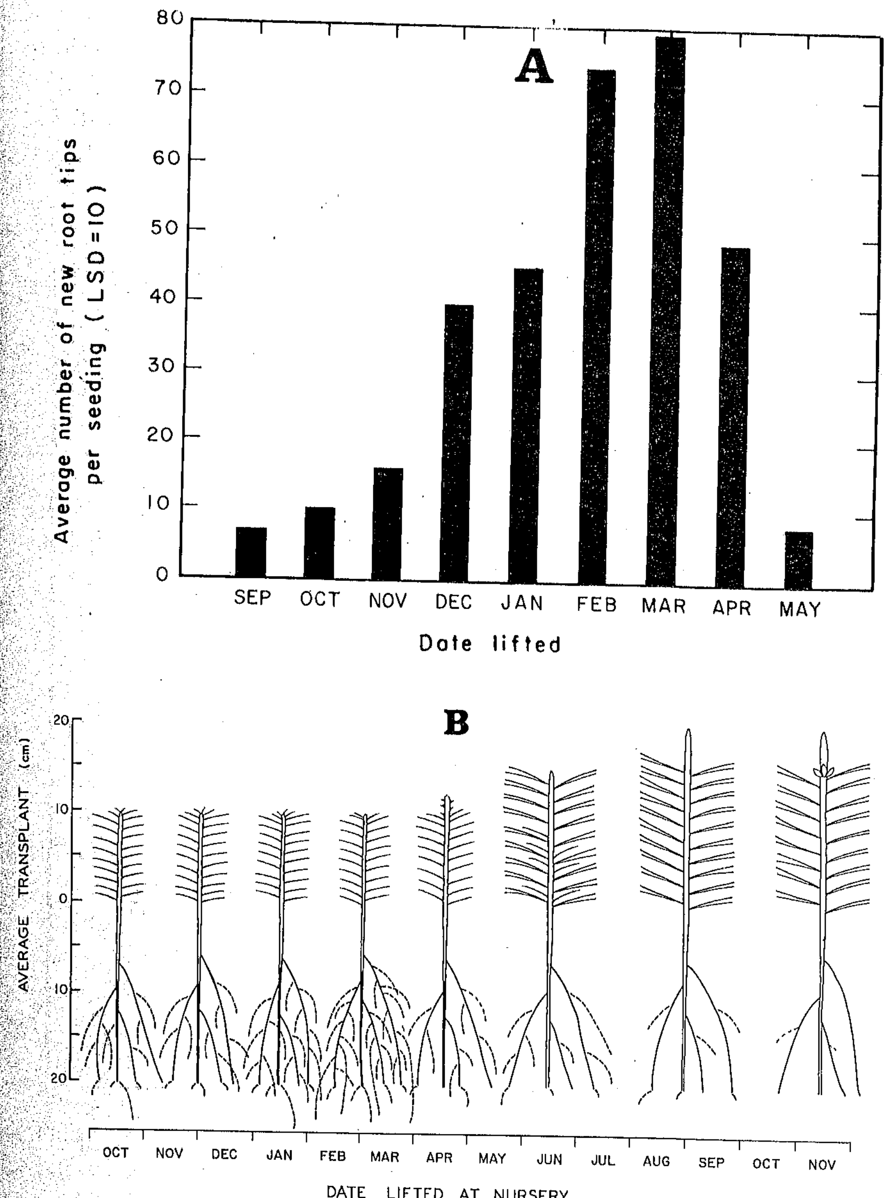

Figure 21. Seasonal trend in root regeneration of ponderosa pine. (A) 1-1, seed zone III, grown at the Placerville Nursery, 1956-57 (Stone and Schubert, 1959c); and (B) 1-0 from Ben Lomond Nursery. The dotted portions of the roots represent root elongation during the 28-day period following transplanting. (From Stone, 1967).

Fall temperature may affect the occurrence of RRP peaks, both in terms of numbers and total length of new roots. For example, Stone (1967) found that a relatively warm fall resulted in a late RRP peak with only moderate root growth. However, a cooler fall resulted in earlier RRP peaks and greater root growth for seedlings from Ben Lomond Nursery (fig. 22, table 15).

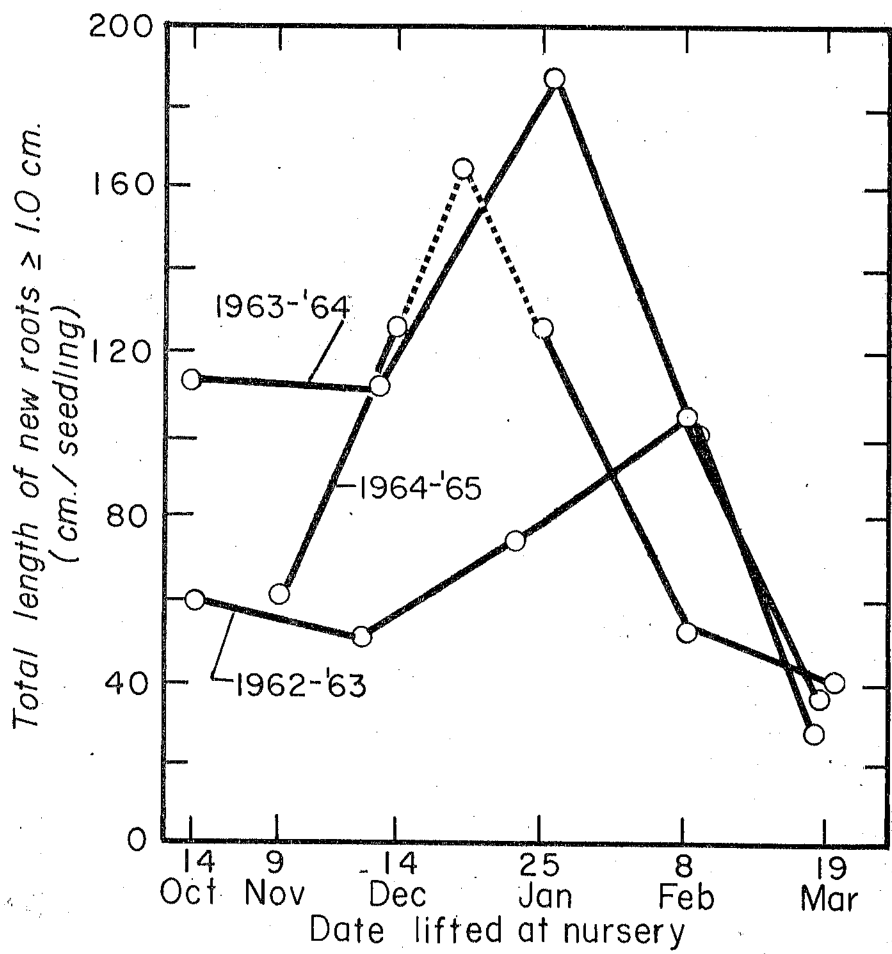

Figure 22. Dates at which maximum nursery-conditioning, in terms of subsequent root elongation (RRP), for ponderosa pine was achieved during 1962-63, 1963-64, and 1964-65 at Ben Lomond Nursery. (From Stone, 1967).

Table 15. Differences in seasonal temperature patterns, and the occurrences of ponderosa pine RRP peaks, during 3 years at Ben Lomond Nursery.

Year	Aug. 1 - Jan. 1		Aug. 1 - RRP peak [1]		Time from Jan. 1 to RRP peak (weeks)
	Cumulative hours at temperatures (° C)				
	≥ 6	≥ 10	≥ 6	≥ 10	
1962-63	370	880	920	1810	9
1963-64	560	1180	860	1590	4
1964-65	610	1510	610	1510	0

Source: Stone, 1967.

[1]/Peaks occurred on March 4, January 27 and January 1 in 1963, 1964 and 1965 respectively.

Lifting Dates

Until recently, many people believed that planting should be done in fall as soon as the ground was well moistened from the first rains. By so doing, seedlings would have more time to become established before the summer drought. But survival under this practice was erratic.

As far back as the early 1930's Person (1937) determined that lifting dates in north coast nursery beds should be no earlier than November 15. Before then redwood, Douglas-fir, Port Orford cedar, and Sitka spruce had not completed their growth.

Since the mid-1950's, considerable information has accumulated from laboratory and field tests that dictate lifting dates only in late fall and winter. As an example, ponderosa pine seedlings from Placerville Nursery generally are not conditioned for lifting until late fall or early winter (Stone and Schubert, 1959 a, d) (fig. 23).

Douglas-fir shows a similar conditioning pattern. Survival of field-planted Douglas-fir was correlated with RRP tested in the greenhouse (Stone, *et al.*,1961). In the greenhouse, root regeneration of Parlin Fork Nursery (closed 1968) stock indicated that November through March was the best lifting time. Survival in the field from

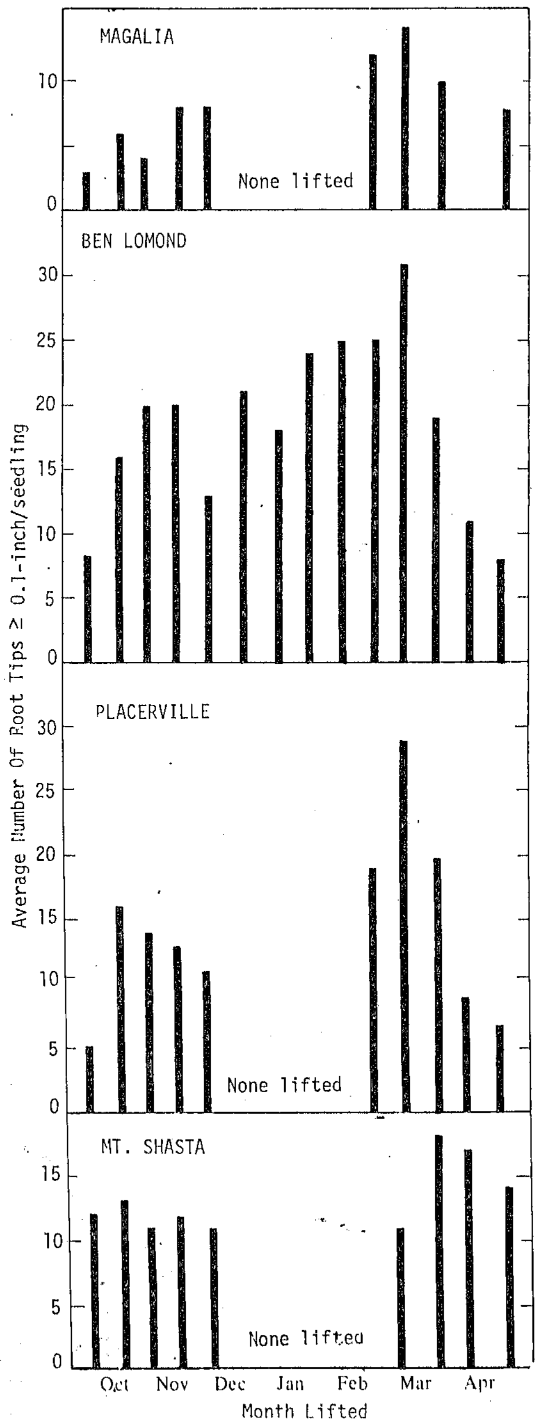

Figure 23. Seasonal Variation in Root Activity of 1-0 Ponderosa Pine Grown at four California Nurseries, 1959-60.

stock of the same source planted at three widely separated locations along the central and north coast was good December through March, with February the best month in all cases.

A mid-February lifting at Ben Lomond nursery produced the highest RRP peak for 1-0 Doulgas-fir (Todd, 1964). The most favorable lifting period was determined to be from mid-January to mid-March.

Additional lifting date information on Douglas-fir is available from tests in Oregon. Lavender and Wright (1960) indicated that field survival was much higher for Douglas-fir seedlings lifted after mid-November than for stock lifted earlier. They also reported that seedlings from the later liftings appeared to be more vigorous. Wright (1964) suggested that in Oregon nurseries, the amount of mycorrhizae on Douglas-fir roots was a good indicator of best lifting dates. If more than 60 percent of seedling roots had mycorrhizae the seedlings were considered suitable for lifting. This condition occurs mostly in midwinter months.

In 3 year field and laboratory studies in Oregon, Lavender (1964) found that the physiological condition of Douglas-fir planting stock was best for lifting between December and just before enlargement of buds in the spring. Cold storage for two weeks or more accentuated poorer physiological condition if trees were lifted other than during winter and early spring.

Seedling Storage

Proper storage of stock is critical in nursery operations. To provide conditioned stock for late season planting at high elevations requires stock to be stored for from 1 to 3 months.

Lifting times for storage differs from those for immediate planting. In general, the results of the 1959-60 stock storage experiment for the California nurseries indicated that: (1) for some planting dates stored stock had a higher RRP than fresh stock; (2) the RRP varied significantly between nurseries at different lifting dates; (3) the RRP of stored stock varied at the different nurseries; and (4) the RRP varied by lifting dates, storage periods, and nurseries (fig. 24).

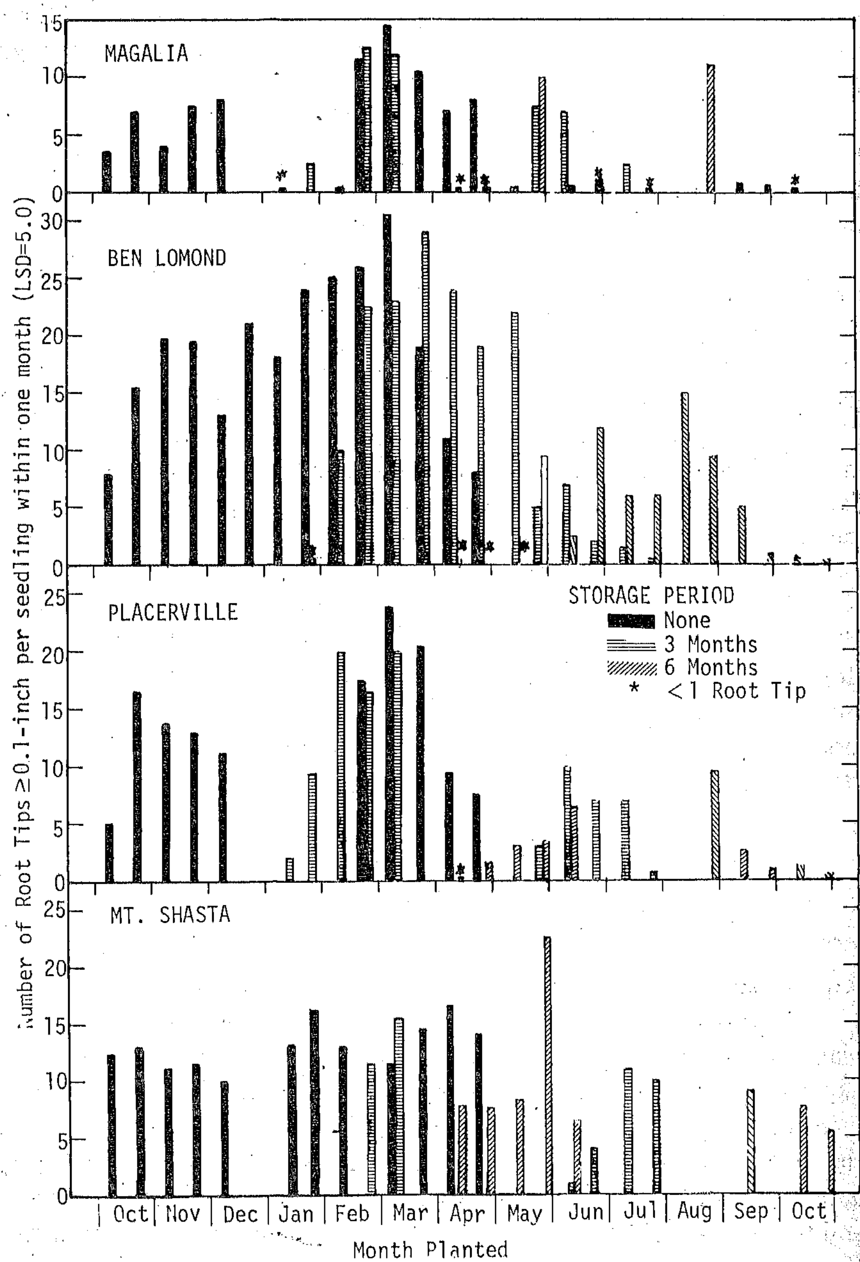

Figure 24. The effect of cold storage on root elongation of 1-0 ponderosa pines from four California nurseries, 1959-60.

In general, stored stock shows a distinct advantage over fresh stock at two different times: (1) When fresh stock shows a decided decline in RRP, and (2) when fresh stock is unavailable from a particular nursery. For example, at warm-climate nurseries (see the section on Selection of Nursery Site) the only need for stored stock would be for plantings after the RRP of fresh stock decreased significantly (fig. 20). At cold-climate nurseries the need for stored stock would be for winter and late spring plantings. Fresh- lifted seedlings should be used whenever possible. Best nursery management may necessitate lifting and storage at other times, particularly when several small plantings are to be made in a relatively short period and when bed space is needed to start the next crop of seedlings.

Hermann (1967) expressed the physiological condition of Douglas-fir seedlings by their ability to withstand root exposure. Root exposure consisted of placing seedlings in a chamber with a temperature maintained at 32 degrees F. and 30 percent relative humidity. Exposure times were 0, 30, 60, 90 and 120 minutes. Nearly 80 percent of seedlings lifted in late January and not stored survived after 120 minutes exposure. But 6 weeks in storage after seedlings received this same exposure, only 55 percent survived. And after 9 weeks storage, only 20 percent survived. Early November and late March liftings produced seedlings with little resistance to root exposure. Even after no storage, only 10 percent or less of seedlings exposed for 60 minutes survived. The late March lifted stock was the most sensitive.

Winjum (1963) found that Douglas-fir stock stored after late fall lifting survived better than storage after spring lifting. And 98 percent of stock lifted in months between November and March stored for 4 weeks survived.

Soil Moisture

Properly conditioned seedlings are required if they may be planted in soils with moisture content less than field capacity (Stone, 1967). Even midwinter planting in California may find soils at less than field capacity since there may be several weeks without winter precipitation and drying winds. Such planting conditions should be avoided but this is frequently impossible. Under these circumstances seedlings must be lifted when the RRP is at maximum.

SELECTION OF NURSERY SITE

The best nursery sites are superior farmland. The cost to improve inferior land probably will exceed the difference in price. Over the long run soil management and other operations will be easier and cheaper on superior farmland. The area should be large enough to meet present needs and future expansion.

Climate

The success of low elevation nurseries in California has demonstrated that the nursery climate need not match that of the planting area. Improved methods of handling nursery stock insure that the trees can be delivered when and where needed. The longer growing season at low elevations has reduced the time required to produce stock of the right size. Species susceptible to frost injury at higher elevation nurseries can be grown at the lower elevations. The site must have good air drainage, be free of detrimental fumes, and be far enough removed from the ocean to be free of salt water spray or mist.

Analyses of seedling growth and climate at several California nurseries have indicated criteria for selecting a nursery site on the basis of temperature and growing season (Krugman and Stone, 1966; Schubert and Baron, 1965; Stone, *et al.*, 1963).

California nurseries may be designated as "warm-climate" or "cold-climate" on the basis of length of growing season and "effective" day and night temperatures. The effective day temperature is computed as mid-way between the daily mean and daily maximum, and the effective night as mid-way between the daily mean and daily minimum (Kimball and Brooks, 1959; Went, 1957). This effective day night temperature method recognizes the importance of maximum and minimum temperatures not reflected in simple daily or monthly means. The annual growth cycle is characterized by computing monthly effective temperature (fig. 25).

A "cold-climate nursery" is defined as one having: (1) a short growing season of 150 days or less, (2) an effective night temperature below 32 degrees F. during November through March, and (3) an effective night temperature of 38 degrees to 55 degrees F. during May through September.

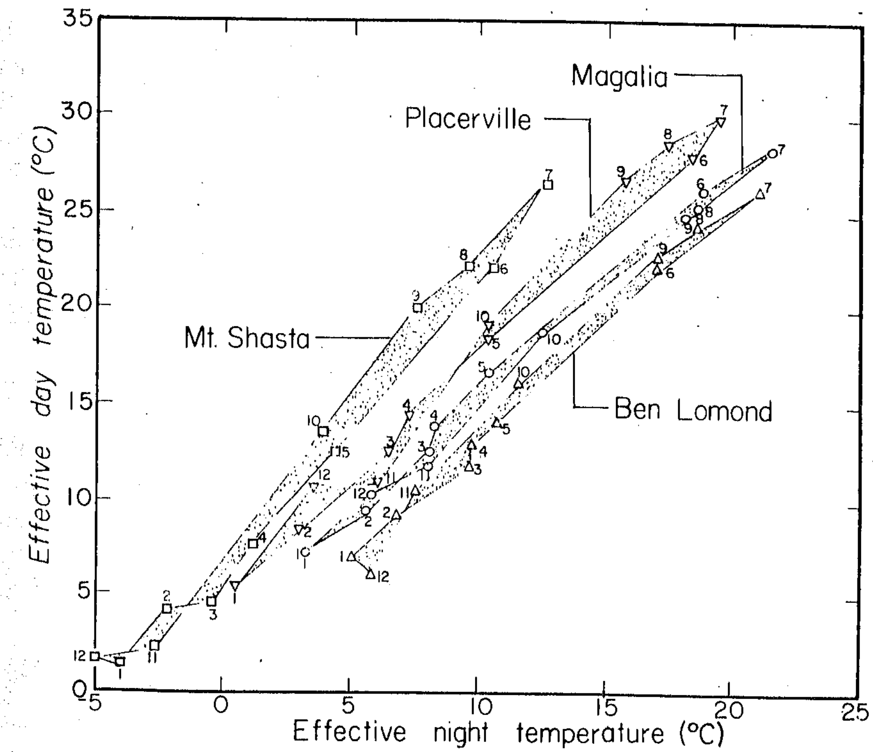

Figure 25. A comparison of Effective Day Temperatures and Effective Night Temperatures at four California nurseries. Each of the points numbered in sequence refers to the Effective Night Temperature and Effective Day Temperature for each of the 12 months beginning with January. (From Stone *et al.*, 1963).

A "warm-climate nursery" is defined as one having: (1) a growing season of more than 150 days, (2) an effective night temperature above 32 degrees F. during November through March, and (3) an effective night temperature of 50 degrees to 75 degrees F. during May through September.

The differences in effective night temperatures and growing seasons are useful to tailor seedlings' maximum RRP for certain planting dates. In addition, the number of cold nights (49 degrees F. or less) in fall should be considered in selecting a nursery site. From 120 to 150 cold nights before the peak RRP appear to be necessary for optimum seedling conditioning (Krugman and Stone, 1966). As an example of tailoring seedlings, Mt. Shasta Nursery (closed 1970) stock has a maximum RRP earlier in fall and later in spring than stock from a warm-climate nursery. This difference should make it more suitable for fall and late spring planting (Stone, *et al.*, 1963). Stock from the warm-climate nurseries is more suited to winter and early spring plantings.

Schubert and Baron (1965) distinguished three of the four nurseries in the State as warm climate and one as cold climate. The warm climate ones are Ben Lomond, Magalia, and Placerville; and the cold climate was Mt. Shasta.

Area and Topography

Land area needed for a nursery depends on . . .

1. Number of trees to be produced.
2. Age and class of trees.
3. Crop rotation and soil management system.
4. Type of water system.
5. Size and arrangement of between-bed paths and roadways.
6. Buildings and storage and parking areas.

Stoeckeler and Jones (1957) suggested that two-thirds to three-fourths of the total nursery area can be devoted to raising trees, the remainder for growing cover crops. For 1 million seedlings growing at a density of 30 per square foot in 4-foot wide seed beds with 18-inch paths between, the area requirement would be 1.26 acres (Wakeley, 1954). Kummel, *et al.*, (1944) recommend 1 acre for 500,000 2-0 seedlings.

The State's recently expanded Ben Lomond Nursery has 15.1 acres of seed beds and paths and 8.3 acres for roadways, buildings, and parking area. It does not allow for a water storage reservoir which is separate from the nursery area. Of the 15.1 acres for production, at least 5 acres are reserved each year for a cover crop. Annual capacity in 1 and 2-year old seedlings is about 5.3 million, depending on the varying ratio of 1-0 to 2-0.

Nursery seed beds should be level or nearly so. A maximum grade of 2 percent is permissible. More slope than this causes erosion problems, necessitating expensive control measures. Also, all mechanical equipment used in forest nurseries operates best on level ground.

Soil Texture and Depth

The best soils for a nursery are loamy sands or light sandy loams 4 to 5 feet deep (Toumey and Korstian, 1949). The soil should have a 15 to 20 percent silt and clay content (Stoeckeler and Jones, 1957), good drainage, freedom from rocks and gravel, and a pH of 5.0 to 6.5. Light sandy loams have good drainage, are easy to cultivate, provide a good medium for root development, and permit root pruning and seedling lifting with least damage to the plants.

Heavy clay and light sandy soils should be avoided. Heavy clay soils have low porosity and poor drainage and lead to problems in cultivation, lifting, root pruning, and frost heaving. Light sandy soils are less objectionable than heavy clay, but have a low water holding capacity. Furthermore, they are generally of low fertility and subject to wind erosion.

Soil Fertility

According to Stoeckeler and Jones (1957) the minimum standards for the top 8 inches of soil are:

1. Total nitrogen: 0.08 percent.
2. Available nitrogen: about 20 pounds per acre.
3. Available phosphorous: 50 pounds per acre.
4. Replaceable calcium: 30 milliequivalents per 100 grams.
5. Replaceable magnesium: 1.0 milliequivalents per 100 grams.

Although exact nutrient requirements for most conifers are not known, a soil analysis should be made to determine the amounts of inorganic chemicals present. As a guide, such an analysis might be compared with one from an undisturbed high site forest land growing the same species as planned for the nursery (Krueger, 1967; Wilde, 1958).

Past Use of Land

The vegetation on the area should be carefully examined for various root rots, nematodes, and foliage disorders. A forest pathologist should examine the site and recommend any corrective action.

Agricultural soils generally lack mycorrhizae and may have numerous weeds and weed seeds. Mycorrhizae may be added by inoculation or addition of forest soil. Most weeds can be eliminated with chemicals or frequent cultivation. The weed species should be identified, as some may not be susceptible to chemical control measures. Fumigation before sowing tree seed generally controls both harmful soil organisms and weed seeds.

Water Supply

The nursery site must have an adequate supply of uncontaminated water. Just to water the nursery beds will require a sustained flow of 40 to 70 gallons per minute per acre for an 8-hour day. This is equivalent to 1/2 to 1 inch of rain. Wakeley (1954) estimated that it would take 136,000 gallons of water per month to produce a million seedlings in the Southeast. During summer months State nurseries use as much as 5,100 gallons per acre per day. In the Northwest, water requirements are 15,000 gallons an hour for 12 hours on a 25-acre nursery (Kummel, *et al.*,1944).

Ordinarily water from lakes, rivers, or underground sources suitable for farm irrigation can be used. Water should not be taken from open irrigation ditches which contain weed seeds or algea. The water should have less than 200 parts per million of silt and calcium and less than 10 ppm of sodium and 0.5 ppm of boron.

Labor Supply

The nursery should be near or within easy commuting distance of an adequate and dependable labor supply.

Transportation and Communication

The area selected for the nursery should be near adequate transportation facilities. The nurseryman must be able to ship stock to field locations by the most expeditious means.

Adequate communication and electric power facilities must be available at the site also.

SOWING THE SEEDBEDS

The number of seedlings that reach plantable size is influenced by such conditions as when the seeds are sown, whether they are pretreated, and how deep they are sown. Each condition affects the time seeds germinate, how many germinate, and how much they will grow.

The time needed to raise acceptable planting stock will vary by species and to some extent by nurseries. Plantable pines, with the possible exception of sugar pine, can be grown in 1 year at Ben Lomond, Humboldt, and Placerville nurseries. The climate there fits the requirements for a warm-climate nursery. At cold-climate nurseries, 2 years' growth is required. All conifer stock at Mt. Shasta Nursery, a cold-climate nursery, required 2 years' growth to be plantable. Planting stock at Magalia Nursery also generally requires 2 years' growth to be of plantable size. Acceptable Douglas-fir and true fir seedlings require 2 years' growth at all nurseries. Sugar pine seedlings may also require 2 years' growth in warm-climate nurseries unless field survival of 1-year stock proves to be acceptable.

Season to Sow

Seeds may be sown either in fall or in spring. The main advantages to fall sowing are:

1. Seeds do not require moist-cold stratification before sowing.
2. Earlier germination is assured in spring.
3. More stock may be produced as 1-0.
4. Sowing dates are not as critical. Sowing may be done any time in October or November before snowfall at cold-climate nurseries, and extended into December at warm-climate nurseries.

However, fall sowing has several disadvantages which may outweigh the advantages such as . . .

1. At cold-climate nurseries, seeds of some species (such as sugar pine and the true firs) may germinate too early in spring and the seedlings be killed by frost unless protected.
2. Sprinkler irrigation must be made ready early to prevent losses from early spring drought that could delay seed germination.

3. At warm-climate nurseries, the seed may not completely break dormancy which would delay germination of sugar pine and other species that require a long period of moist-cold pretreatment.

4. Few seedbeds may be available for fall sowing because stock from the preceeding crop may not be lifted yet. This condition would apply only to nurseries that do not have sufficient area for fallow and cover crop.

5. Seeds have to be protected from birds and rodents for a longer period for fall than for spring sowing.

6. Heavy rains may wash seed away.

In California, most seeds are sown in spring at Forest Service and State nurseries. For spring sowing, the time of sowing is more critical than for fall sowing. In fall, a month or two may have no effect on seedling quality, whereas in spring, differences may be apparent for sowings a week or two apart. For example, Show (1930) reported that the earliest sowing on May 16 produced about 25 percent more first-quality seedlings than the sowing made 2 weeks later. And a third sowing on June 15 netted only few good-quality seedlings.

The seed should be sown as early in spring as possible so that seedlings will benefit by the entire growing season. This sowing date will vary depending on climate and nursery operations. At warm-climate nurseries, the seeds usually can be sown as soon as space is available and soil condition permits preparation of seedbeds -- generally in April.

At cold-climate nurseries, and at others where freezing may be a problem, seedbeds may be sown in late April or early May at the latest. Without protective devices, new sugar pine seedlings from too early sowing may be severely damaged when the air temperature near the ground drops below 25 degrees F. (Schubert, 1955). True fir and Douglas-fir seedlings may also be damaged at this low temperature. Ponderosa and Jeffrey pine seedlings can withstand lower temperatures than sugar pine (Schubert, 1955). Therefore, the seeds may be sown to coincide with the date of the average last killing freeze. Coniferous species that are highly susceptible to freezing should be produced in warm-climate nurseries.

In production nurseries, spring sowing operations are usually completed within a few days to take advantage of earliest good weather conditions coinciding with best soil conditions.

Pregermination Treatment of Seed

All seeds sown in spring should be conditioned by moist-cold stratification before sowing. This treatment will benefit almost all species and will not harm the few that may not need it.

Before seed is stratified, however, each lot should be thoroughly mixed so that it is uniform in quality at the time of sowing. This procedure is described in Chapter II, under "Cone and Seed Processing". Moist-cold stratification may be either of the two techniques described under "Methods to Break Seed Dormancy" in the same chapter.

Show (1930) reported that fall sown seeds germinated from 2 to 8 weeks earlier than unstratified spring sown seed. By stratifying the seed for the recommended period, spring sown seed will germinate as promptly as fall sown seed.

Depth to Sow

As a general rule, seeds should be sown to a depth equal to three times their thickness. This technique insures adequate cover to keep seeds moist but not too much to hinder seedling emergence.

The depth at which seeds are sown affects the rate of germination; and may affect the number that germinate and the seedling quality. Both Quick (1947) and Show (1930) reported that shallow sown seeds germinate earlier than deep sown ones. Quick (1947) found that stratified sugar pine seed would all germinate within 2 to 3 weeks when sown at a depth of ¼ to ½ inch, but none would germinate if sown deeper than 2 inches.

Show (1930) indicated the seedling quality was affected by sowing depth (table 16). Ponderosa, Jeffrey, and sugar pine seed germinated well and produced a high proportion of high quality seedlings when sown at 1/2 inch. Incense cedar, Douglas-fir, and white fir did better when seeds were sown at 1/8 to 1/4 inch. Fall sown seed can be planted deeper than spring sown.

Method of Sowing

All Forest Service and State nurseries use tractor-drawn seed drills to sow seedbeds (fig. 26.). The drill can be adjusted to sow at

Table 16. Number of seed germinated and first-class 1-0 seedlings produced from seed of different species sown at various depths.

Species	Season of sowing	Depth of sowing	Germinated per lineal foot	First class seedlings per lineal foot
		Inch	Number [1/]	
Ponderosa pine	Spring	1/8	30	22
		1/4	40	23
		1/2	48	28
		3/4	58	28
Jeffrey pine	Spring	1/4	44	31
		1/2	62	39
		3/4	51	30
		1	37	26
Sugar pine	Spring	1/4	42	26
		1/2	45	21
		3/4	25	13
		1	22	13
Sugar pine	Fall	1/4	48	25
		1/2	48	28
		3/4	45	26
		1	35	20
Douglas-fir	Spring	1/8	47	20
		1/4	40	17
		1/2	30	16
		3/4	17	10
White fir	Spring	1/8	43	27
		1/4	31	17
		1/2	13	7
		3/4	4	2
Incense-cedar	Spring	1/4	22	10
		1/2	10	5
		3/4	10	5
		1	3	2
Incense-cedar	Fall	1/4	42	24
		1/2	48	34
		3/4	22	15
		1	22	16

Source: Show (1930)

the desired density and depth and to pack the soil lightly in the row (Lanquist, 1954c). Normally eight rows are sown per 4-foot wide seedbed.

Broadcast seeding has been done successfully at nurseries; however, it is slower and more difficult to regulate sowing density and depth, and necessary cultural protection such as weeding and cultivating are more difficult later in the season. In addition, stratified seed must be covered immediately after sowing to prevent drying. This is generally a separate operation from the sowing.

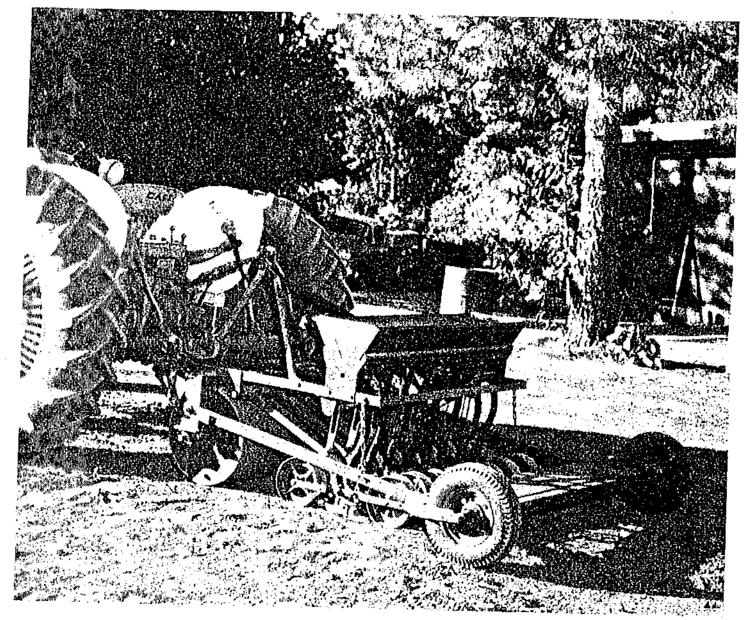

Figure 26. Tractor-drawn seed drill used at Placerville Nursery.

SEEDLING DENSITY

Each nursery bed should be sown to produce the maximum amount of high quality seedlings per unit area at the lowest cost per thousand. The number of high quality trees [9/] that can be produced

[9/] Plantable trees that meet minimum size specifications and have a well-developed top and root system. (See "Culling and Grading Nursery Stock").

will vary by species and age class, and may vary for different nurseries. In general, a given unit area can produce a certain amount of plant material. This growth may be concentrated on a few seedlings or spread out over many. The objective is to have this growth on the greatest number of seedlings without sacrifice of quality. If too few or too many seedlings are raised, nursery production suffers, and costs per unit increase.

The optimum densities in California nurseries vary from 20 to 40 seedlings per square foot, depending on species and nursery sites (Baron and Schubert, 1963b). An increase in the number of plants above an optimum density will reduce seedling size and result in a smaller number of plantable trees.

Higgins (1928) reported a 14 percent drop in field survival of 2-year-old ponderosa pine when the density was increased from 75 per square foot to 150, and the cost per thousand surviving trees increased by 28 percent. Show (1930) indicated a decrease in plantable trees from 85 percent to 26 percent when seedling density was increased from 20 to 160 per square foot.

Density studies at Mt. Shasta Nursery suggested that stem diameter and seedling height decreased significantly as seedling density increased. Over 94 percent of the pine seedlings grown at the 20-density level had a stem diameter greater than 0.11 inch compared to only 34 percent at the 60-density level. Seedling weights and field survival decreased with increased seedling density, but top-root ratios showed no correlation with seedling density (Baron and Schubert, 1963b).

At Mt. Shasta Nursery, the greatest number of plantable pine trees were produced at the 40-density level (table 17). The production rate at a density of 60 was less than at a 20-density level.

A 10-year history of 2-0 Douglas-fir production, at the British Columbia Forest Service Duncan Nursery, also showed that 40 Douglas-fir seedlings per square foot at the end of the first growing season produced the most plantable seedlings per square foot (Long, 1966). Plantable trees amounted to about 30 seedlings. Further studies were done at this nursery and at Luison Nursery. At Duncan, density reduction from 55 to 29 2-0 Douglas-fir per square foot increased dry weight by 77 percent. And at Luison, a density drop from 69 to 31 increased dry weight by 50 percent. Reduced densities at Duncan improved the ratios of 2-0 plantable seedlings to viable seed from 41.9/106.5 to 7.4/11.5.

Table 17. Expected number of plantable trees per unit area at different seedling densities at Mt. Shasta Nursery, California.

Seedling density per square foot		Based on cull of . . .			Plantable trees [1]	
Range (No.)	Average (No.)	Root [2]	Stem [3]	Total	Per square foot	Per 400-foot bed
		Percent			Number	
16-25	20	2.6	5.7	8.3	18	28,800
26-35	30	3.4	16.7	20.1	24	38,400
36-45	40	4.1	23.5	27.6	29	46,400
46-55	50	7.9	50.1	58.0	21	33,600
56-65	60	7.2	66.2	73.4	16	25,600

1/Trees with a well developed root system and a stem diameter of at least 0.11 inch.
2/Trees with a poorly developed or mutilated root system (basis - 58,028 trees).
3/Trees with stem diameter less than 0.11 (basis - 999 trees).

The effect of density on 1-0 seedlings grown at Placerville Nursery was the same as for 2-0 at Mt. Shasta. The biggest stock was produced at the lowest seedling densities (table 18). The 1-0 ponderosa and Jeffrey pine seedlings grown at Placerville were comparable in size to the 2-0 seedlings from Mt. Shasta. However, to be of the same size, the seedlings at Placerville would have to be grown at half the Mt. Shasta density.

From a study of seed bed densities at the U. S. Forest Service Bend Nursery in Oregon, Edgren (1966) found that when 2-0 ponderosa pine densities were increased from 10 to 30 per square foot, stem diameter decreased from 7.1 to 5.2 mm (1mm = 0.04 inch). But increasing densities from there to 70 per square foot only decreased stem diameter to 4.6 mm.

If 0.11 inch is the minimum acceptable stem diameter, the best density to raise 1-0 ponderosa and Jeffrey pines at Placerville would be 20 per square foot. The high cull percents for the 30 and 40 densities would reduce the number of plantable trees too much to justify the higher densities. To take full advantage of the long growing season, earlier seed sowing may increase seedling growth enough to reduce the cull percent to an acceptable amount. On the other hand, an improvement in seedling vigor may justify use of seedlings with a lower minimum stem diameter.

The 1-0 sugar pine seedlings grown at Placerville showed similar trends in growth with increased densities as the other pines (table 18). However, none of the seedlings had stems that would meet the

Table 18. Seedling dimensions, 1-0 stock, at U. S. Forest Service Nursery, Placerville, California by species and seedbed density, 1959. [1/]

Item	Seedbed density (seedlings per square foot) . . . 10	20	30	40
Height of top....Inches				
Sugar pine	4.0	3.7	3.8	3.8
Jeffrey pine	3.6	3.4	3.4	3.4
Ponderosa pine	4.8	4.2	4.3	4.2
Stem diameter [2/]...Inches				
Sugar pine	.098	.090	.084	.087
Jeffrey pine	.133	.119	.106	.102
Ponderosa pine	.143	.117	.108	.104
Total weight of seedling....Gm.				
Sugar pine	3.19	2.94	2.74	3.07
Jeffrey pine	6.73	5.25	4.18	4.00
Ponderosa pine	9.45	8.17	5.08	4.28
Top/root weight (T/R):				
Sugar pine	1.61	1.30	1.31	1.11
Jeffrey pine	1.22	1.16	1.11	1.06
Ponderosa pine	1.27	1.21	1.20	1.20
Cull [3/]...Percent				
Sugar pine	100	100	100	100
Jeffrey pine	6.8	23.5	42.5	62.0
Ponderosa pine	2.2	18.9	43.7	48.8
Plantable trees per square foot....No.				
Jeffrey pine	9	15	17	15
Ponderosa pine	9	16	17	18

[1/] Averages of four samples of 20 seedlings each.
[2/] 0.004 inch was significant difference at the 5-percent level.
[3/] Less than 0.11-inch diameter.

minimum acceptable diameter of 0.11 inch for ponderosa and Jeffrey pines. It may be necessary to grow 2-0 stock, or use a smaller minimum diameter of about 0.09 inch and grow the stock at a 20- or 30-density level.

Optimum seedling densities have not been determined for the other California nurseries. However, estimates are possible from comparisons of seedling growth reported by Baron and Schubert (1963a) for ponderosa pine grown at the same density at different nurseries (table 19). Most seedlings are grown at a density of 30 per square foot at California Division of Forestry nurseries.

Table 19. Recommended seedling densities and expected number of plantable trees per square foot for several California nurseries.

Nursery	Number seedlings per square foot	Expected number of plantable trees [1/]
Ben Lomond	30 or 40	22 or 30
Humboldt	30 or 40	22 or 30
Magalia	20 or 30	15 or 22

[1/] Based on an average 25 percent cull factor for all species.

NURSERY BED SPACE AND SEED REQUIREMENTS

The amount of bed area and seed required to produce a specified number of plantable trees will vary for different seedling densities. Seedbeds can be sown to produce any desired seedling density. In sowing the seedbed, number of plantable seedlings per square foot should be stressed. All trees compete with each other whether they are plantables or culls. The seedling densities indicated in the preceding section should produce maximum plantable trees. And they should be used to determine sowing rates.

To help nurserymen calculate the total length of nursery bed required and the amount of seed needed to sow the bed to predetermined densities, three formulas are suggested:

Formula 1: Sowing Rate

To obtain a specified density at the end of 1 or 2 years requires information on seed viability and seedling mortality. The number of seeds to sow per square foot can be determined by the formula:

$N = \frac{D}{G x S}$ in which N = number of seeds to sow, D = desired seedling density, G = average expected nursery germination expressed as a decimal, and S = average expected seedling survival expressed as a decimal.

For example, a density (D) of 40 per square foot would require 56 seeds (N) with a germinative capacity (G) of 80 percent and a survival percent (S) of 90 as:

$$N = \frac{40}{0.80 \times 0.90} = 56 \text{ seeds per square foot}$$

The value for (G) is derived by adjusting the estimated viability to reflect nursery germination. Some nurserymen define (G) as the actual laboratory germination and place all other variables in the survival factor (S). Each nurseryman should develop a conversion factor for each species by comparing laboratory viability with nursery germination and seedling survival for a period of years. The laboratory viability test must be made currently for each batch of seeds to be sown. Never use an estimated viability based on older tests or experience, as this practice may lead to serious problems of over- or under-sowing.

The value for (S) is based on past records of seedling survival in nursery beds. Since seedling survival will vary by density and species, a separate (S) value must be determined for each species-density combination. To arrive at a representative (S) value, data must be restricted to normal seedling mortality. Heavy losses due to unusual and unpredictable causes should not be included as these unpredictable losses must be compensated for by sowing additional nursery beds. At the federal nurseries an additional 5 to 15 percent of nursery beds is sown as a safety factor to cover unexpected losses.

Formula 2: Area Requirement

The total length in seedbeds required can be determined by the formula:

$$\text{Total length of bed, in feet } (L) = \frac{\text{Total number plantable trees needed (T)}}{\text{Number plantable/sq.ft. } (D_1) \times \text{ width of bed (w)}}$$

The number of plantable trees per square foot are given in tables 17, 18, and 19. The value for D_1 would be the number of plantable trees for the sown seedling density. For example, if the nurseryman at Mt. Shasta needed to produce 2 million plantable 2-0 ponderosa pine seedlings at a seedling density of 40 per square foot, in beds 4 feet wide, he would have to sow a bed about 17,240 feet long:

$$L = \frac{2{,}000{,}000}{29 \times 4} = \frac{2{,}000{,}000}{116} = 17{,}241.4$$

Then to provide a 15 percent safety margin for unpredictable losses, the length (L) would have to be increased by 2,585 feet for L_1 = 19,825 feet. If the beds are 400 feet long, he would need to sow about 49.5 beds.

Formula 3: Seed Requirement

The pounds of seed needed to produce any number of plantable trees can be calculated by the formula:

$W = \frac{L_1 \times N \times w}{C \times P}$ in which W = the total weight of seeds needed in pounds;

L = total length of seedbed in feet which includes the added space for safety margin as determined by formula (2); N = number of seeds to sow per square foot as determined by formula (1); w = width of bed in feet; C = average number of seeds per pound; P = purity percent expressed as a decimal.

From the examples used to illustrate formulas (1) and (2), if we needed to produce 2 million plantable 2-0 ponderosa pine seedlings at Mt. Shasta Nursery, the value of L_1 = 19,825 feet; N = 56 seeds; w = 4 feet; C = 12,000 seeds, and P = 0.98, about 378 pounds of seed would be required:

$$W = \frac{19{,}825 \times 56 \times 4}{12{,}000 \times 0.98} = 377.62 \text{ pounds}$$

The amount of seed needed per seedbed can be derived by dividing the total amount of seed by the number of seedbeds.

CARE AND PROTECTION

Seeds and seedlings require constant care and protection from animals, competing plants, adverse weather conditions, and nutritional disorders. Some of the control measures are needed before the seedbeds are sown; others are required throughout the period that the young plants develop into trees for planting.

Damping-off and Root Rot Fungi

Damping-off and root rot fungi frequently are found in nursery soils. Damping-off fungi may kill many seedlings during or immediately after seed germination. And some types may kill older seedlings. The first indication of damping-off may be a spotty occurrence of dead seedlings; however, with modern methods of soil cultivation the disease may be spread uniformly over the nursery.

Soil acidification with sulphuric acid, aluminum sulphate, and ferrous sulphate has been used with varying degrees of success ranging from no effect to good results (Kummel, *et al.*, 1944; Toumey and Korstian, 1949; Wakeley, 1954). If the soil pH is below 6.0, further acidification may not be effective.

Kummel, *et al.*, (1944) and Wakeley (1954) suggested that damping-off damage could be reduced by getting the seed to germinate early and rapidly before the temperatures became favorable for fungus growth. Seedlings that emerge after the fungus has a head start are most likely to be killed by damping-off fungi. Several fungicides, such as arasan, ceresan, simesan, teresan, and others, have successfully controlled damping-off in some trials, but not in others. Regulating watering so that the soil surface down to 1/4-inch is permitted to dry and remain so for short periods will assist in fungus control (Kummel, *et al.*,1944).

Bega and Smith (1960) reported several kinds of damping-off and root rot fungi present in California nurseries. They found the charcoal root rot fungus, *Macrophomina phaseoli (Sclerotium bataticola)* to be the main cause of high mortality of young sugar pine, Douglas-fir, and Sierra redwood seedlings.

Nurserymen should consult the pathologists at the Pacific Southwest Forest and Range Experiment Station whenever they suspect disease problems. Research is underway to identify the serious pathogens and to develop the best control methods. Soil fumigation with methyl bromide and chloropicrin or a combination of both 2 weeks before sowing has yielded good results. However, most soil fumigants are highly toxic or irritating and require special methods of application and precaution.

If used correctly, fumigants will not destroy the mycorrhizae–and may even improve their development (Bega and Smith, 1960). There have been other reports, however, that methyl bromide will destroy beneficial mycorrhizae for 1 year in the nursery (Wright, 1964).

To control root rotting fungi, Bega and Smith (1960) treated the nursery beds just before seed sowing with 450 pounds per acre of a soil fumigant composed of 57 percent methyl bromide and 43 percent chloropicrin (Pathofume). The fumigant was applied by shank injection. The beds were then sealed under polyethylene plastic for 24 hours. Seedlings produced in these fumigated beds were larger and had better color and root development than seedlings in unfumigated beds.

Fumigation at Ben Lomond Nursery increased the RRP of Monterey pine (Krugman, Stone and Bega, 1965). *Pythium sp.* may have been the pathogen inhibiting new root growth. Figure 27 shows the kind of fumigation equipment used in State nurseries.

Protection from Birds and Rodents

Birds and rodents often cause serious losses of seeds and young seedlings. Birds are particularly destructive from the time the seeds are sown until after the seed coats are cast off the cotyledons. Various noise devices have been used with varying success for short periods, but their effectiveness soon diminishes. If noise devices are

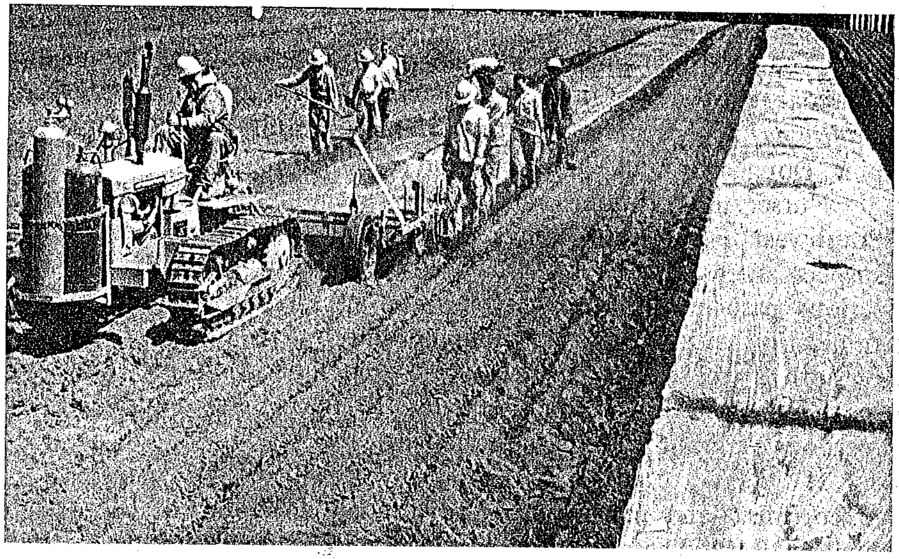

Figure 27. Nursery tractor equipped for soil fumigation. Fumigant is in right cylinder, nitrogen to pressurize fumigant in left cylinder.

ineffective, it may be necessary to cover the seedbeds with special netting or woven wire fence. Coating the seeds with Arsan 42-S has been effective in repelling birds in the Southeast (Derr, 1964), and is standard practice in several California forest nurseries.

Rodents, particularly mice, rats, ground squirrels, and gophers, destroy seeds and seedlings of all ages. Coating seeds with endrin for reforestation seeding has helped control mice, but not larger rodents. Many nurseries are enclosed in a special fence which excludes most rodents. The fence should have a metal shield or 1/4-inch mesh hardware cloth that protects an area about a foot or so below the ground surface to 2 feet above. The fence above this protection should be close-woven to help prevent larger animals from entering. Trees should be removed around the nursery to keep squirrels from jumping over the fence.

Protection from Insects

Young seedlings are frequently killed by root and stem feeding insects. Keen (1952) reported that most damage is done by white grubs, root weevils, wireworms, and cutworms. He found that

wireworms could be killed by the soil fumigants "D-D" (dichloropropane-dichloropropylene) and ethylene dibromide. The D-D is applied at the rate of 400 pounds per acre at a depth of 6 to 8 inches. The ethylene dibromide is applied at 10 percent by volume strength dissolved in a naphtha 200-base thinner at a rate of 20 gallons per acre. The treatment should precede seed sowing by at least 15 days when the soil is moist and the temperature at 8 inches below the surface is not below 50 degrees F.

Other insects can be killed by clean cultivation for 1 to 2 years or by rototilling. When these methods fail the beds can be treated with dieldrin, aldrin, or chlordane (Speers and Schmiege, 1961). These insecticides are poisonous and should be handled, used, and stored as recommended by directions and precautions given by manufacturers.

Insects can also be killed during soil fumigation by a mixture of methyl bromide and chloropicrin.

Shade and Mulch

Shade and mulch have been recommended for their beneficial effects on seed germination and young seedlings (Stoeckeler and Jones, 1957; Toumey and Korstian, 1949; Wakeley, 1954). They both help to conserve soil moisture, reduce extreme changes in temperature, and protect seedlings from birds, heat and freezing damage. Mulching, however, is not now practiced in large California nurseries because spring sown seed does not need this protection.

Lath shade should be oriented so that the lath are north and south to provide a moving shade across the seedlings (Kummel, *et al.*, 1944).

A shade may be provided by saran fabric (fig. 28), woven slat snow fence, or cloth, usually arranged to provide from one-third to half shade. Half shade seems to be most beneficial to sugar pine, Douglas-fir, and true fir seedlings. Ponderosa and Jeffrey pine and incense-cedar seedlings normally do not require shade. To reduce heat and frost injury, shade may be kept over the seedlings until they are well established.

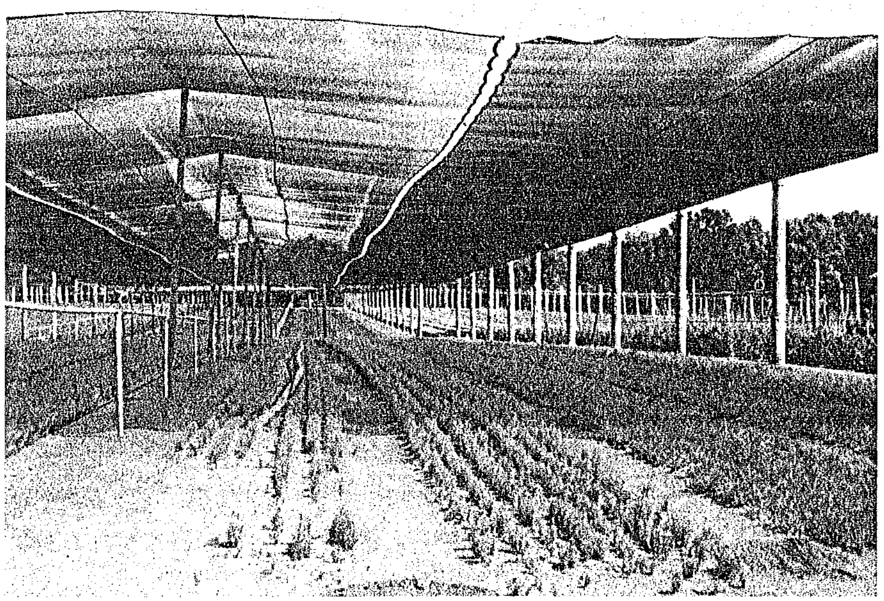

Figure 28. Seed beds under saran, Ben Lomond Nursery.

Mulch where required to protect fall sown seed from erosion and frost heaving may be of pine needles, sawdust, or burlap. Black polyethylene plastic covering may be used as a mulch in small nurseries to speed up germination by increasing soil temperatures. Burlap and polyethylene mulch must be removed when the seeds start to germinate. Sawdust and pine needle mulch may be left in place if it does not interfere with seedling development.

At California nurseries, water from overhead irrigation is used to reduce the need for shade and mulch–particularly for the more hardy pines. Each nurseryman should examine his particular situation to determine the best method to develop and protect high quality nursery stock. The effect of "shading" by water depends on nursery climate; interior nurseries are more difficult to shade by water.

Watering Schedules

Nursery beds require different amounts and frequency of water depending on stage of plant development, type of soil, time of year, and weather conditions.

The seedbeds must be sprinkled immediately after the seeds are sown in the spring and kept moist continuously until the seedling roots are 2 to 3 inches long. During this period frequent, light watering of 1/4 to 1/2 inch is needed for seed germination and for prevention of heavy mortality of newly germinated seedlings. Fall sown seedbeds generally do not require watering until the following spring when they must be kept moist to prevent seed drying and delayed germination.

After the seedling roots reach a depth of 4 to 5 inches, watering can be heavier and at less frequent intervals unless it is being used to prevent high soil temperatures. Time-wise, this may be a week or two after germination is completed as initial root development is quite rapid. The top inch may be allowed to dry between waterings and the top 10 inches recharged to field capacity. Water added in excess of field capacity of the soil is wasted and may leach out needed nutrients. Nurserymen should determine the amount and frequency of watering needed for their nurseries.

In summer when soil temperatures exceed 110 degrees F., watering between 10 a.m. and 3 p.m. may be used to lower the temperature. Several light waterings during the hottest part of the day generally are more effective than one heavy watering.

Beginning in late August or early September, watering should be at less frequent intervals to help harden off the plants and induce drought resistance. Shirley and Meuli (1939a) reported that seedlings subjected to moderate drought during the period of late vegetative activity increased the drought resistance of jack, red, and eastern white pine.

Water has also been used in California nurseries to protect trees from heavy frosts in late spring and early fall, and from excessive soil erosion by strong winds. Addition of extra water during windy days has been effective in holding light sandy soils in place. In the Lake States, the sprinklers are turned on in late evening or night when the temperature drops below 30 degrees F. in spring (Stoeckeler and Jones, 1957). At Mt. Shasta, frozen trees were watered from early morning until they had gradually thawed out. Stoeckeler and Jones (1957) reported that no trees were damaged in temperatures as low as 20 to 22 degrees F. when watering was used. Protection against freezing in spring and fall is needed primarily for such species as sugar pine, Douglas-fir, and true firs. These species are most susceptible to freezing injury. Other species found susceptible to

Weed Control

Most weeds in California nurseries are controlled before sowing by fumigating with a methyl bromide-chloropicrin mixture. After seedling emergence, weeds not controlled by fumigation may be reduced by solvent sprays. In most nurseries, however, weed densities after fumigation are sparse enough that hand weeding will easily eliminate them.

Solvents used are aromatic hydrocarbons or mineral spirits, such as Stoddard Solvent, Sovasal No. 5, Stanisol and Shell 20. The material should have about a 20 percent aromatic hydrocarbon content and be applied at full strength with a pressure sprayer at rates of 40 to 100 gallons per acre depending on tree seedling development. The chemical should be applied when the weed plants are small and succulent, with treatment repeated as needed.

These chemicals have been used in many nurseries; however, rates and frequency of application have varied by tree species and age of seedlings (Stoeckeler and Jones, 1957; Wakeley, 1954). Young seedlings, such as Douglas-firs under 6 weeks old, may be seriously damaged even at low rates; whereas, older Douglas-fir seedlings are not harmed by rates of 40 to 50 gallons per acre (Stoeckeler and Jones, 1957). At Mt. Shasta Nursery, rates of 70 to 100 gallons applied at full strength with materials containing about 20 percent aromatic hydrocarbons caused no serious damage to pines. Rates of 30 to 40 gallons per acre should be tried first. If inadequate, the rate can be increased until the desired weed kill is obtained without damage to the conifers.

Weeds may often be controlled more cheaply and effectively with some of the new preemergent herbicides (Clifford, 1963; Winget, Kozlowski, and Kuntz, 1963). Rates of 2 pounds or less per acre may give adequate control for the entire growing season. However, since some conifer species can be damaged or killed by such herbicides as the trizones, the nurseryman should first test different rates on a few small plots before he applies the treatment to entire nursery beds. The most promising herbicides are: (1) propazine, (2) simazine, and (3) atrazine. These should be tried at rates of 1/2, 1, 2, and 4 pounds per acre, applied about 1 week before and at the same time as sowing the conifer seeds. The beds

should be watered immediately after treatment with about 1/10 to 1/4 inch of water.

Hand weeding is usually necessary as a follow-up to chemical treatments in California nurseries.

Nutrient Deficiencies

Stunted growth and foliage discoloration may indicate nutrient deficiencies. The following symptoms to be observed on the more common conifer seedlings may serve as clues to indicate which one or more nutrients might be deficient (Stoeckeler and Jones, 1957; Wakeley, 1954; Wilde and Voigt, 1952). Small test treatments should be made to verify the diagnosis before treating large areas because several deficiencies may show the same symptoms:

Nutrient deficiency	Symptom
Nitrogen (N)	New needles short, pale green or yellowish-green. Older needles may have brown or dead spots.
Phosphorus (P)	Needles short, pink, reddish, or purplish and may have dead spots. Often new needles on some pines normally turn purple during cold weather; however, a premature color change may indicate phosphorus deficiency.
Potassium (K)	Needles yellow or bluish-green with tan to copper coloration at tips.
Magnesium (Mg)	Needles yellowish-green with dead spots at later stages.
Calcium (Ca)	Needles near terminal bud stunted; pale yellow-green to gray-green and tips may be brown.
Sulphur (S)	Needles pale green which later turn yellow. Youngest needles turn color first.
Boron (B)	Plant stunted, needles chlorotic and may have dead spots; buds show deterioration.
Iron (Fe)	Terminal needles chlorotic.
Manganese (Mn)	Stunted growth and all needles may be chlorotic.

Nutrient deficiency	Symptom
Copper (Cu)	Stunted growth, needles pale green to light yellow.
Zinc (Zn)	Stunted growth; needles yellow mottled.

Nurserymen should check other factors too as possible causes of stunted trees or discolored needles, such as poor drainage, too heavy application of fertilizer, failure to wash fertilizer off needles, insecticide damage, and others.

Soils specialists at the University of California School of Forestry and Conservation or the University's Soils Department should be called on for assistance in solving nutrient problems.

ROOT PRUNING AND SEEDLING LIFTING

Every nurseryman hopes to produce the maximum number of plantable trees per unit area; unplantable trees represent a financial loss. Unplantable trees may be those with mutilated roots, poor root systems, or inadequate size. Injury losses range from less than 5 percent to as high as 50 or more percent. Losses due to inadequate root systems can be reduced by pruning to stimulate a more compact fibrous set of roots. The plant size can be increased by growing the trees at a lower density. Injury to the plants can be reduced by greater care and use of proper tools during pruning and lifting.

Root Pruning

Seedling roots are pruned to control top growth, to improve the root system and top-root balance, and to facilitate seedling removal from nursery beds. Root pruning is an economical substitute method for transplanting, which has been used to produce these same effects. The benefits derived from root pruning will be affected by when the roots are cut and at what depth. Some species require root pruning, others do not.

Seedlings of some species, such as Monterey pine, grow too tall and spindly unless their growth is retarded by removal of a part of the root system. Many of the pines like Monterey will send down a long single root unless it is cut to force more lateral root

development. While still others, such as the true firs, may produce short roots with few laterals unless the root terminals are cut to encourage development of more root segments. The same species may have different rooting habits when grown at different nurseries. Root pruning can be an aid in tailoring seedlings to nurserymen's specifications.

Plants that make too rapid height growth or have a spindly root may need to be root pruned several times during the growing season (Fullaway, 1966). The first scheduled pruning should be made when the root depth exceeds 6 inches at which time the roots should be pruned at about 4 inches. The second and third pruning should be made when the roots extend several inches below the cutting depth. Each successive cut should be about 2 to 3 inches deeper than the preceding cut. However, very few species may need to be root pruned more than twice before the seedlings are lifted from the nursery beds.

Seedlings to be lifted as 1-0 stock, that require only one root pruning during the growing season, should be pruned at a depth of about 5 to 6 inches during late summer. Seedlings for 2-0 stock may be pruned during the first summer at a depth of 5 to 6 inches and again before the start of the second growing season (early spring) at a depth of 7 to 8 inches. When the seedlings are to be lifted, the blade should be set at a depth of about 10 to 12 inches.

Root pruning should be done in spring, after danger from frost heaving is over, and in summer. Fall or too early spring root pruning is not recommended. At the Magalia Nursery, almost all the fir seedlings and over half of the pine seedlings that were root-pruned in fall were frost heaved during one winter. Late fall pruned seedlings also may die during dry-open winters. Trees root-pruned in summer will develop new anchor roots before winter.

Care in Root Pruning

Damage to seedling roots can be reduced in at least three ways: (1) by keeping the pruner blade sharp at all times; (2) by setting the blade at the correct depth; and (3) by insuring that the soil and seedlings settle back in place after the blade has cut the roots. A dull pruner blade will break or strip off the roots. These damaged roots are more susceptible to disease attack and are less able to produce new roots than undamaged ones. An improperly set blade may shear off too much of the root system or too little to do any good. If an air pocket is left at the cut line or large cracks are left in the soil, new root growth will be reduced or the seedlings may die of desiccation. Light sandy loam soils generally settle back into place; however, heavy clay soils do not. Heavy watering of the beds immediately after root pruning will help settle the soil.

Lifting Seedlings

The method used to lift nursery stock depends on the quantity of trees to be lifted and the equipment available at the nursery. If only a small amount is to be lifted, the entire job is done by hand methods. A shovel or spade is used to loosen the soil and the seedlings are lifted by hand. The excess soil is removed by gently shaking the trees. They are then either placed in a crate with moist peatmoss or sawdust or dipped in water and put into a polyethylene bag. Seedlings loosened with a shovel or spade usually are not root pruned until after the trees are lifted.

When large quantities of seedlings are to be lifted, the nursery beds are undercut with a combination root pruner-lifter (Fig. 29). This machine cuts the roots at the desired depth and loosens the soil and seedlings in one operation. Lifting fingers bolted to its cutting blade loosen the soil. The seedlings are then lifted by hand.

A common lifting practice is to perform the seedling harvest operation in three stages: First, the lifting crew removes the seedlings from the nursery beds and heels in the seedlings in bunches of about 50 trees. Second, a crew picks up the trees and places them in field packing crates that hold about 2,000 trees. Third, a crew then hauls the filled crates to the grading and packing shed. Some nurseries lift and place the seedlings directly in crates.

To cut down on the amount of handling and to permit grading, counting and packing in the field, Lanquist (1954b) developed a tractor-drawn endless belt machine that straddles five beds. The "seedling harvester", (fig. 30), is towed in front of the lifting crew. The plants are lifted, placed on the conveyor in bunches of 25 to 50, and packed 2,000 per crate. To keep the seedling roots moist while on the conveyor belt, the seedling harvester is equipped with hood to shade the seedlings and with a mist sprayer to keep roots moist (Schubert and Lanquist, 1959).

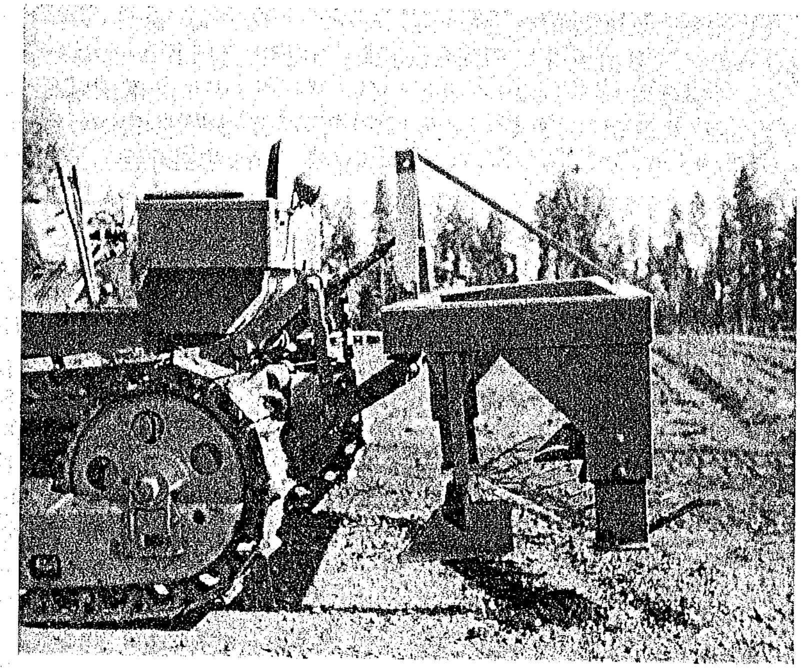

Figure 29. Combination root pruner and seedling lifter helps to loosen soil.

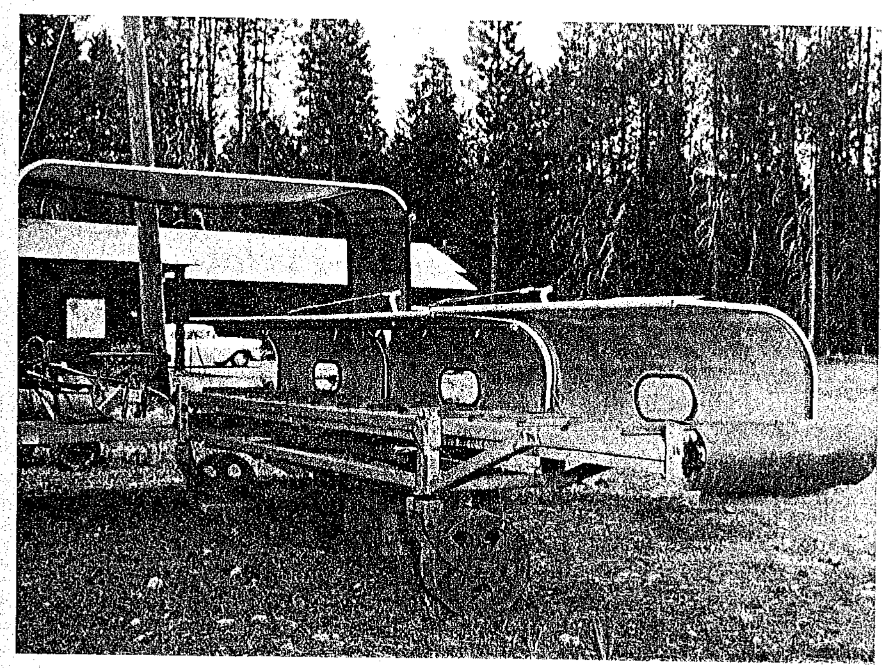

Figure 30. The "seedling harvester" in rearview, shows location of mist nozzles over the conveyor.

Seedling harvesters that cut under seedlings, lift them and deposit them in containers are being developed (Florida For. Serv., 1970 ; Heltzel, 1970). Such machines are an advantage only where production is geared to lifting several hundred thousand seedlings a day (North Carolina For. Serv., 1969; U. S. Forest Service, 1969).

Care in Lifting

During lifting, trees may be injured by stripping the roots or by drying. Plants lifted singly are more apt to sustain damage than plants lifted in groups.

Seedling roots should be kept moist at all times. Some exposure of roots is unavoidable during lifting, but it should be kept at a minimum. Studies indicate that trees can withstand a rather surprising amount of air drying. However, even relatively short exposures of 1 to 3 minutes may cause some reduction in survival, and exposures of 15 or more minutes may result in severe losses. Three-year-old Jeffrey pine transplants were exposed for six different time periods by spreading them on unshaded boards laid on the ground in Mt. Shasta Nursery in October on a partly cloudy day. The trees were then stored over winter and planted the next spring on the Ash Creek Sink Burn on Shasta-Trinity National Forest. First-year survival was 70 percent for the trees exposed for a half minute and 6 percent for those dried for 60 minutes.

Trees should not be lifted during dry windy weather. Precautions must be taken at all other times to keep roots moist by covering seedlings with wet burlap or shingle-tow during lifting operations.

AGE AND SIZE CLASSES OF STOCK

Normally only seedling stock is grown at Forest Service and California Division of Forestry nurseries. The two State nurseries growing bare root stock have produced small quantities of transplant stock to fill special needs for studies. Some private nurseries also produce transplant stock. The third State nursery, at Davis, produces about 200,000 potted seedlings annually, but does not supply bare-root seedlings or transplants.

Tests of different classes of planting stock have been made in California since 1915. Show (1930) concluded from his studies in the Pine Region that...

1. Seedling stock, with its poor top to root balance, was generally unsuitable for field planting.
2. 1-1 transplants were best for ordinary planting sites.
3. 1-1-1 transplants should be used on all the unfavorable planting sites.

Person (1937) reported higher survival for 1-1 transplants than for 1-0 or 2-0 seedlings in plantings made from 1923-27 in Humboldt and Mendocino Counties (table 20). Survival for plantings in Southern California was generally higher for 1-1 transplants than for 1-0 or 2-0 seedlings (Sischo, 1958).

Table 20. Average survival in 1931 of trees planted by commercial timber companies in Humboldt and Mendocino Counties, 1923-1927.

Species and class of stock	Humboldt County	Mendocino County	Weighted average
	Percent		
Redwood, 1-0	40	52	45
Redwood, 1-1	47	66	65
Douglas-fir, 1-1 and 2-0	34	42	37
Port Orford cedar, 1-0, 1-1, 2-0	70	58	66
Sitka spruce, 2-0 and 2-1	38	67	47
Weighted average	41	56	48

Source: Person, Hubert L. Commercial planting on redwood cut-over lands. U. S. Dept. Agr. Cir. No. 434. 1932.

Improved nursery practices, earlier sowing of seedbeds in the spring with stratified seeds, and lower seedbed densities have made it possible to produce excellent seedlings without the necessity of transplanting (fig. 31). The improvement in these seedlings is reflected in higher average survival in current plantings than was possible in earlier ones. For example, survival of plantings made in 1958 with 2-0 and 3-0 root pruned Doulgas-firs on Jackson State Forest on February 14 was 94 percent, and those made near Eureka on March 22 was 92 percent (Stone, Gilden, *et al.*, 1961). Earlier plantings with Douglas-fir seedlings were often failures.

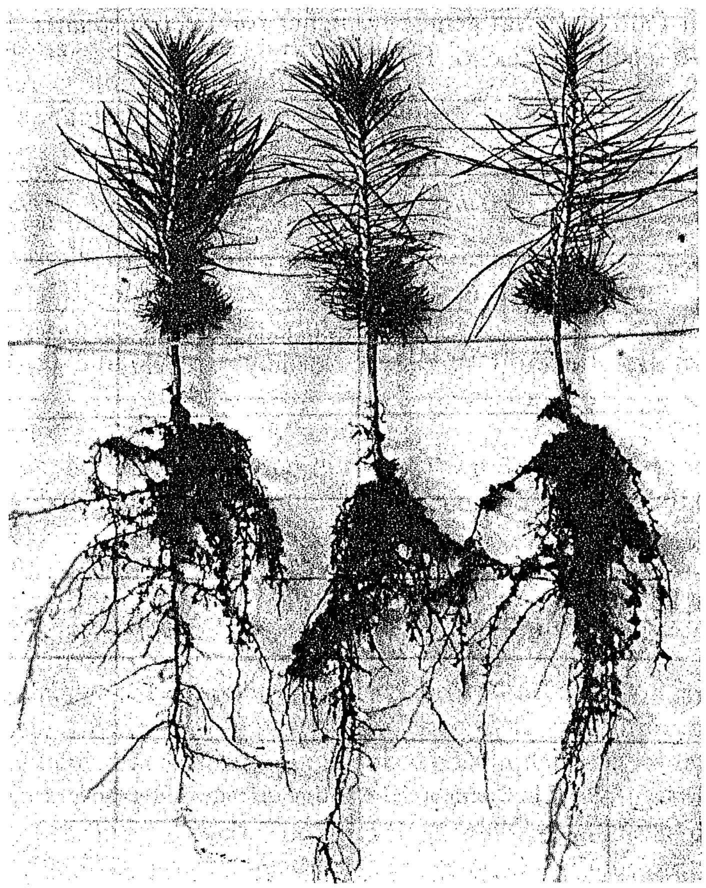

Figure 31. Excellent top and root development of 1-0 ponderosa pine seedlings from Placerville Nursery.

In southern Oregon, 3-0 Douglas-fir survived better than 2-0 on south facing slopes (Berntsen, 1958); survival was 51 percent and 33 percent, respectively. Since the older stock was larger it was more able to withstand surface soil movement.

Age classes and size classes within age classes, top-root ratios, and such descriptive terms as "Firsts", "Seconds", and "Culls" were most often used during the early planting days in California (Show, 1930). Today the emphasis is more on condition of the root system and stem diameter than on age classes per se. And the terms "Firsts" and "Seconds" are no longer used. Top-root ratios are still used, but have little practical meaning unless combined with other criteria.

Culling and Grading Nursery Stock

The main purpose for culling and grading nursery stock is to eliminate poor risk trees and, in some cases, to group the good ones into two or more quality classes. About all that can be done is to remove those trees that appear "least likely" to survive, on the basis of visible characteristics, e.g., plant size, injury, root systems, and balance between tops and roots. As the plants pass the graders on a conveyor belt, the nurseryman has no positive way to eliminate all plants that appear to be satisfactory but are physiologically dead.

Over the years, various specifications for culling and grading have been developed to serve as guides to remove trees with a low probability to survive and grow after field planting. Certain age or size class trees, or trees with certain top-root ratios, or the presence or absence of winter buds or secondary needles have been found to be or believed to be assoicated with survival under certain conditions (Corson and Fowells, 1952; Fowells, 1953a, b; Fowells and Dunning, 1948; Show, 1930). Most of these specifications have been tested, at least in part, as they affect field survival. However, results have been quite variable with seedlings of high morphological grades, even on favorable sites. These results suggest that nonvisible physiological characteristics may be as important as size and external conditions (Fowells and Dunning, 1948).

Culling Stock

Cull in nursery practice is a general term applied to all seedlings judged to be unsuitable for planting. The plants may be culled on the basis of size, injury, or disease. Culling based on size will be covered in the discussions under grading. Seedlings should not be culled merely because they did not develop winter buds.

In general, cull seedlings with these characteristics:

1. Roots severely damaged or bark stripped off.
2. Main root split in upper 6 inches.
3. Root system less than 8 inches long.
4. Top severely damaged or bark stripped off.
5. Visible evidence of disease infection on tops or roots.
6. Dry roots.
7. Weak top or root system.

The number of seedlings culled under these guides are normally less than 5 percent. If the cull percent, based on these characteristics greatly exceed 5 percent, it usually indicates improper care in growing and handling the stock.

Grading by Top-Root Ratios

Nurserymen generally agree that plants with a well balanced top-to-root ratio have a better chance to survive than those that are completely out of balance– especially when the root system is much smaller than the top. However, plants with a favorable top-to-root ratio are not necessarily good planting stock. The plants must also be of the right size. In a study with unpruned 2-0 ponderosa pine seedlings, the heaviest seedlings had the highest survival (Baron and Schubert, 1963b).

Fowells [10] could find no consistent relationship between top-root ratios and survival of nursery stock. Based on records of top-root ratios and survival of about 9 million trees planted from 1930 to 1942, the correlation coefficient between top-root ratio and survival was -0.0855 for ponderosa pine and -0.55 for Jeffrey pine. For ponderosa pine, correlation between top-root ratio and survival was practically nonexistent. Although the correlation with Jeffrey pine was large enough to suggest a relationship, the top-root ratio explained only about 30 percent of the variation in survival. In the southeast, top-root ratios have never proved useful in grading southern pine seedlings and have not been included in the grading rules (Wakeley, 1954).

The failure to show a strong correlation between top-root ratios and survival does not completely rule out the use of top and root weights as a grading criterion. Actually the top-root weight relationship can be quite useful, if the limitations are properly recognized. The weights establish a relationship of tops to roots which other methods may not show as clearly or accurately. However, the shortcomings mentioned above limit top-root ratios to a supplementary role in grading nursery stock.

The Washington State Department of Natural Resources is producing relatively large quantities of large transplant stock to overcome problems with vegetative competition and animal damage. It has discarded the old concept of balanced top/root ratio. Some 2-3 Douglas-fir stock has had a top-root ratio of over 4 and survival has been high (Nelson and Anderson, 1966).

[10] Office memorandum from H. A. Fowells to C. W. Corson on establishment of planting stock grades, dated March 4, 1950.

Grading By Height Classes

Grading nursery stock by height size classes is considerably easier, faster, and less complicated than grading by methods based on weight measurements. Grades based only on height, however, have certain inherent weaknesses. Tall weak trees would be included and short sturdy trees would be culled. Unless the roots are considered, many trees with a good top and a poor root system would be planted and the purpose of grading defeated.

For tests to establish grading standards, stock is usually divided into thirds and planted on a variety of sites. If differences in survival between the top two grades are small, these classes are normally combined, and the smallest third discarded as culls. On some of the best planting sites there may be no appreciable difference in survival for any of the grades, and all trees would be classed as plantable except the damaged ones.

Results of several height-grade tests during the past 50 years have been quite variable. Show (1930) reported highest survival for the tallest ponderosa pines, but medium-sized Jeffrey pines were best in a 2-year study on Shasta National Forest. In the seed and stock size study reported by Fowells (1953a), differences in survival by size class varied from 2 to 4 percent during the first year (table 21). By the ninth year, survival of large plants averaged from 3 to 11 percent higher than the small plants.

In most of the above studies, average survival would not have been greatly improved by culling the shortest plants.

Table 21. Survival of classes of ponderosa pine and Jeffrey pine at successive years after planting.

Size class	Ponderosa pine Years after planting . . . 1	3	5	9	Jeffrey pine Years after planting . . . 1	3	5	9
				Percent				
Seed:								
Large	98	94	92	92	93	86	85	85
Medium	98	92	89	88	95	93	93	92
Small	97	93	90	90	97	93	92	91
Seedling:								
Large	98	96	95	94	94	92	91	91
Medium	98	94	92	92	95	91	90	90
Small	96	88	85	84	95	89	88	88
Transplant:								
Large	99	97	95	95	97	96	95	95
Medium	99	94	93	92	94	91	90	89
Small	94	87	84	84	93	86	84	84

Source: Fowells (1953a).

Grading By Stem Diameter Classes

Stem diameter has been recognized as a good indicator of seedling quality. But like seedling height, it should not be used as the only criterion to judge plant quality. With diameter as the measure of quality, spindly seedlings of all height sizes are culled and the short thick ones are retained. However, as with height classes, the root system must also qualify before the plant is classified as plantable.

Results of grading studies based on stem diameter indicate that it is an effective method to cull trees that have a low probability of survival. In a study at the old Feather River Experiment Station, near Quincy, California, the average diameter of the trees that survived was 0.120 inch for ponderosa pine and 0.125 inch for Jeffrey pine. The average diameter of the trees that failed was 0.098 inch for ponderosa and 0.103 inch for Jeffrey pine. In another test, the average survival of 2-0 ponderosa pine was 75 percent for stock with a stem diameter over 0.10 inch and 50 percent for the stock that was smaller. The larger stock averaged 0.115 inch and the smaller was 0.085 inch.

Stem diameter has been accepted as a basis for quality specifications for planting stock on National Forests in California and that produced by State nurseries. A minimum stem diameter of 0.11 inch was recommended for 1-1 ponderosa and Jeffrey pine transplants (Corson and Fowells, 1952); however, since Jeffrey pines are often about 0.02 inch larger than ponderosa pines, the minimum diameter for 1-1 Jeffrey pine was raised to 0.13 inch for National Forest plantings (U. S. Forest Service, 1957).

The minimum stem diameter was set on the basis of performance of ponderosa and Jeffrey pine transplants raised in a cold-climate nursery (Corson and Fowells, 1952). The same diameter limit is used for seedling stock of most species grown in nurseries that have different climates. Some adjustment in minimum specifications of planting stock may be necessary because of the differences in growth at the present nurseries (Baron and Schubert, 1963a).

Stem diameter measurements of stock from five seed collection zones grown at four nurseries during 1957-1959 are shown in table 22. If the minimum stem diameter is set at 0.11 inch, 1-0 seedlings can be grown at all nurseries except at Mt. Shasta. Some differences in diameter growth are also apparent for seed origin. Stock from Zone I was generally the smallest at each nursery. Seedlings grown at Placerville Nursery averaged slightly smaller than those grown at Ben Lomond (Baron and Schubert, 1963a).

Table 22. Average stem diameter of ponderosa pine seedlings, by age class and seed collection zone, grown at four nurseries in California, 1957-1959.

Age class and seed zone	Mt. Shasta	Magalia	Parlin Fork	Ben Lomond	Average
	Nursery				
	Inch				
1-0: I	0.060	0.120	0.110	0.120	0.102
II	.090	.140	.120	.140	.122
III	.070	.100	.130	.120	.105
IV	.090	.120	.130	.120	.115
V	.060	.110	.150	.120	.110
Average	.074	.118	.128	.124	.111
2-0: I	.176	.213	.239	.281	.227
II	.202	.264	.337	.364	.292
III	.174	.218	.254	.300	.236
IV	.218	.284	.288	.340	.282
V	.205	.250	.294	.319	.267
Average	.197	.246	.282	.321	.262

Sugar pine and Douglas-fir should be grown as 2-0 stock at all nurseries since they do not attain an acceptable stem caliper as 1-0. Similarly 1-0 ponderosa pine seedlings from some seed sources may have to be grown for 2 years at some nurseries to exceed minimum specifications.

On the basis of tests with ponderosa pine size grades, Adams (1964) found that 3/32 (0.094)-inch stem diameter with 3-inch top should be the minimum for 1-0 ponderosa pine and 4/32 (0.125)-inch with 3-inch top for 2-0. These essentially are minimums used by the State.

Recommended Grading Procedures

The main objectives of a grading system for forest planting stock are:

1. To eliminate as culls, trees with damaged or diseased tops or roots.
2. To eliminate trees below minimum standards of size and root development.
3. And to segregate the trees that exceed minimum standards into two or more quality grades. Generally this segregating is not done in production nurseries unless the demand justifies the extra costs. Such a request also would be accepted only for relatively large numbers of the larger than normal size grade. A justified use of large stock would be in machine planting.

The minimum stem diameter and top height specifications should be about as follows:

Species:		Stem diameter	Top height
		Inches	
Ponderosa pine	1-0	0.09	3
	2-0	.11	4
Jeffrey pine	2-0	.13	4
Sugar pine	2-0	.10	4
Monterey pine	1-0	.08	6
Other pines		.11	5
True firs	2-0	.09	3
Douglas-fir	2-0	.09	6
Spruces		.08	3
Other species		.10	4

Trees culled because of small size or poor root systems should not exceed 15 to 20 percent.

To aid graders, nurseymen should provide each grader with a calibrated measuring device for the minimum specifications. He should also prepare a display board with samples or enlarged photos of cull and plantable trees for each species. The minimum specifications should be adjusted whenever field results indicate a need for correction.

Before packing seedlings in containers for storage or shipping it may be necessary to trim roots more than what was done by the lifting blade passing under the nursery beds. The lifting blade does not cut long laterals, for instance, that may hang down below the desired 10 or 12 inches. Seedling roots may be pruned to the desired length by using a paper cutter type device, revolving toothless saw blades, or large shears. This pruning is usually done after the seedlings have been gathered in bundles of 25 or 50.

Roots should not be pruned shorter than 10 inches. Several studies have been made since 1938 that demonstrated survival and growth of seedlings with long roots was better than seedlings with short roots. [11] In one study, survival averaged 7 to 11 percent higher for trees with 12-inch roots than for trees with 8-inch roots (table 23). Although differences in survival have been statistically significant, the differences were not considered enough to compensate for the higher planting costs.

Table 23. First-year survival of 1-1 ponderosa pines root pruned at 8 and 12 inches and planted on different sites.

Site condition	Trees with roots pruned at - - 8 inches		12 inches	
	Planted	Survival	Planted	Survival
	Number	Percent	Number	Percent
Stripped mountain misery	1,905	44	1,863	55
Fresh burn	1,200	74	1,200	81
Bulldozed old burn	89	71	2,156	79

Differences in top growth also have been statistically significant in favor of the trees with longer roots. For example, the trees with 12-inch roots planted in the fresh burn were 0.7 inch taller at the end of the first growing season than those with the 8-inch roots. Although this small difference may not be statistically significant, it does indicate that trees with better vigor can compete with other vegetation.

Root pruning affects new root growth of field-planted trees. In one study, fall planted, root-pruned ponderosa pines made no root growth until spring, and spring planted trees showed no appreciable root growth before 20 days from unpruned laterals and 40 days from pruned points (U. S. Forest Service, 1940). By early summer, most new root growth was from elongation of unpruned laterals.

[11] Unpublished study progress reports, California Forest and Range Experiment Station, U. S. Forest Service, Berkeley, California.

Therefore, root pruning and handling injuries immediately before planting may contribute to early summer losses from drought in plantations even though soil moisture was adequate for growth at time of planting.

NURSERY STOCK LIFTING AND STORAGE SCHEDULES

Nursery stock may be lifted for immediate field planting, for transplanting in the nursery, or for field planting at some future date. The physiological condition of seedlings largely determines lifting schedules, although physical effects of weather such as frozen ground in the seed beds, snow on the nursery, and drought at planting locations may modify such schedules.

Results of root regeneration studies upon which lifting schedule recommendations are based have suggested that:

1. Seedlings from a cold-climate nursery reach a suitable physiological condition for immediate planting or storage earlier in fall and later in spring than do seedlings from a warm-climate nursery.

2. Seedlings from a cold-climate nursery needed for winter or early spring planting, when fresh stock is unavailable, are in the best physiological condition for storage in late fall.

3. Seedlings needed for spring planting after fresh stock has started to grow in the nursery are in best physiological condition for storage before the occurrence of the RRP peak.

4. Peak RRP at each nursery may fluctuate from year to year, both in intensity and time. A warmer than normal fall will delay and reduce the RRP. A warmer than normal spring may activate earlier root growth.

5. Storage periods should be kept short and need not exceed 3 months from any nursery. Too long storage may cause seedling deterioration.

6. Storage will reduce the RRP when stock is lifted before it has been adequately conditioned in fall or lifted after it has reached its peak RRP in spring.

Guidelines for lifting based on the physiological condition of seedlings at the time of lifting generally will provide the highest quality planting stock. At cold-climate nurseries some modifications are necessary because of snow and soil conditions.

Cold-Climate Nursery Lifting and Storage Schedules

A. For late fall planting (November 1 to December 21):

1. Stock for immediate planting may be lifted from November 15 to early December. Usually its physiological condition will be suitable before November 15, but planting sites generally have not received sufficient moisture before then.
2. If stock must be stored for later planting in December, it should be lifted from about November 1 to November 15.

B. For winter planting (December 22 to March 21):

1. If planting requires stock in late December, January, and February, stock lifted from November 1 to 15, and stored should be used. Since cold climate nurseries usually raise stock for high elevation plantings, no stock should be required for early and midwinter planting.
2. Stock for first 3 weeks of March may be either fresh-lifted or late fall-lifted and stored. Preference should be given to fresh-lifted stock, if lifting can be done without damage to root system. Some years, soil in the nursery beds still may be frozen or too wet for early March lifting.

C. For spring planting (March 22 to May 21):

1. Fresh-lifted stock should be provided for early spring planting as the RRP is then highest.
2. For late April and early May plantings, stock should be lifted in late March or early April and stored until needed.

Warm-Climate Nursery Lifting and Storage Schedules

A. For late fall planting (December 1 to December 21):

Fresh lifted stock is most suitable. Seedlings generally should not be lifted before December 1.

B. For winter planting (December 22 to March 21):

Fresh lifted stock is again most suitable, although RRP may drop off near mid-March.

C. For spring planting (March 22 to May 21):

Stock should be furnished from stored seedlings lifted in January or February or just before the peak RRP is reached.

The above lifting and storage schedules should help the nurseryman to plan, integrate, and execute his other operations to greatest advantage. They provide sufficient latitude and flexibility to meet most ordinary nursery and planting needs.

Weather is a most important factor affecting lifting schedules. Temperature and precipitation from early fall to spring affect the physiological condition of the seedlings and the physical condition of the nursery soil. Their effects may require some adjustment in the schedules. Weather forecasts of impending rain or snow storms and extended dry periods can be used to adjust plans to lift and store the correct amount of stock needed for each planting season.

PLANTING STOCK STORAGE

Cold storage of planting stock can increase flexibility in a reforestation program. This flexibility is essential in regions, such as California, where climate differs markedly between nurseries and planting sites. Since it is impractical to have a nursery match each planting site requirement, planting stock must be held in storage at near optimum conditions for areas to be planted when fresh stock is unavailable or below acceptable physiological standards.

Recent studies have demonstrated that trees can be stored successfully for periods sufficiently long to meet any of the planting requirements. For California, these storage periods should not exceed 3 months.[12] Trees can be stored longer, but generally survival and the root regeneration potential are greatly reduced. Hellmers (1962) found that the food reserves in the stems and buds were largely depleted at the end of 4-1/2 months, but there were still some in the roots. These depleted reserves decreased the plant's ability to grow. Even for successful storage at short periods, the trees must be (1) lifted at the right time; (2) stored in the right way; and (3) stored under the right conditions.

Lifted at the Right Time

If the lifting and storage schedules outlined in the preceding section are followed, the trees will be in good physiological condition for storage.

Stored in the Right Way

Trees can be stored safely in a special refrigerated room, commercial cold storage rooms, heel-in beds, or cellars (Fowells and Schubert, 1953; Wakeley, 1954). For short periods, baled trees may be stored in cool warehouses or in cool, shaded places near the planting site (Ursic, 1956). When trees are stored in large quantities for long periods, refrigerated rooms are best. Heel-in beds are used for short storage periods. Many times trees are stored by two or more methods from the time they are lifted until they are replanted.

Packing Methods and Packaging Materials.--Whatever storage method is used, packing methods and packaging materials are all important considerations. Maintenance of stock in good physiological condition during storage and shipment depends on the materials used and on care exercised in packing operations.

Various packing methods and packaging materials have been tested in California (Fowells and Schubert, 1953). Vermiculite (medium fine grade used in nurseries for soil amendment) generally has been better than peatmoss, sawdust, or shingle-tow in retaining moisture around seedling roots (table 24). For storage periods up to 3 months, vermiculite, peatmoss, and shingle-tow have been equally effective. In other tests, no significant differences in survival were found for trees packed in crates or bales, wrapped in green-core wrap or plastic, or for trees with their roots covered with sawdust or sterilized peatmoss (Fowells and Schubert, 1953). Heavy mold developed on trees when the packing material covered part of the needles. Most mold was found on seedlings packed in unsterilized peatmoss and the least with vermiculite.

[12] Schubert, Gilbert H., and Frank J. Baron. Nursery sites determine planting stock storage schedules. 1965. Report on file at Berkeley, California. Pacific Southwest Forest and Range Experiment Station, U. S. Forest Service.

Table 24. Survival of ponderosa pine planting stock stored for 3 and 6 months at three temperatures and in four packing materials.[1]

Packing material	Stored 3 months at ...			Stored 6 months at ...		
	23° F.	32° F.	36° F.	23° F.	32° F.	36° F.
	Percent					
Vermiculite	0	84	96	0	71	98
Peatmoss	0	87	96	0	70	82
Sawdust	0	65	85	0	81	79
Shingle-tow	0	92	94	0	46	71
Average	--	82	93	--	67	82

Source: Fowells and Schubert (1953).

[1] Basis: 1,152 trees; 48 per treatment.

In a storage test made in 1953-54 with 1-1 ponderosa pines packing materials were compared with dipping the plants in lanolin. Survival was highest for fresh lifted stock and lowest for trees packed in unsterilized peat. The lanolin treatment lowered the survival of all treated stock and was most pronounced for stock packed in vermiculite.

Monterey pine and Douglas-fir stock is more subject to deterioration during storage or transportation than some other species, if periods are prolonged or conditions less than ideal. In an attempt to determine improved treatments that would increase seedling resistance to deterioration, the State in a series of studies tried treating Monterey pine and Douglas-fir stock with five chemicals (Adams, *et al.*, 1967; Adams and Eden, 1967). These were phytoactin, an antibiotic; Shell 4901, a hormone material; the root antidesicants Rutex 59 and Rutex MCT-1019-1; and Rutex W-3, a transpiration inhibitor. Under conditions of the tests, chemically treated seedlings survived no better after storage and transportation than untreated ones. In a few instances chemicals reduced survival.

Storage in Polyethylene Bags--A problem in stock storage is to find a packing material that will hold enough water to keep the tree roots moist for the entire storage period. In addition, the material should be inert, nonphytotoxic, and a poor medium for fungal growth. Vermiculite satisfies all these requirements; however, recent studies indicate that trees can be stored in polyethylene bags without a special moisture holding medium.

At Mt. Shasta Nursery, Lanquist and Doll (1960) compared survival of ponderosa pines stored for 5-3/4 months in polyethylene bags with and without added packing material. The trees, packed 100 to a bag, were stored at 33 to 34 degrees F. at a relative humidity of 92 percent. The "bare root" trees were soaked in water before being bagged. The others had a wet 50-50 mixture of fine wood shavings and vermiculite around the roots. The trees were entirely enclosed in the bag and the top secured with a rubber band. Survival the first year was 85 percent under both treatments.

Landquist and Doll (1960) repeated the test the following year with ponderosa pine and Douglas-fir. This time they placed 50 trees in each bag and 40 bags in a crate. The survival of ponderosa pines for both treatments was 94 percent, and was 40 percent higher for Doulgas-firs stored without the packing material.

Materials for packing Douglas-fir were tested by the State in conjunction with the chemical treatment studies (Adams and Eden, 1967). Survival of seedlings packed in polyethylene-coated kraft bags was significantly higher for those with roots wrapped in Tufflex, a blotter-type paper, than for those wrapped with shingle-tow or without a moist medium. First year survival was 92, 76, and 82 percent, respectively.

Duffield and Eide (1959) reported that the bulk of the 13 million trees produced annually at Col. Greeley Nursery in Washington was packed in poly-coated kraft bags. The procedure used is similar to that reported for Mt. Shasta except that two

handfuls of wet peatmoss are placed over the roots of each bunch of 50 seedlings. Fifty seedling bundles are then placed alternately top to bottom in a poly-coated kraft bag, the bag closed at the top and placed in the cold storage room.

According to findings at Mt. Shasta Nursery, the packing material is not needed, but Duffield and Eide (1959) indicated that the planting crews preferred to have these small quantities of moist peat to replace the dried peat in their planting bags. At the planting sites, the trees, baled in poly-coated bags, are temporarily stored in moist shady locations as a substitute for heeling-in.

Ventilation of Stored Trees.--During storage and shipment proper circulation of fresh air is required to prevent overheating and to reduce mold contamination. Individual crates or bales should be stacked to permit air movement through the spaces between bundles and between tiers of bundles. Deffenbacher and Wright (1954) reported that mold developed whenever the bundles or trees in adjacent bundles were in contact. Mold formation has occurred at Mt. Shasta Nursery and State nurseries under similar conditions. In refrigerated rooms, bundles should be stacked to leave 4- to 6-inch spaces between bales or crates and at least 2 feet between tiers of bundles.

Similar space provisions should be made for field stored bundles. If a canvas is placed over the stacked trees, the canvas should be supported to provide adequate air circulation.

The choice of storage may be governed by personal preference, convenience, facilities available, advantages, or other reasons. Refrigerated rooms are preferred by many because large quantities can be stored under controlled conditions. Others may prefer heel-in beds for convenience or because the seedling roots may be conditioned to start growth earlier than stock from refrigerated rooms (Muelder, 1961). At planting sites, trees may be kept in bales for convenience or to reduce extra handling.

Results from studies of storage methods have been quite variable (Fowells and Schubert, 1953). Generally, trees stored in refrigerated rooms have been in better condition for planting than stock stored in heel-in beds or cellars. However, at times survival of trees from heel-in beds has been just as high or higher than for refrigerated stock. Often differences in survival of stored stock that have been attributed to storage methods may have resulted from improper procedures or poor physiological condition of the stock (Stone and Schubert, 1959.)

A study of ponderosa and Jeffrey pines stored for three periods by three methods indicated low survival of stock lifted in fall and stored for six weeks (table 25) (Fowells and Schubert, 1953). The stock was all planted in early November so the stock stored 2 weeks was lifted about the middle of October, the stock stored for 4 weeks was lifted in early October, and the stock stored for 6 weeks was lifted about mid-September. More recent studies on the effect of lifting dates indicated that the stock stored for 4 and 6 weeks was lifted before the trees were properly conditioned (Stone and Schubert, 1959d), so the comparisons for fall-lifted and stored stock are not valid. Spring-lifted stock showed equally good results under all three storage methods for the three storage periods.

In another storage test in which fall lifted stock was stored in heel-in beds and refrigerators, the survival of heeled-in stock was 91 percent compared to 81 percent for refrigerated stock (Fowells and

Table 25. First-year survival of stock stored for three time periods by three methods in spring and in fall. 1/

Species and length of storage	Spring Cellar	Spring Heel-in	Spring Refrigerator	Fall 1/ Cellar	Fall 1/ Heel-in	Fall 1/ Refrigerator
	Percent 2/					
Ponderosa pine:						
2 weeks	98	100	90	100	98	98
4 weeks	95	100	100	28	85	73
6 weeks	95	98	100	18	47	53
Jeffrey pine:						
2 weeks	97	100	95	100	100	97
4 weeks	87	100	98	98	97	95
6 weeks	100	98	100	62	72	72

Source: Fowells and Schubert (1953).
1/Stock was all planted in early November, and lifted 2, 4, and 6 weeks before planting.
2/Basis: 2,160 trees; 60 per treatment.

Schubert, 1953). This stock had been lifted in late November when it was properly conditioned. Survival of fresh lifted stock was 96 percent. In Oregon, survival of Douglas-fir seedlings stored for 2 months was 72 percent compared to fresh lifted stock at 73 percent (Ruth, 1953).

Stored Under the Right Conditions

Planting stock can be stored successfully if correct procedures are followed (Fowells and Schubert, 1953). How well it maintains its vitality during storage depends a great deal upon the storage conditions. Even with stock lifted at the best time and stored by the best method, seedling mortality can be extremely high if stored under conditions in which (1) the temperature is too low or high; (2) the moisture and relative humidity are too low; (3) the trees are contaminated with fungi; (4) the handling procedures are wrong or carelessly executed; or (5) there are other less obvious factors.

Temperature.--The best storage temperature for refrigerated stock is from 33 to 36 degrees F. (Fowells and Schubert, 1953). When trees were stored at 0 degrees and 23 degrees F., none survived even 1-month storage. Temperatures much higher than 38 degrees F. favored the development of mold which caused deterioration of the stock (Deffenbacher and Wright, 1954; Fowells and Schubert, 1953).

Two studies were specifically designed to determine the best temperature to store pine seedlings in California (Fowells and Schubert, 1953). In the first test, survival of ponderosa and Jeffrey pine seedlings was highest for stock stored up to 4 months at 32 degrees F. All trees stored at 0 degrees F. died, and those stored at 41 degrees F. were covered with mold. In the second test, survival of stock stored at 36 degrees F. was higher than that stored at 32 degrees F., and all stock stored at 23 degrees F. died. Storage at 34 degrees F. has also been satisfactory (Stone and Schubert, 1959c). Deffenbacher and Wright (1954) reported excellent results for Douglas-fir and ponderosa pine stored at 35 degrees F. in Oregon. This temperature is similar to the suggested storage temperature of 33 to 36 degrees F. for California.

Trees, stored in heel-in beds or in bales in a warehouse or at the planting site, must be kept cool. Heel-in beds or areas for baled trees at the planting site should be located in the shade either on the north side of trees or an artifical structure. A canvas or other type of cover should never be placed directly on the trees as it may lead to overheating and death of the trees.

Moisture and Relative Humidity---Tree roots must be kept moist at all times. Whether the trees are in bales or in heel-in beds, the roots should be checked often enough to insure that they do not become dry and water added as needed.

The relative humidity in refrigerated rooms should be at least 90 percent (Fowells and Schubert, 1953). Deffenbacher and Wright (1954) stated that the relative humidity should be from 90 to 95 percent for storing Douglas-fir. They noted that the tops dehydrated when the humidity dropped below 90 percent.

Satisfactory moisture content of a Doulgas-fir seedling top as judged by needle turgidity does not necessarily indicate that the entire seedling holds sufficient moisture. The roots may have been desiccated during nursery handling or storage, and thus permanently damaged (Tarrant, 1964). However, Tarrant (1964) found that during 8 weeks storage at 35 degrees F. and 95 percent relative humidity, plants gained moisture, roots apparently gaining faster than tops.

TREE SHIPMENTS

Trees may be shipped by truck, railway express, or air freight in refrigerated or nonrefrigerated units. The method used will depend on distances involved and availability of particular types of transportation.

Whatever type of transportation is used the packing medium in bundles or crates must be checked for moisture content, and the medium moistened as needed.

For short distances, trees are generally transported by unrefrigerated trucks. For long distances, the trees should be shipped by refrigerated trucks, or rail cars, or by air. At times, shipment of Forest Service stock by Forest Service trucks is made at night.

If trucks are unrefrigerated, those with open beds should have supported tarpaulin covers over the trees to provide ventilated protection from sun and wind. Trucks with enclosed beds should be well ventilated. If the truck is stopped en route, it must be parked in a cool shady place.

Trees shipped by any method must be protected against overheating while awaiting loading from docks, while in transit, and on arrival at the destination. Again, they must be kept moist.

However, trees shipped by refrigerated truck or rail car, or by air seldom need watering en route. Upon arrival at their destination, all crates or bales should be examined and the trees watered if necessary.

All shipments must be carefully planned in advance. The departure time should be set so the trees arrive in time for proper disposition immediately upon arrival to prevent weekend layovers. The shipping agent or truck driver should be instructed to notify the proper authorities immediately upon arrival of the trees. The trees must then be placed in a moist-cool place until planted (see section on stock storage for details).

If adequate local storage facilities are available, all trees needed for the planting operation can be requested for delivery at the same time. Otherwise the amount requested at any one time should be restricted to a week's supply.

Shipment of trees across state lines or from certain restricted areas must be cleared in advance. Each nurseryman must be familiar with plant-quarantine regulations.

Nurseries in California can be cleared by local County Agricultural Commissioners so that no inspections of individual shipments are necessary at their destination. The nurseries are usually inspected twice each year, and if found to be free from injurious pests are issued a California Nursery Stock Certficate for Interstate and Intrastate Shipments.

MAINTENANCE OF SOIL FERTILITY

The continuous production of nursery crops rapidly depletes soil nutrients unless the supply is replensihed with organic or inorganic fertilizers or the plowing under of cover crops (Anderson, 1966). The addition of fertilizers high in nitrogen, phosphorus, and potassium almost always results in greater plant growth. However, excess amounts are wasteful and may be harmful.

Very little is known of the specific nutrient requirements of conifer seedlings at California nurseries. Soil and foliar analyses in 11 western nurseries, including four in California, were made by

Youngberg (1958). They suggested a correlation between nutrient uptake of seedlings and available soil nutrients. Further work in Douglas-fir foliar analyses in the Northwest has assisted nurserymen in determining nutrient needs (Krueger, 1967). Analyses of seedlings from four nurseries were compared with those of fast growing forest seedlings on 10 recently clean-logged areas. Seedlings from one nursery and a section of another showed phosphorus deficiencies when compared with forest-grown seedlings. And the same section of the latter nursery appeared to be low in nitrogen.

Nutrient requirements may differ greatly at each nursery from year to year. As with plants in general, relatively large amounts of nitrogen, phosphorus, potassium, and calcium are required with lesser amounts of iron and sulphur and trace amounts of manganese, magnesium, boron, copper, zinc and other minor elements.

Nurserymen in California have tried to maintain high fertility levels by applications of organic and inorganic fertilizers. However, the amounts added are generally based mainly on past experience. Since many factors influence the availability of certain nutrients, each nurseryman should fertilize small test plots to determine the quantities needed for a proper fertilization program. Soils laboratories at the University of California should be called upon to assist by running foliar analyses and pot tests.

At Mt. Shasta Nursery, ammonium-phosphate was applied each year at a rate of 600 pounds per acre (U. S. Forest Service, 1957). Other nutrients were added to correct observable deficiencies. A similar program is followed at other nurseries.

At times, attempts at improving seedling vigor by adding fertilizers have failed to show a conclusive advantage of fertilized over nonfertilized seedlings (Adams, 1962). Inconclusive results may occur (1) when the fertility level in the nursery is already adequate, (2) when the amounts added may have been insufficient to affect seedling vigor, or (3) when the outplanting was in an area possessing adequate nutrients.

Inorganic Fertilizers

Inorganic fertilizers differ in composition and chemical reaction which may produce a different effect depending on soil pH, structure, and composition. Some fertilizers change the soil pH while

others have little or no effect on it. The availability of nutrients may be changed completely by soil acidity, the base-exchange capacity, soil texture, watering practice, or other factors. An application rate of a specific fertilizer may be adequate at one nursery but be ineffective or too much at another. Complete soil analyses and small test plots may not solve all problems, but they would provide the nurseryman with certain guides to follow.

Generally inorganic fertilizers should be added before the seedbeds are sown. Applications after seedling emergence should be made to correct nutritional deficiencies or to improve frost hardiness and drought resistance. Phosphate fertilizers have been found to increase both frost hardiness (Kopitke, 1941) and drought resistance (Shirley and Meuli, 1939b); however, nitrogen applied in late summer or early fall has decreased frost hardiness in many cases (Wakeley, 1954) and drought resistance (Shirley and Meuli, 1939b). Ward (1954), however, found that 2-0 Doulgas-fir seedlings fertilized with 50 pounds of nitrogen per acre in late August were better conditioned against frost damage than unfertilized stock. Seedlings with mycorrhizal roots were found to absorb more phosphorus than seedlings without mycorrhizal roots (Kramer and Wilber, 1949; McComb, 1938).

Fertilizers may be spread over the ground surface and then incorporated in the soil or applied in liquid form through sprinkler systems (Lanquist, 1954a). For best results, phosphorus fertilizers should be injected as liquids into the soil in bands or tilled in as dry material since phosphorus moves very little in the soil by leaching. Fertilizers added to nursery beds after seedling emergence must be washed off the seedlings to prevent chemical injury. This can be accomplished easily by sprinkling the seedlings an extra 10 minutes immediately following fertilization.

Organic Fertilizers

Both organic and inorganic fertilizers are needed to produce high quality stock. Inorganic fertilizers are the easiest to apply and often the most economical way to correct nutrient deficiencies. However, organic matter is needed to improve the physical and chemical properties of the soil. Many organic fertilizers require fortification with inorganic fertilizers particularly, nitrogen, phosphorus, and potassium.

Organic material may be added in the form of well rotted manure, sawdust, or turned-under cover crops. Cover crops should be plowed under while the plants are still succulent, readily decomposable, and before their seeds mature. Legumes, inoculated with nitrogen-fixing bacteria, were used as cover crops at Mt. Shasta Nursery. Grain crops produce the greatest amount of organic material, however. 13/

Many nurserymen have successfully used both raw and well-rotted sawdust to build up the organic matter in place of cover crops. The use of sawdust eliminates the need to take a nursery area out of production as is required with cover crops.

Allison and Anderson (1951) reported that about 24 pounds of nitrogen are needed per ton of dry sawdust. They also found that sawdust increased the need for available phosphorus. Wakeley (1954) indicated that sawdust with suitable amounts of inorganic fertilizers appeared to be an excellent way to increase organic matter without injury to the seedlings. All organic matter should be thoroughly mixed with the soil.

Maintenance of Soil pH

Conifer seedlings grow best in acid soil, usually with a pH of 4 to 6. The pH can be regulated by adding sulphuric or nitric acid, sulphur, calcium or by adding fertilizers with either an acid or alkaline physiological reaction.

The amount of chemical to be added depends on the present pH and type of soil. To do so the nurseryman removes a block of soil down to the normal cultiviation depth and adds varying amounts of chemical until the desired pH is reached. Since the pH will vary in different parts of the nursery, he will need to sample several areas and test each separately. Or he may send the samples to a soils laboratory for analysis and recommendations.

Test kits to determine pH are available at garden, farm and forestry supply houses.

If damping-off fungi are present, part of the acid may be added as a top dressing after the beds are sown. Otherwise, the entire amount of acid or other chemical should be incorporated before sowing the beds.

13/ Martin, William. The use of cover crops at Magalia Nursery, 1967 (Personal communication).

VEGETATIVE PROPAGATION AND WILDLINGS

Most of the planting stock in California is produced from seed in nurseries. However, there are times when some planting stock is produced from cuttings, grafts, or wildlings.

Rooting Cuttings

Mirov (1944) conducted a number of rooting experiments with ponderosa pine cuttings from 4- and 5-year old trees. The best results with 4- year old pines were obtained with cuttings treated for 24 hours with 50 p.p.m. of indole-butyric acid and then placed in coarse sand in a hotbed. Untreated cuttings set in coarse sand in the hotbed gave the same results but required a longer period.

Metcalf (1924) indicated that rooted redwood suckers could not be used for planting stock unless they were grown for 1 year in the nursery. Rooted redwood suckers not grown for a year in a nursery had a mortality of 75 percent.

Monterey pine can be successfully rooted in special galvanized metal containers with a peatmoss, oak leaf mold, and soil mixture. 14/ More than 65 percent of the cuttings rooted satisfactorily.

Root Growth Substances

Fowells (1943) reported that the average root length of ponderosa pine seedlings treated with 5 p.p.m. of indole-acetic acid was significantly greater than the growth on the untreated controls for the trees grown in nutrient solution. For those grown in soil, the only significant difference was the number of roots on seedlings treated with 50 p.p.m. of indole-acetic acid. Vitamin B and 25 p.p.m. indole-acetic acid had little or no effect on growth of tops or roots of seedlings. Plants grown in nutrient solution showed no significant differences with respect to number of secondary roots or number of short roots.

14/ Libby, William. Propagating Monterey pine from cuttings for provenance tests at the Univ. of Calif. School of For. & Con., 1969. (Personal communication).

In a study with Doulgas-fir seedlings, Osburn (1960) tried two commercial preparations ("Gro-Fast" and "Transplantone") to determine the effect on root initiation. Neither product showed conclusive positive results even though "Transplantone" seemed to show some increase.

Grafting Pines

Mirov (1940) reported on five methods of grafting pines: (1) grafting seedlings on transplants; (2) grafting seedlings on seedlings; (3) grafting shoots of older pines on nursery transplants; (4) grafting single needle bundles; and (5) inarching or approach grafting. He grafted seedlings or transplants of 15 pine species and stated that at least for experimental purposes the scions of any pine species can be grafted on any other pine species. Treating the scions of ponderosa pine seedlings with colchicine improved their survival when grafted on untreated ponderosa pine seedling stock. Shoots of older pines, even of overmature trees, were successfully grafted on young transplants. Needle bundles of ponderosa and Coulter pines were successfully grafted. Inarching of different species of pines was found to be the easiest way to graft pines under semiarid conditions.

Wildlings

Forest-grown seedlings (wildlings) have been planted to a limited extent in California. Generally wildlings have been used only as fill-in stock on understocked plantations, young natural stands, or on small scale planting operations.

Wildlings are usually inferior to nursery-grown trees in terms of quality. These forest-grown trees are likely to have root systems too poorly developed for successful field planting (Kozlowski and Scholtes, 1948; Metcalf, 1924). Metcalf (1924) recommended growing redwood wildlings 1 year in the nursery before field planting because too much of the root system was lost. Unless the trees are watered the first year, survival may be extremely low–11.5 percent compared to 22 to 50 percent for wildlings irrigated during the first growing season. In a small scale study at Challenge Experimental Forest, 2-year-old ponderosa pine wildlings had a first-year survival of 77 percent. These ponderosa wildings were planted on a

well-prepared site and watered immediately after planting and several times during the summer.

Wildlings are also inferior to nursery stock in terms of cost, control of supply, and quantity production. The occurrence of numerous natural seedlings along skidroads and road banks is impressive and though they appear to be numerous, the quantity is extremely small in terms of needs and amounts that can be grown in nurseries. The supply is further limited by the infrequent occurrence of good seed years, coincidence of a favorable seedbed and weather conditions, and by seed-eating animals. Costs are also likely to be higher than for nursery stock, unless the wildlings are readily accessible, easy to lift without serious damage to the root system, and are close to the planting site.

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IV SITE PREPARATION

NEED FOR SITE PREPARATION

The most important need for site preparation in California is to conserve soil moisture and nutrients for tree seedling establishment and early rapid growth. In this initial period in a tree's life, the relatively small amount of moisture in the top foot of soil is inadequate to supply the water and nutrient requirements of both young trees and other vegetation (fig. 32). After young trees have developed a wide-spreading and deep root system, the water and nutrient use by other vegetation is less critical; however, tree growth still may be retarded.

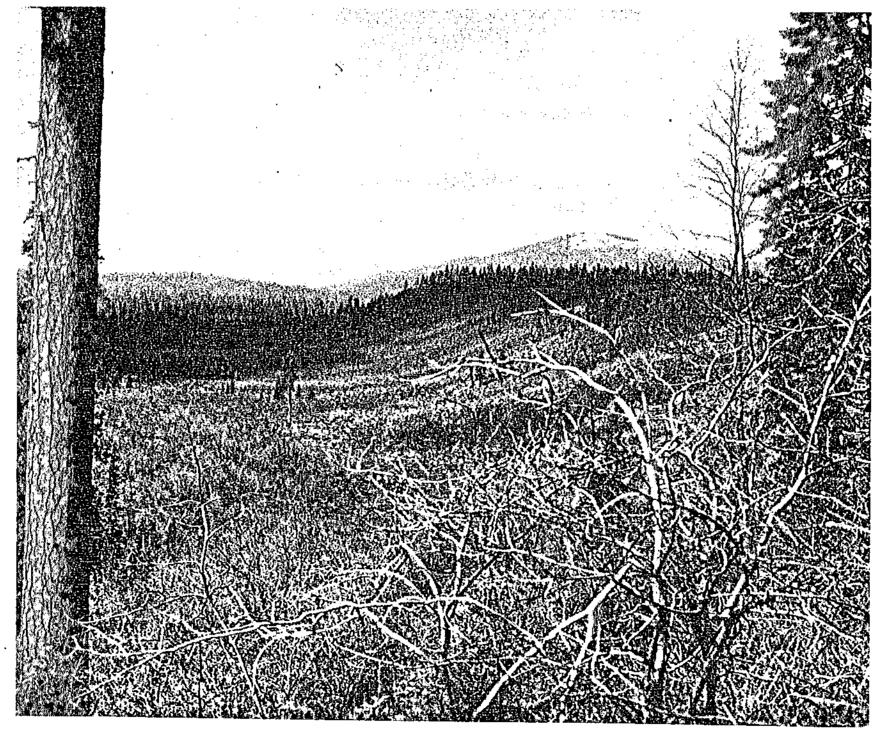


Figure 32. Severe competition for moisture in this brushfield near Mt. Shasta has prevented adequate tree establishment.

Other important needs for site preparation are to remove obstacles (fig. 33) that interfere with the planting operation and to eliminate or reduce habitat conditions that favor destructive small animals and soil insects (fig. 34).

Figure 33. Logging slash and other debris must be removed before an area can be planted (U. S. For. Serv. photo).

Competing Vegetation

In general, plantings and seedings have been successful only on areas where competing vegetation was destroyed or effectively reduced (Baker, 1955; Dunning and Kirk, 1939; Fowells, 1953b; Fowells and Dunning, 1948; Person, 1937). Where competing vegetation has been removed by fire, logging, or bulldozers, tree survival has been high--even during dry years (Baker 1951, 1955; Buck, 1959; Fowells, 1944, 1953a; Fowells and Stark, 1965).

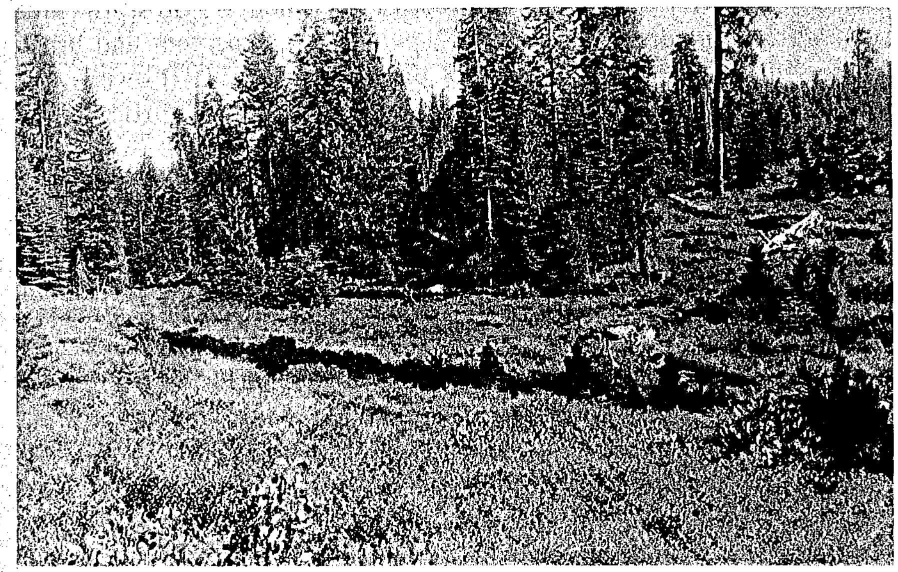


Figure 34. Brush, grass, and logs provide favorable habitat for many small animals and soil insects (U.S. For. Serv. photo).

Fowells and Dunning (1948) examined a series of plantations established from 1930 to 1945. Of the 23,000 acres planted, 12,500 were reported as satisfactory.[15] Tree survival in these satisfactory plantations averaged 70 to 95 percent on prepared sites, but only 40 to 50 percent on the best of the unprepared areas. The 10,500 acres of plantations rated as unsatisfactory were mainly on unprepared sites.

Similar results were reported by Buck (1961) for plantations established from 1958 to 1960 in the pine region on National Forests in California. Tree survival was 83 percent on prepared sites; 53 percent on unprepared sites.

It is extremely important that for best results seeding or planting immediately follow removal of competing vegetation. In his survey of commercial planting on cutover redwood lands Person (1937) found that survival of trees planted the second or third year after logging was about 50 percent lower than for first-year plantings

[15] Those with tree survival exceeding 40 percent.

(table 26). Plantings delayed 6 or more years usually failed. From 6 to 12 years after logging on Stanislaus Experimental Forest, the area in bare ground decreased from 22 percent to 8 percent and brush increased from 17 percent to 50 percent (table 27) (Fowells and Schubert, 1951). This increase in brush increased difficulty of seedling establishment.

Table 26. Survival of planted redwood in relation to the interval between logging and planting.

Interval years	Survival 1-0 stock	Survival 1-1 stock	Average	Basis: plots 1-0 stock	Basis: plots 1-1 stock
	- - - Percent - - -			- - - Number - - -	
0-1	47	61	55	6	26
2-3	28	- -	28	7	0
4-5	24	- -	24	5	0
6 or more	15	17	16	13	5

Source: Person (1937).

Table 27. Change in ground cover after logging. Stanislaus Experimental Forest.

Surface condition	Time examined: Immediately after logging 1/	1935	1947
	- - - Percent - - -		
Bare ground	22	8	2
Brush	17	50	58
Litter	39	25	24
Logs, etc.	22	17	16

Source: Fowells and Schubert (1951a).

1/ Plots cut in 1923, 1928 or 1929.

Drought

The precipitation pattern in California strongly influences establishment of regeneration. Nearly all parts of the State supporting stands of timber have a wet winter and dry summer. Almost all of the precipitation falls from November to April, with almost none from mid-June to mid-September.

Site preparation can be the means by which the adverse effects of summer droughts are minimized. Soil moisture in summer is appreciably higher where competing vegetation has been removed. For example, ponderosa and Jeffrey pines in an experimental planting near Quincy on a prepared site survived 90 percent at the end of 9 years. Mean annual precipitation at the site is 32 inches, and less than 1 inch of rain falls in the months of June through September (fig. 35). On Stanislaus Experimental Forest, with a rainfall pattern similar to that of Quincy, but with about 10 inches more total precipitation, open areas without vegetation still had a soil moisture content of 17.8 to 26.6 percent in late August.

Soil moisture in the upper 3 inches of areas covered with grass, brush, or weeds, is frequently below the wilting point and may be within 1 to 2 percent of the wilting point down to a depth of 21 inches (fig. 36). On prepared areas, the moisture content of the first 3 inches of soil may also be below the wilting point, but at depths below 3 inches there is usually adequate moisture for plant growth (fig. 37).

The adverse effect of low soil moisture on prepared and unprepared sites is greater for seedings than for plantings. Unless newly germinated seedlings can develop roots that extend below 3 inches before July they cannot survive--even on prepared areas. In early April, above normal temperatures contributed to failure of a machine seeding trial in Sierra County at the 5,000-foot elevation (Adams, 1967). Douglas-fir seeds 1/4 to 1/2 inch deep had germinated, but root radicles withered from dry shallow soil.

Planted trees with roots 8 to 10 inches at time of planting, generally have adequate moisture on prepared sites. Exceptionally vigorous ones may even survive on unprepared sites but this is generally the exception. Fowells and Kirk (1945) found that

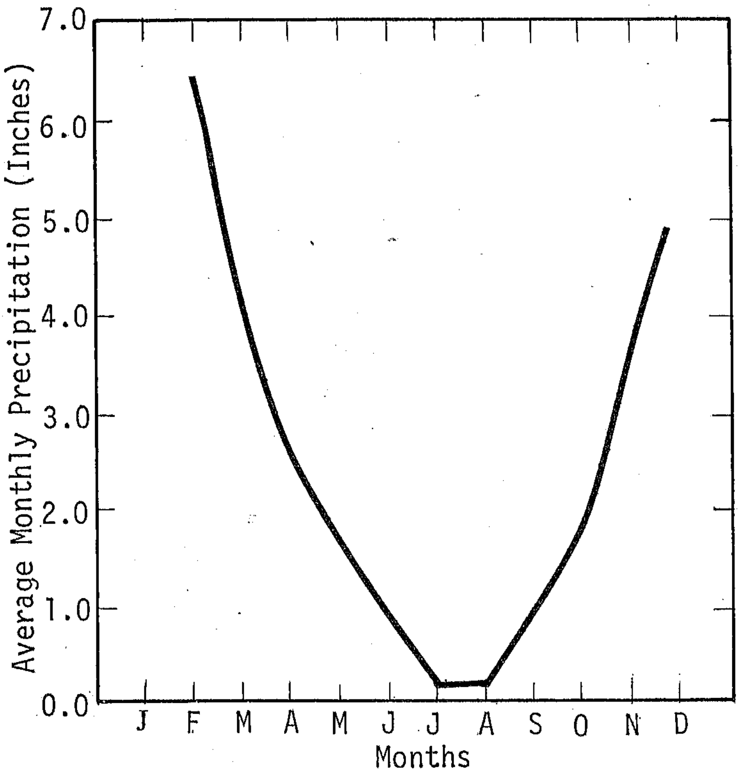


Figure 35. Average monthly precipitation at Feather River Experiment Station near Quincy, California (1912-1938).

ponderosa pine with undamaged roots survived in fine sandy loam soil at a moisture content of 2 to 3 percent below the permanent wilting point for sunflower of 6.4 percent. This soil had a field capacity of 15.5 percent. Stone and Fowells (1955) confirmed this, and in addition found that artificial dew extended the survival period at the low soil moisture levels. Artificial dew extended the life of ponderosa pine 2 months in clay loam soil and 3 months in sandy loam (Stone, 1957; Stone and Shachori, 1954).

The amount of soil moisture available to plants is least on coarse textured soils and highest on fine textured ones (Stone, 1957). Pharis (1966) determined lethal soil moisture contents for five western conifers grown in builders' sand and Glide pumice. For ponderosa

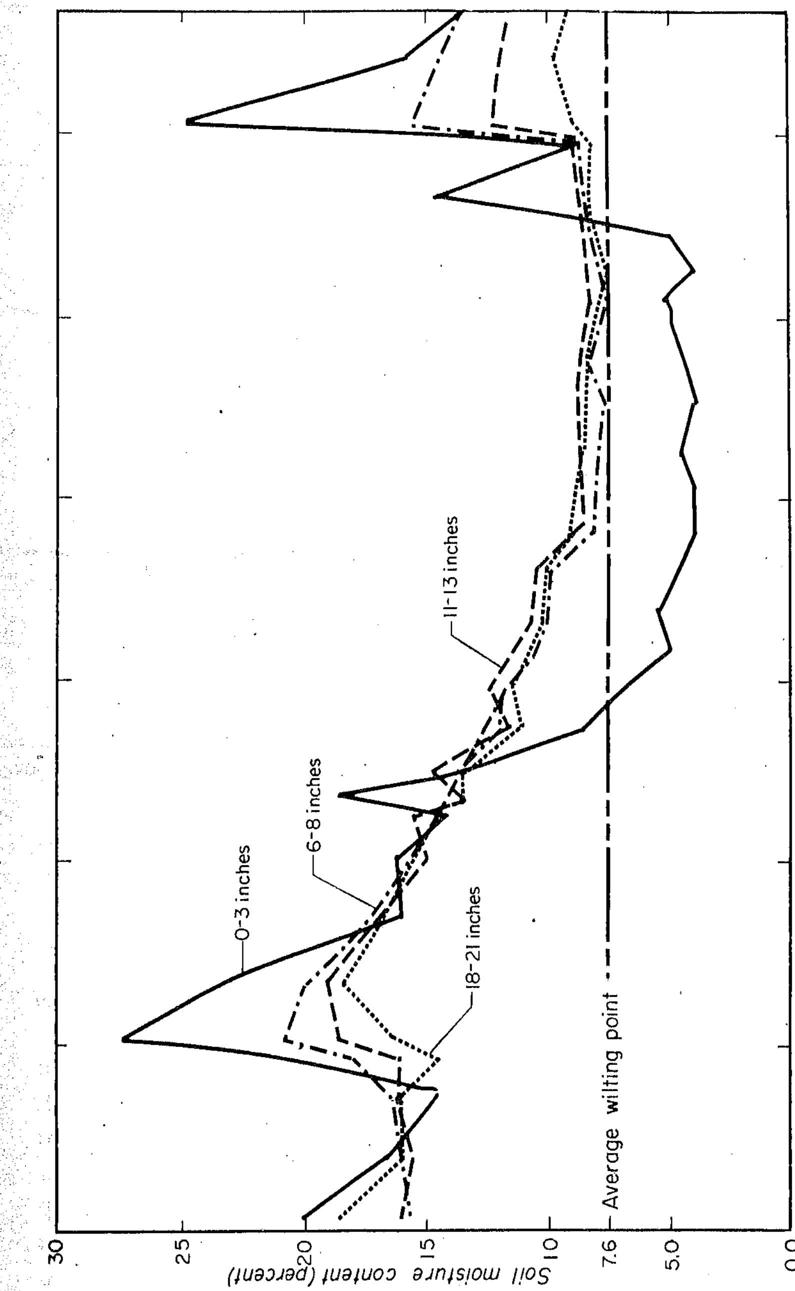


Figure 36. Moisture content of soil occupied by vegetation on Stanislaus Experimental Forest in summer and fall of 1936.

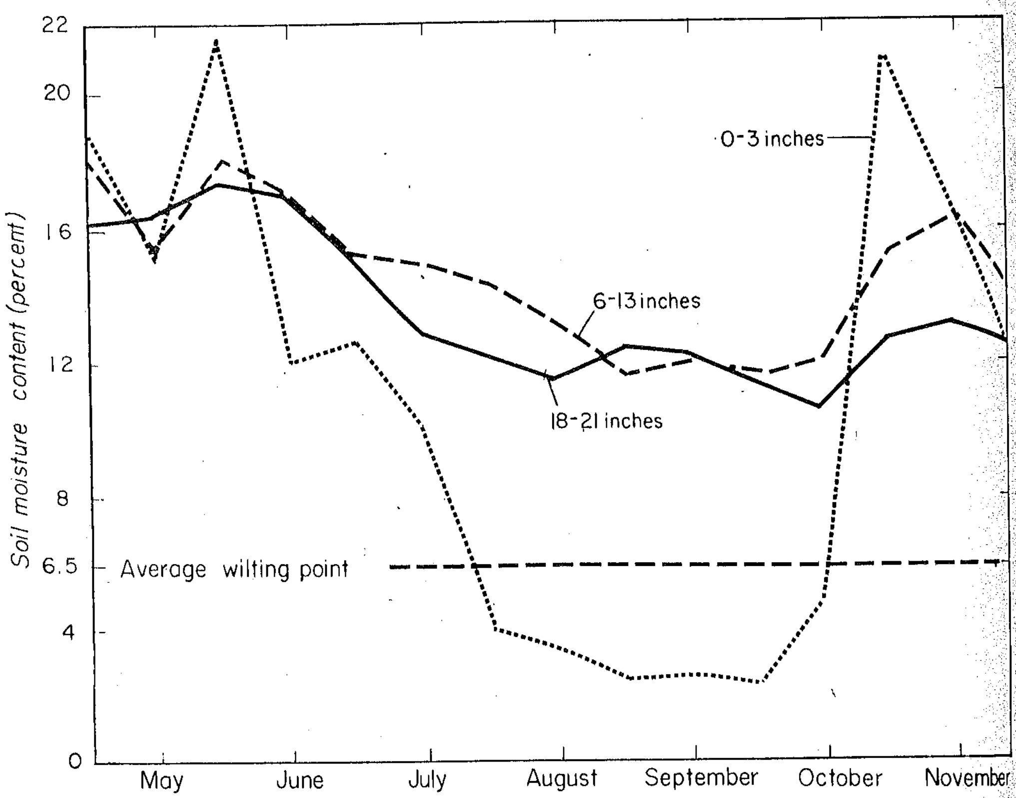


Figure 37. Average soil moisture content at different depths on a cleared site, Stanislaus Experimental Forest, 1936.

pine it was 1.28 percent in sand and 6.97 percent in pumice. For sugar pine it was 1.55 percent in sand and 7.60 percent in pumice.

Some evidence indicates that shade from brush benefits the initial establishment of trees (Dahms, 1950; Show, 1924, 1930); however, brush competition is generally harmful after trees are established (Tackle and Roy, 1953). Tarrant (1957, 1958) found that the soil moisture on plots with cleared or dead brush remained above the wilting point in central Oregon. The moisture content under live shrubs, however, dropped below the wilting point at the 20- to 24-inch depth before the first rain in September.

In some areas, grass is sown to reduce soil erosion or to provide forage for livestock. This practice can prevent successful reforestation. Baron (1962) found that trees and grass could be started simultaneously. However, if the grass had become established for a year or two, trees were unable to compete favorably for moisture. Areas that have been reoccupied by grass or brush should be cleared before an attempt is made to reforest them.

In addition to competing for moisture, dry grass near seedlings compounds the problem by raising temperatures and reducing humidity. These two changes increase the vaporization stress within the seedlings (Newton, 1964).

Rodents and Insects

As with moisture depletion, brush and grass are also associated with animal and insect damage to seedlings. In the Burney Spring Plantation, rabbits were responsible for much mortality (Kirk, 1947). Although the brush was cleared off in strips, the cover between strips provided favorable habitat conditions. More than 90 percent of the ponderosa and Jeffrey pines planted in these narrow cleared strips were severely damaged or killed by rabbits. Other rodents and larger animals also have found the protective brush cover to their liking.

Grass-covered areas provide excellent habitats for insects and animals, particularly grasshoppers, mice and ground squirrels. In addition, high cutworm and grub populations feed on the grass and tree roots and destroy many young seedlings. The grass must be destroyed completely to overcome the adverse effects of these destructive agents.

MECHANICAL SITE PREPARATION

The earliest plantations in California were established almost exclusively on unprepared sites. From 1911 to 1930, planting in the Pine Region was done primarily in old brushfields and to a limited extent on recent burns (Show, 1930). Brushfields with scattered seed trees (fig. 38) and all recently cutover timber areas (fig. 39) were excluded from the planting program. These areas were expected to restock eventually from natural seeding; however, many of these areas have failed to restock adequately--even after 50 or more years of waiting.

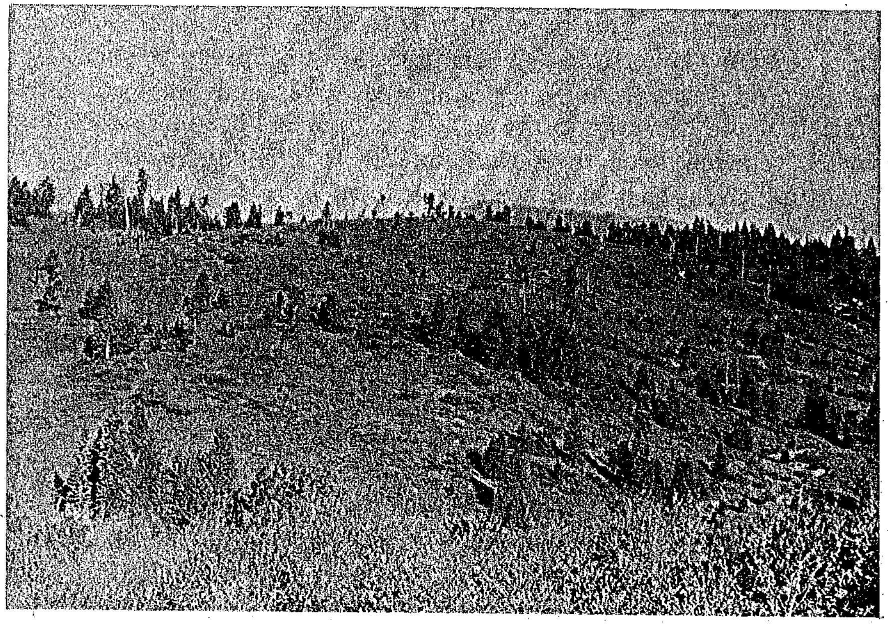


Figure 38. Brushfields with scattered young seed trees have failed to produce fully stocked stands (U. S. For. Serv. photo).

Narrow Cleared Strips

The first serious attempt to prepare sites in advance of seeding or planting started after 1930 on areas that were 100 percent brush-covered (Dunning and Kirk, 1939). During the 1930's, the general consensus was that brush had to be removed, at least partially, to admit entry of planting crews and to reduce competition so that trees could survive and grow.

With few exceptions, mechanical clearing during the period 1930 to 1945 consisted of cleared strips 6 to 8 feet wide spaced about 20 feet apart (fig. 40). Clearing was done either with tractor-trailbuilders (fig. 41) or with a special machine known as the "Plumas Stripper" pulled by a tractor (fig. 42). Very few wider strips or small blocks were cleared in this period. About 40 percent of the planting effort between 1930 and 1945 went into reforesting brushfields; the other 60 percent was directed toward reforesting recent timber burns that lacked an adequate seed source.

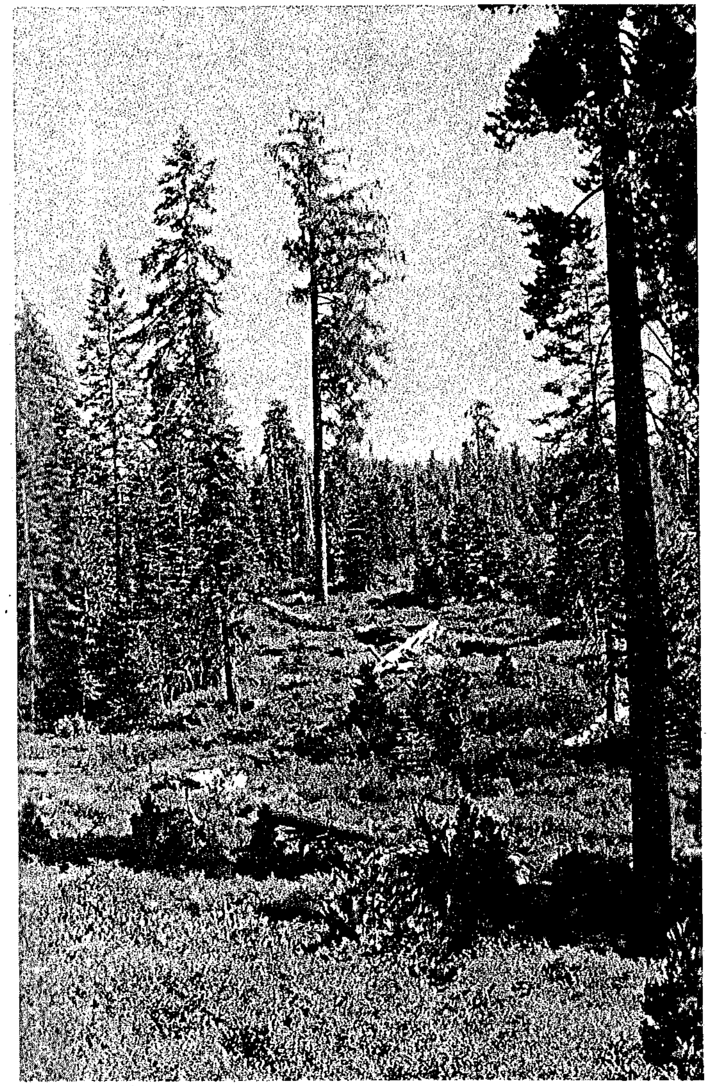


Figure 39. Natural restocking has been sparse on many recent cutover areas even though seed supply was adequate.

Figure 40. Brush in strips 6 to 8 feet wide and spaced about 20 feet apart was mechanically eradicated in the 1930's (U. S. For. Serv. photo 342287).

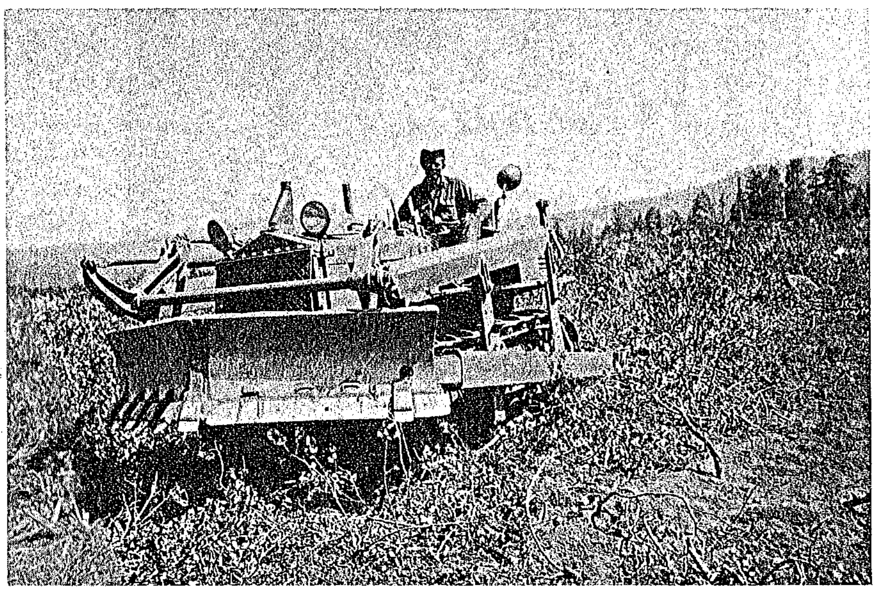


Figure 41. Trailbuilder used in brushfield stripping in the 1930's (U. S. For.

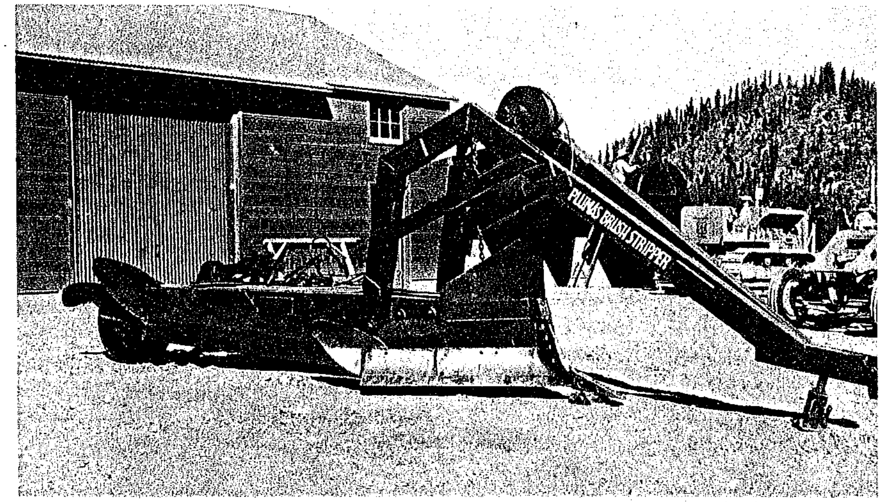


Figure 42. Plumas brush stripper used to clear lanes 6 feet wide in brushfields of northeastern California in the 1930's (U. S. For. Serv. photo).

Stripping removed 35 percent of the brush cover. However, reinvasion was rapid. The most prevelant species, greenleaf manzanita *(Arctostaphylos patula)*, sprouts vigorously. In a few years, cleared areas were reduced to 23 percent (fig. 43) (Fowells and Dunning, 1948).

Stocking on the strips was generally unsatisfactory. Over 80 percent of the acreage had less than 60 percent survival. Growth of the trees also was rated as unsatisfactory (Fowells and Dunning, 1948). To stay ahead of brush, trees must make rapid early growth (fig. 44). In many brushfields, shrubs ranged from 4 to 6 feet tall (fig. 45); whereas, the surviving trees after 10 years growth averaged less than 2 feet, with only 9 percent rated as having good vigor (Fowells and Dunning, 1948).

On the Burney Spring Plantation, survival of planted trees was 89 percent at the end of the first growing season and 77 percent after 2 years (Kirk, 1947). By the end of the 10th year only 5 percent were alive, with 85 percent of them less than 2 feet tall.

The low survival and slow growth of trees planted in narrow-stripped brushfields have not been entirely the result of competition for the short supply of moisture. The pine reproduction

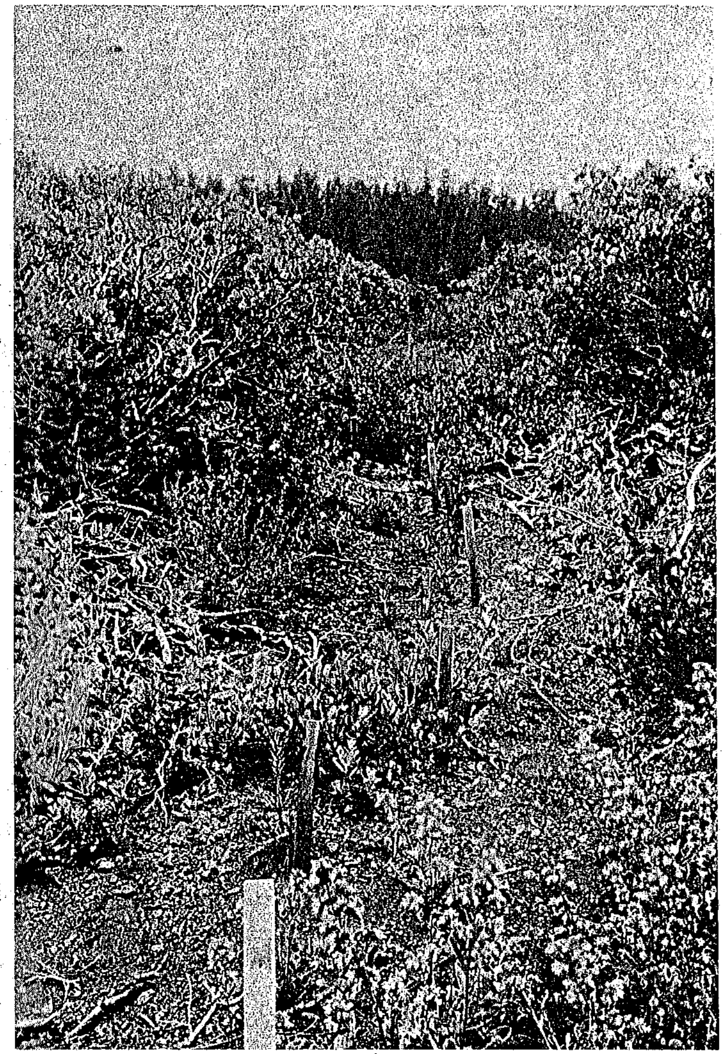


Figure 43. Brush reinvaded a cleared strip in the second year after clearing (U. S. For. Serv. photo 376836).

Figure 44. A 6-year-old ponderosa pine stand is growing vigorously in mountain whitethorn.

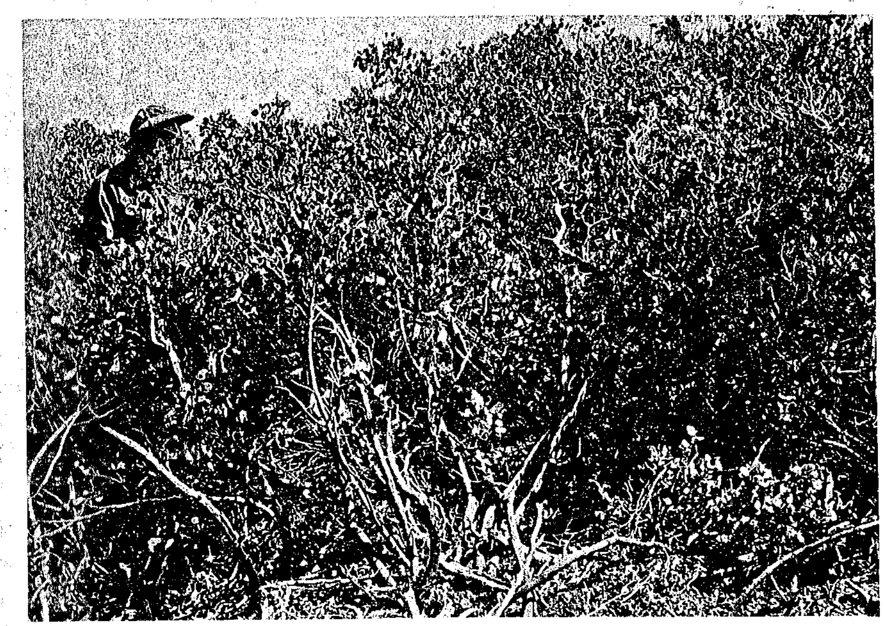


Figure 45. Greenleaf manzanita often can grow to heights of 4 to 6 feet.

weevil has caused severe top kill of these trees in northern California (Fowells and Dunning, 1948). The low vigor and slow growth of the trees make them more susceptible to insect attack than trees with high vigor and rapid growth. Rabbit damage was severe, and deer and cattle channeled into the narrow cleared trails have also caused severe tree damage by browsing and trampling.

Wide Cleared Strips or Blocks

Plantations in narrow stripped brushfields generally have been unsuccessful, but those in wider stripped or cleared block brushfields have been more encouraging in terms of stocking and growth (Fowells and Dunning, 1948). In Pine City Plantation, where stripping was 20 to 24 feet wide, tree survival at the end of 9 years was 74 percent and the average tree height was 4 feet. Manzanita Chute Plantation on cleared blocks 25 feet square had a survival of 84 percent at the end of 6 years; however, because of poor site qualities, the trees averaged only 1 foot high.

Plantations on Eldorado National Forest provide some of the best examples of good site preparation. Tree survival has been high on these wide stripped brushfields. In the Allen Ranch Plantations, survival of ponderosa pines planted in 1953 was 98 percent in some plantations; however, stocking on some parts planted with sugar pine and white fir was rated as only good to poor. 16/ Slate Canyon Plantation, planted in 1954 on stripped brush, had a survival of 97 percent.

Complete Site Preparation

Planting successes have been best on areas receiving complete site preparation (fig. 46). Since 1956, major emphasis has been placed on this method on most National Forests (Buck, 1959) and private land planting projects. Complete site preparation provides all the maximum advantages for optimum soil moisture, reduction of pest habitats, and easy access. All brush is uprooted with bulldozers (fig. 47) or brushrakes (fig. 48) and pushed into windrows spaced 50 or more feet apart (fig. 49). On areas cleared with bulldozers, the top layer of duff containing brush seed is also removed from the area. The brushrake permits removal of brush roots without excessive displacement of the top soil. Depending on width of cleared strips, the windrows may be from 10 to 15 feet wide and 4 to 6 feet high (fig. 50).

16/ Planting records, Eldorado National Forest.

Figure 46. Six-year-old ponderosa pine plantation on Eldorado National Forest.

Brush species found on timber soils vary in composition on different sites. In the northern brushfields, greenleaf manzanita accounted for 43 percent of the brush cover; snowbrush for 29 percent, chinquapin for 11 percent, and bitter cherry for 10 percent (Fowells and Dunning, 1948). In brushfields on Eldorado National Forest south to Sierra National Forest, whitethorn grew on 41 percent of the area examined; mountain misery on 24 percent; greenleaf manzanita on 18 percent; and deerbrush on 18 percent. In northeastern California, grasses, sedges, rabbit brush, and big sagebrush are the main species. In northwestern California, the cover consists mainly of snowbrush, manzanita, tanoak, madrone, alder, maple, chinquapin, and various smaller shrubs.

Figure 47. Among the types of bulldozers used in site preparation is this one.

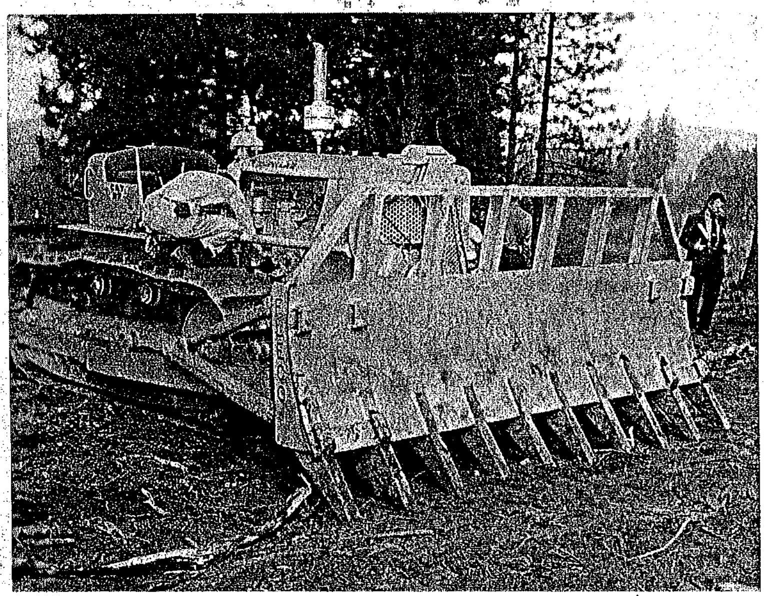
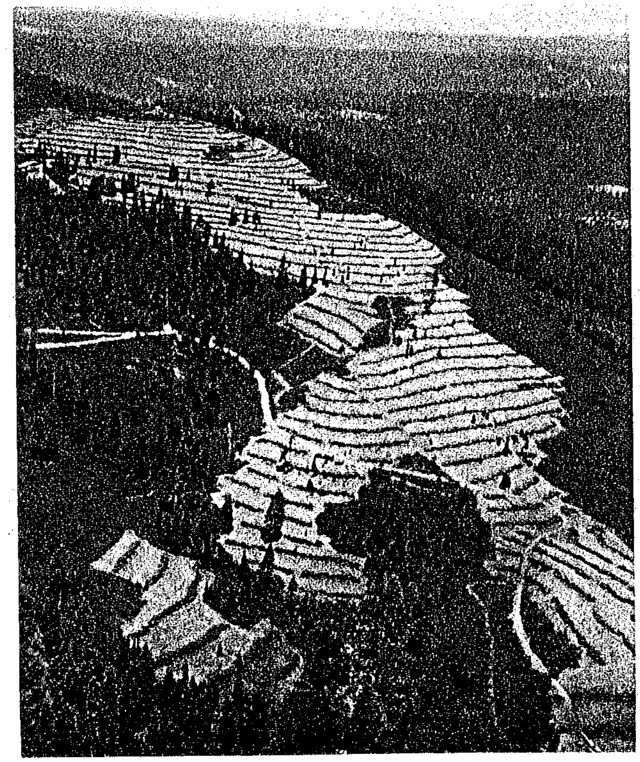


Figure 48. Brushrake uproots and pushes brush off planting area.



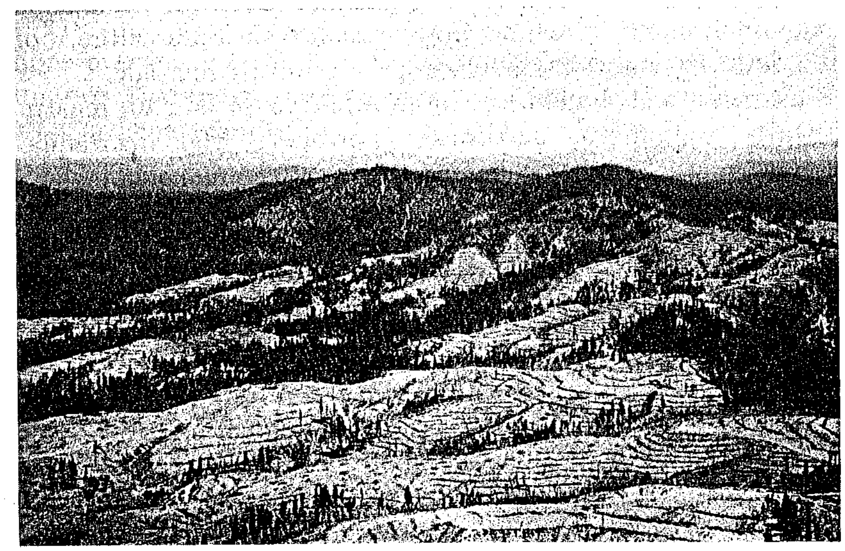


Figure 49. Typical areas with complete site preparation.

Figure 50. Site preparation on the Pilot Creek area, Eldorado National Forest.

These species vary considerably in resistance to complete eradication. All are active sprouters and prolific seed producers. Whitethorne and deerbrush are easiest to root out, manzanita next, and chinquapin and mountain misery the most difficult. Chinquapin and mountain misery offer the most resistance since the entire root systems must be removed; otherwise sprouts quickly reinvade.

Brushrakes and bulldozers offer effective means to remove mountain whitethorn, deerbrush, snowbrush, and manzanita. Brushrakes are ineffective on mountain misery and chinquapin. The bulldozer is best for these two species since removal of at least 6 inches of soil is required to eliminate the small sprouting roots. Removal of more than 6 inches of soil presents a difficult problem and probably lowers site quality. Deep contour-trenching (fig. 51), up to 24 inches on the uphill side, was effective on Stanislaus National Forest Wrights Creek Burn to prepare a planting area in mountain misery. The same method was used by American Forest Products Corporation in preparing a site for natural seeding in Amador County (Adams, 1969).

The Marden Brush Cutter will destroy some brush species and slash (fig 52). In Oregon, the brush cutter was effective on lodgepole

Figure 51. Deep contour-trenching is used to remove mountain misery.

pine slash, but not completely satisfactory on snowbrush or sedge (Hopkins and Anderson, 1960). In tests conducted on Latour State Forest in California, the tractor-drawn brush cutter was most effective on whitethorn, wedgeleaf ceanothus, and manzanita; and least effective on chinquapin (Ritchie and Dodge, 1962). The machine operates best on level to moderate slopes free of large rocks or stumps. The prepared areas seem most suitable for seeding and least for machine planting.

Scalping is a must if planting is to be done in grass-covered areas. A spot at least 4 feet in diameter should be scalped for each hand planted tree. For machine planting, it will be necessary to machine scalp.

FIRE FOR SITE PREPARATION

Except in northwestern California, fire is not used extensively to prepare areas in advance of seeding or planting. Wildfires burn over far more acres of commercial timberland in some years than can be reforested. Although burning has been effective under certain conditions, foresters have been reluctant to set fires deliberately. Difficulties encountered in controlling wildfires have engendered a healthy respect for fires of any kind.

Figure. 52. Filling a Marden Brush Cutter with water adds weight to improve its cutting ability.

Unpredictable weather conditions and fire behavior restrict the use of fire over extensive areas. When burning conditions are safe, it has been difficult to get a clean burn that will permit free movement of planting crews and equipment.

Fire has been used extensively to burn logging slash. However, these fires were used primarily to reduce fire hazards. Where fire is used in the Sierra Nevada, the slash is generally piled or windrowed and then burned when conditions are considered safe. Broadcast burning has been used mostly in the northwestern California redwood-Douglas-fir type where machine bunching of the slash was impractical or impossible. This kind of burning has been used successfully in Challenge Experimental Forest to reduce logging slash on patch-cutting experiments (Hall, 1968).

Small areas of brush have been burned experimentally by National Forests (Bentley and Estes, 1965), California Division of Forestry (Adams, 1969; Cox and Ritchie, 1960), and Pacific Southwest Forest and Range Experiment Station (McDonald and Schimke, 1966) to prepare planting or seeding areas. Studies conducted on these experimental burns and on burns by wildfires have yielded some information useful in artificial reforestation. Six conclusions can be drawn from past research; (1) planting or seeding to be effective must be done by the first year after the burn; (2) some brush species are more effectively destroyed than others; (3) tree survival and growth have been better on timber burns than on narrow stripped or burned brush; (4) plantings on burned-stripped brushfields have been better than on stripped or burned brushfields; (5) rapid resprouting of burned brush may require follow-up chemical treatment; and (6) burning may affect the physical and chemical properties of the soil which, in turn, may affect the erodibility of the soil and plant response.

Relation to Age of Burn

A delay of one or more years in reforesting a burn decreases chances of survival unless additional site preparation is done to eliminate vegetative competition for moisture. Several years' experience in the Redwood Region indicated that only the most recent burns should be planted (Person, 1937). Survival of trees planted on the 1955 Sequoia National Forest Magee Burn the first year after the burn averaged over 80 percent. Plantings made 2 years after the burn failed. Survival of trees planted on Klamath National Forest Bogus Burn during the first year after the fire was 60 percent compared with 25 and 8 percent for those planted the second and third years (Baron, 1962).

Effect of Brush Species

Planting the first year after the fire does not necessarily insure good results. Sprouts and seedlings of some brush species grow 4 to 6 feet within the first 2 or 3 years after the burn. Several small plantations on Wrights Creek Burn, planted the same fall after the fire in September, were hopelessly overtopped by deerbrush the first year after planting. Similar plantations on the same burn planted in an area with mountain whitethorn have kept ahead of the brush (fig. 53).

Figure 53. Ponderosa pines outgrew mountain whitethorn on Wrights Creek Burn (U. S. For. Serv. photo).

Trees planted after burns in areas covered with willow and bitter cherry are generally overtopped by sprouts within a year or two. However, trees planted in areas that were covered with bracken fern or littleleaf ceanothus have a good chance to outgrow the brush. Even though mountain misery is a low shrub, plantings following a burn where this species was growing have all failed.

Timber Burns

Fowells and Dunning (1948) found that trees on timber burns, on lower site quality lands, were more vigorous (tables 28, 29) at comparable ages than trees on stripped brushfields on areas of higher site quality and they were twice as tall.

Table 28. Distribution of plantation acreages in stripped brush and in burns, by 100-tree stocking classes.

Condition [1]	Stocking, trees per acre				
	0-99	100-199	200-299	300-399	400-499
	Percent				
Stripped brush	16	38	36	10	0
Timber burn	12	36	40	5	7

Source: Fowells and Dunning (1948).
1/For 3,660 acres of stripped brush and 3,166 acres of timber burn planted during period 1930-45 on National Forests.

Table 29. Distribution of plantation acreages in stripped brush and timber burns by vigor classes. [1]

Condition	Vigor classes		
	Good	Medium	Poor
	Percent		
Stripped brush	9	48	43
Timber burn	36	38	26

Source: Fowells and Dunning (1948).
1/Based on successful plantations established between 1930 and 1945 on National Forests.

Plantations established on timber burns generally have a much better chance for success than those on brushfield burns. The site quality of brushfields, especially those that have been burned several times, is often much lower than timber stands. After an area has been burned repeatedly, a high proportion of the nutrients may be leached out of the soil and the top soil lost through erosion. Furthermore, some areas are covered with brush rather than trees because the site quality may have been too low for adequate tree growth.

Burned-Stripped Brushfield

In terms of tree survival, the burned-stripped treatment (fig. 54) was best, burned alone was intermediate, and narrow stripped was worst in the Burney Spring brushfield (table 30). Although brush density in planted rows at the end of the second growing season was 33 percent for the stripped, 37 for the burned-stripped, and 65 for the burned, soil moisture was not limiting in the 10- to 12-inch zone during the first 2 years. However, mortality for the 8-inch root pruned trees was 23 percent for burned plots and 11 percent for the burned-stripped plots (Kirk, 1947). This difference may have been caused by deficient moisture in the top 8 inches of soil. In the first 2 years after planting, the soil moisture at the 2- to 4-inch depth dropped from 5 to 8 percent below the wilting point.

Figure 54. View of the burned-stripped plot, Burney Spring Plantation, fall 1936 (U. S. For. Serv. photo 306112).

Table 30. Survival of trees by brush treatment and years, Burney Spring Plantation.

Brush treatment [1/]	Year 1937	1938	1939	1940	1941	1946
	Percent					
Burned	87.2	83.1	67.3	46.6	32.4	6.8
Stripped	89.1	77.4	49.7	21.8	12.8	4.8
Burned-stripped	89.8	88.7	85.6	79.2	75.0	29.5
Difference required for significance at 5 percent level	13.6	14.9	21.8	20.8	18.0	9.4

Source: Kirk (1947).

[1/] Based on 10,800 trees, 3,600 per brush treatment.

Dunning and Kirk (1939) found that roots of surviving trees extended down below the 10-inch depth before the minimum soil moisture level was reached in September (table 31). They suggested that the dense growth of grass and sedge was probably the main cause of seedling mortality during the first 2 years.

Crushing brush with a bulldozer before burning provides a cleaner burn than no crushing. Passing the bulldozer over the brush with the blade lowered to within 1/2 to 1 foot of the soil breaks many stems and compacts the vegetation (Bentley, 1967). This treatment provides drier fuel for spring burning.

In the Sierra Nevada, burning brush fields to convert to timber growing is one of three site preparation steps. First is crushing, second is burning, and third is following up with chemicals to control regrowth. Burning alone seldom provides adequate control of a site.

Table 31. Average root penetration of surviving Jeffrey and ponderosa pines planted in burned-stripped brushfields.

Date	1937		1938	
	Jeffrey pine	Ponderosa pine	Jeffrey pine	Ponderosa pine
	inch			
July 10	9.0	10.5	10.0	10.5
Sept. 10	17.2	18.6	13.2	12.7
Nov. 10	25.5	23.0	--	--

Source: Dunning and Kirk (1939).

Effect on Physical and Chemical Soil Properties

Some concern has been expressed in the past that burning seriously alters the physical and chemical properties of the soil. Tarrant (1956a) reported that severe burns on some soils seriously lowered the rate of moisture movement. Water infiltration was reduced after wildfires on brush watersheds in southern California (Krammes and Debano, 1965). Under laboratory conditions, it was found further that for certain southern California watershed soils, burning at 400 degrees F. for 10 to 20 minutes appreciably reduced infiltration (Debano and Krammes, 1966). Where this reduction occurs the soils may become more erodible and the amount of soil moisture may be insufficient for tree establishment. Light burning had no harmful effects on the soil in regard to water movement. The thick layer of fine ashes in burned slash piles on Stanislaus Experimental Forest prevented water movement over a 2-year period. Tarrant (1956b) found that light burning tended to increase the percolation rate in the 0- to 3-inch layer of two soils and that severe burning greatly reduced it. Moisture holding capacity was reduced proportionately to the intensity of the burn according to Neal, *et al.*, (1965) in western Oregon.

Morris (1958) reported that soil temperatures on fire-blackened surfaces reach greater extremes of heating and cooling than lighter colored surfaces. He also found that the surface temperature of the organic layer will rise higher in the daytime and fall lower at night than that of mineral soil. During hot summer months on a south slope, temperatures at a 2-inch depth were 20 degrees F. higher on a burned area than an unburned one (Neal, *et al.*, 1965). These high daytime temperatures may cause heat injury or kill very young seedlings. Soil color may indicate very roughly the intensity of a burn; however, it cannot be used as a precise measure of fire intensity (Tarrant, 1953b).

Tarrant (1956b) reported that the pH was temporarily higher and mychorrhizae were less on burned areas. The pH change may be as much as 1.2 units on the more intense burns (Neal, *et al.*, 1965). This difference did not affect germination; however, damping off was increased. Microflora in Douglas-fir soils are substantially reduced immediately after a hard burn, and nearly 2 years must elapse before the population is back to normal (Wright and Bollen, 1961). Mineral nutrient levels are temporarily increased after a fire (Fowells and Stephenson, 1934; Tarrant, 1956b). Fowells and Stephenson (1934) reported that burning liberates basic ash material and stimulates nitrification. This condition produces a liberal supply of plant food available for tree growth. In the 0- to 3-inch layer of lightly burned areas, total nitrogen, phosphorus, and exchangeable potassium were higher 1 year after the burn than on unburned areas (Tarrant, 1956b).

Comparison of germination and development of Douglas-fir on several different seed beds in Oregon showed that charcoal covered seed beds and hard burned soil provided the best germination (Herman and Chilcote, 1965). The seed beds were coarse textured and retained moisture at the bottoms of particles and in crevices. Increases in pH, temperatures, and available nitrogen all tend to increase microbial activity (Neal, *et al.*, 1965). This increase probably enhanced chances of damping off infection in newly germinating seedlings (Tarrant, 1956b). Subsequent growth of seedlings, however, is not affected (Tarrant and Wright, 1955).

A number of these studies indicate that burning for site preparation may be less desirable for seeding operations than is mechanical clearing. However, burning should be satisfactory preparation for planting.

CHEMICAL SITE PREPARATION

The main uses for chemicals in California reforestation are to kill brush as a follow-up treatment in combination with other measures and to release young trees from competing brush (Bentley and Estes, 1965). Other uses are to kill brush and grass before planting and to serve as a preparatory treatment for burning.

Almost all woody shrub species in the commercial timber zone produce large quantities of seeds. Some seeds retain their viability for years, then germinate when exposed to favorable condition, such as removal of overstory timber and soil disturbance (Quick, 1956, 1959). Quick (1956) found over 2.8 million viable brush seeds per acre in the duff and soil under a virgin stand of overmature timber. Many of the more common brush species sprout from stumps and roots after the aerial parts have been killed (figs. 55 and 56) (Bruce, 1939; Dunning and Kirk, 1939; Leonard and Harvey, 1956; Roy, 1955; Schubert, 1950, 1955).

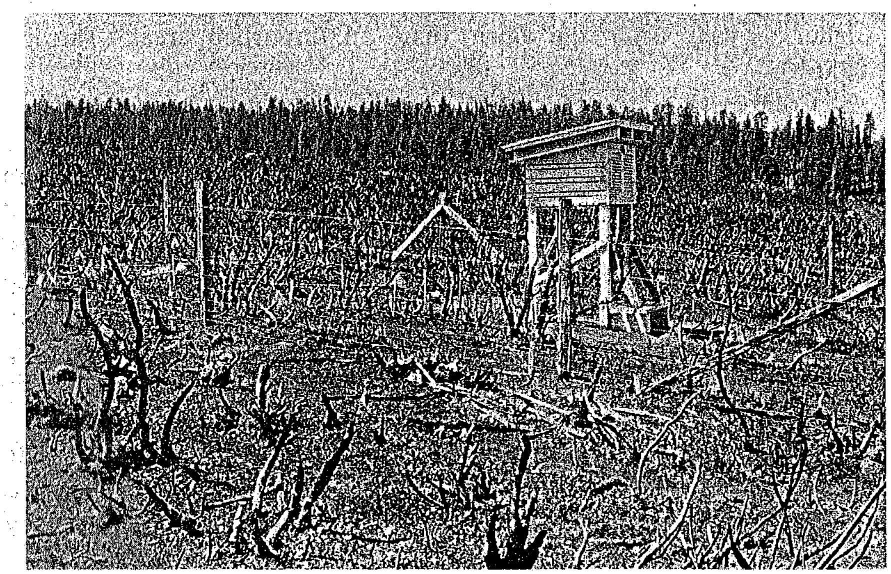


Figure 55. An intense fire killed all the aerial portions of brush at Burney Spring Plantation, May 1937 (U. S. For. Serv. photo).

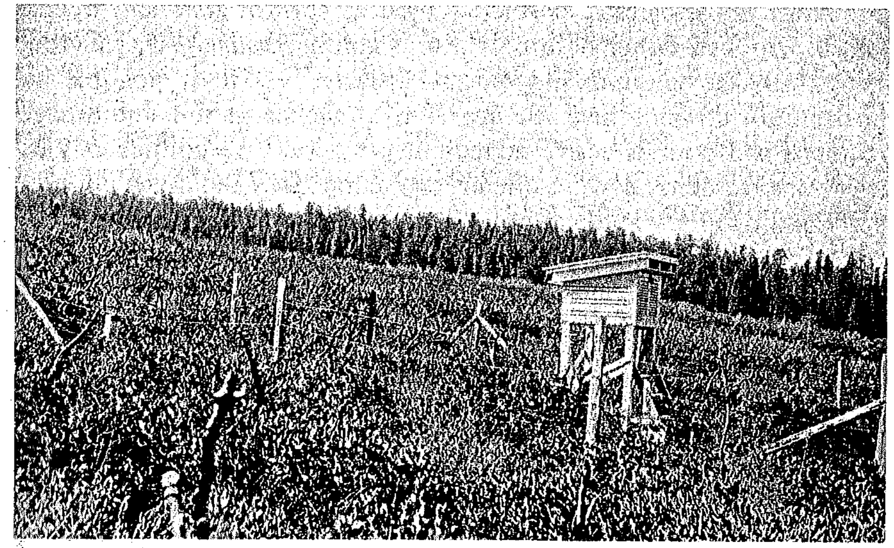


Figure 56. Greenleaf manzanita, snowbrush, and bitter cherry sprouted profusely 2 years after the Burney Spring Plantation burn (U. S. For. Serv. photo 376842).

Chemicals and Methods

Many chemicals have been tested as brush and grass killers in western forest areas. Of all the chemicals tried, dalapon, atrazine, and paraquat have been most effective on grass, and the herbicides 2,4-D and 2,4,5-T have been the most extensively tested and widely used on brush. The water-miscible, low-volative ether esters of 2,4-D and 2,4,5-T have been generally favored because they have given consistently good results on woody plants and minimized risks of damaging crop plants near treated areas (Bentley and Estes, 1965; Corson and Dircksen, 1954; Dahms, 1955, 1961; Gratkowski, 1959, 1961; Leonard and Harvey, 1956).

Grass, with its dense mat of roots in the top foot of soil, may at times be more detrimental than brush. Often grass tops have been browsed or burnt off, so the need for site preparation may not be apparent. Treatment with 5 to 10 pounds of dalapon per acre during the growing season has resulted in complete kill in the Southwest.[17]

Atrazine, a selective herbicide, used to control grass and weeds, may be applied either before or after planting Douglas-fir (Newton, 1967). If the ground has been cultivated or it is possible to incorporate atrazine into the top 4 to 5 inches of soil, the dosage required is 3 pounds active ingredient per acre. Five pounds may be necessary on dense soils, while average conditions require 4 pounds. Fall and winter applications are preferred for atrazine since considerable rainfall is needed to move it into the soil. Broadcast application of atrazine is possible from fixed-wing aircraft or boom-equipped ground rigs, the choice depending on terrain and size of operation.

Paraquat is a selective herbicide that can be used on grasses and herbs before or after trees have been planted. It can be used with atrazine to combine immediate kill with a relatively long lasting effect.[18] It should be applied in fall or winter at 1/2 pound paraquat and 4 pounds atrazine per acre.

Tordon,[19] or picloram, a more recently developed herbicide shows promise in brush control (Green, Goodin, and Plumb, 1966). However, for general work it is more expensive and is not suitable as a selective spray for release of conifers. In the Pacific Northwest, it showed considerable promise in control of vine maple--something not possible with 2,4-D or 2,4,5-T (Finnis, 1967).

Some brush species are easily killed by low rates of herbicide applications regardless of when the plants are treated. Generally nonsprouting species can be killed by a single application of 2,4-D or 2,4,5-T. Some sprouting species are more difficult to kill than others and may require two or more applications.

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[17] Personal communication from L. J. Heidman, Research Forester, Rocky Mountain Forest and Range Experiment Station.

[18] Personal communication from Clyde Elmore, Extension Weed Control Specialist, Univ. of Calif., Davis, Jan. 1970.

[19] Registered trade name of the Dow Chemical Company.

Many researchers have attempted to identify the field conditions that will result in optimum kill of brush, recognizing that stage of plant development, soil and climatic environment, species of plant, and even time of day when sprays are applied must be evaluated (Bentley and Estes, 1965; Buttery, Bentley and Plumb, 1959; Dahms and James, 1955; Gratkowski, 1959; Leonard and Harvey, 1956; Offord, 1949; Offord, *et al.*, 1958; Schubert 1950, 1955). In small trials with Sierra evergreen chinquapin in California, Schubert (1955) obtained best results with early morning treatment with 2,4,5-T. Early morning and late afternoon treatments with 2,4-D gave better kill than those at midday but were not as effective as the early morning sprays with 2,4,5-T. Where mixed species of brush are concerned, it will always be necessary to make a practical compromise on when and how to treat.

Foliage sprays usually provide the most effective control of brush. On undesirable hardwood trees, however, better kill has been obtained by applying the chemicals to cut stumps or in frills. Enough solution was applied per tree to fill the frill of the completely girdled trunk near the root crown. Roy (1956) found that the effects of the herbicide in frills were delayed, but the vigor of treated trees decreased more the third and fourth years than that of trees treated by a basal spray. Bruce (1939) reported a 95 percent kill on live oak stumps treated with a 10 percent aqueous solution of sodium chlorate. With a 1 percent solution of 2,4-D, Schubert (1950) found that madrone proved easier to kill than tanoak. The midsummer treatment was best on madrone and the fall treatment for tanoak.

Tordon proved more effective than 2,4,5-T in killing some eastern hardwoods by the tree injection and frill method (Watson and Mesler, 1964). Basal injection or frills was better than frills at breast height. Tree injector tools for injecting chemicals near the ground line, and special hatchets that meter chemicals into frills as the frill is made, can reduce time required for treating trees.

Black oak competing with young conifers were killed on Mt. Home State Forest by using amine salt of 2,4-D in breast-high frills (Otter, 1960). Frills with as much as 10 inches of undisturbed bark between were effective.

For foliage spraying hard-to-kill species, the addition of a gallon of light summer oil per acre (Dahms, 1961) or about 5 percent of volume of diesel oil (Gratkowski, 1959) has increased the kill in

Oregon. Leonard (1961) reported that the addition of some oil to spray mixture increased the kill. The amount of oil (either kerosene or diesel oil) to be added should normally not exceed 1 percent or 1 gallon per acre for California brush species. Schubert (1955) found that adding wetting agents or emulsifiers did not increase the effectiveness of sprays appreciably.

Herbicide treatments suggested by various investigators for common brush or hardwood species in California are listed in table 32. The list was compiled from results from the studies cited. Details are given in the references shown. Because the treatments listed are interpretations, the data may differ from the published results.

Preparatory Chemical Treatments

Chemicals may be used alone or in combination with other treatments. To get a maximum top kill, dosages listed in table 32 may be increased. Oil also may be added to the spray for the hard-to-kill brush species.

Combination mechanical and chemical treatments were successfully used in trials on Tahoe National Forest in Sierra County (McDonald, 1966). Six combinations of mechanical with chemical methods were used. These were:

1. Bulldoze in spring, spray in following spring, plant 24 months after initial work.
2. Same as above, except use a brush rake.
3. Bulldoze in fall, spray in following fall, plant 18 months after initial work.
4. Same as No. 3, except use a brush rake.
5. Bulldoze in fall, no spraying, plant 6 months after initial work.
6. Same as No. 5, except use a brush rake.

Table 32. Herbicide treatment for common brush or hardwood species in California.

Plant species 1/	Time to treat 2/	Herbicide 3/	Rate 4/	Top and root kill 5/	Reference 6/
			lb.a.e./Ac.	Pct.	
Bearmat (mountain misery) (S) (*Chamaebatia foliolosa*)	Sept.-Nov. March-May	2,4-D or 2,4-D + 2,4,5-T	4-8	100/80-95	Adams (1969); Corson & Dircksen (1954); Schubert (1955)
Big sagebrush (S) (*Artemisia tridentata*)	April-June	2,4-D	2	100/100	Cornelius & Graham (1958); Gould (1961); Leonard & Harvey (1956)
Bigleaf maple (S) (*Acer macrophyllum*)	May-June	2,4,5-T	4	100/ ?	Leonard & Harvey (1956)
Bitter cherry (S) (*Prunus emarginata*)	Aug.-Oct. March-April	2,4,5-T or 2,4-D + 2,4,5-T	4	100/90	Buttery, Bentley & Plumb (1959) 7/
Blueblossom ceanothus (N) (*Ceanothus thyrsiflorus*)	Aug.-Oct. March-April	2,4-D or 2,4,5-T	2	100/100	Leonard & Harvey (1956)

Table 32. (Cont.)

Plant species 1/	Time to treat 2/	Herbicide 3/	Rate 4/	Top and root kill 5/	Reference 6/
			1b.a.e./Ac.	Pct.	
Bracken fern (S) *(Pteridium)*	June-July	2,4,5-T	1	100/90	7/
California black oak (S) *(Quercus kelloggii)*	Oct.-April	2,4,5-T or 2,4,5-T + 2,4-D	4	90/50-90	Leonard & Harvey (1956) 7/
Chamise (S) *(Adenostoma)*	Nov.-June	2,4-D	3	90/80	Buttery, Bentley, & Plumb (1959); Leonard (1961); Leonard & Harvey (1956)
Chokecherry (S) *(Prunus)*	May-June Aug.-Oct.	2,4,5-T	4	100/90	7/
Currant (S) *(Ribes)*	May-June	2,4,5-T	2	100/90-100	Offord, Quick & Moss (1958)
Deerbrush ceanothus (S) *(Ceanothus integerrimus)*	July-Oct. April-May	2,4,5-T or 2,4-D	2	100/70-90	Gratkowski (1959)

NOTE: See footnotes at end of table.

Table 32. (Cont.)

Plant species 1/	Time to treat 2/	Herbicide 3/	Rate 4/	Top and root kill 5/	Reference 6/
			1b.a.e./Ac.	Pct.	
Golden chinquapin (S) *(Castanopsis chrysophylla)*	June-July (April, Sept.-Nov.)	2,4,5-T	4	60/0	Gratkowski (1959) 7/
Gooseberry (S) *(Ribes)*	May-June	2,4,5-T	2	100/90-100	Offord, Quick & Moss (1958)
Grass (S)	June-Sept.	Dalapon	5-15	100/80-100	Heidmann (1967)
Greenleaf manzanita (S) *(Arctostaphylos patula)*	Sept.-Oct. April-May	2,4-D (Fall) 2,4,5-T (Spring)	2	100/90-100	Schubert (1955)
Hairy manzanita (N) *(Arctostaphylos columbiana)*	June-July	2,4-D or 2,4,5-T	1-2	100/100	Gratkowski (1959)
Littleleaf ceanothus (N) *(Ceanothus parvifolius)*	April-Nov.	2,4,5-T	1	100/100	Schubert (1955)
Madrone (S) *(Arbutus)*	June-July	2,4-D or 2,4-D + 2,4,5-T	4	100/28	Schubert (1950)

Table 32. (Cont.)

Plant species 1/	Time to treat 2/	Herbicide 3/	Rate 4/	Top and root kill 5/	Reference 6/
			lb.a.e./Ac.	Pct.	
Mariposa manzanita (N) *(Arctostaphylos mariposa)*	May-June	2,4-D or	4	100/28	Schubert (1950)
Mountain whitethorn ceanothus (S) *(Ceanothus cordulatus)*	April-May Sept.-Nov.	2,4,5-T	2	Old plants 100/20 Young sprouts 100/80	Schubert (1955)
Parry manzanita (N) *(Arctostaphylos parryana)*	April-June	2,4-D or 2,4,5-T	2	100/100	Cox & Richie (1960); Dahms (1955)
Poison-oak (S) *(Toxicodendron quercifolium)*	May-June	2,4-D + 2,4,5-T	2	100/90	Leonard & Harvey (1956)
Rabbitbrush (S) *(Chrysothamnus)*	May-June	2,4-D	2	100/100 (?)	Gould (1961)
Salal (S) *(Gaultheria shallon)*	May-June Sept.-Oct.	2,4-D + 2,4,5-T	2	?	7/

NOTE: See footnotes at end of table.

Table 32. (Cont.)

Plant species 1/	Time to treat 2/	Herbicide 3/	Rate 4/	Top and root kill 5/	Reference 6/
			lb.a.e./Ac.	Pct.	
Scotch broom (S) *(Cytisus scoparius)*	Aug.-Oct.	2,4-D	2	100/90 (?)	Leonard & Harvey (1956)
Serviceberry (S) *(Amelanchier)*	July-Sept.	2,4,5-T	2	100/80	7/
Sierra evergreen chinquapin (S) *(Castanopsis chrysophylla)*	Sept.-Nov.	2,4,5-T	8	Old 100/20 Young 100/60	Cox & Richie (1960); Schubert (1955)
Snowbrush ceanothus (S) *(Ceanothus velutinus)*	April-June Aug.-Oct.	2,4,5-T or 2,4-D	2	100/50	Dahms (1955); Gratkowski (1959)
Squawcarpet ceanothus (S) *(Ceanothus prostratus)*	Sept.-Nov. March-May	2,4,5-T 2,4-D + 2,4,5-T	2	100/90	Leonard & Harvey (1956)
Tanoak (S) *(Lithocarpus densiflorus)*	Sept.-Nov.	2,4-D, 2,4,5-T or 2,4-D + 2,4,5-T	4	Trees 65/30; Sprouts 100/100	Roy (1956); Schubert (1950)

NOTE: See footnotes at end of table.

Table 32. (Cont.)

Plant species 1/	Time to treat 2/	Herbicide 3/	Rate 4/	Top and root kill 5/	Reference 6/
			lb.a.e./Ac.	Pct.	
Whiteleaf manzanita (N) *(Arctostaphylos viscida)*	Sept.-Nov. April-May	2,4-D	2	100/100	7/
Willow (S) *(Salix)*	July-Sept.	2,4-D	2	100/80 (?)	Leonard & Harvey (1956)

Source: Schubert (1962)

1/S equals sprouting species; N equals non-sprouting species. Non-sprouting species are generally killed with one spray treatment. Many sprouters may require two or more treatments to obtain satisfactory kill.

2/The best time to spray has not been determined for all brush species. Where both spring and fall periods have been included, the fall months have usually given the best results. Brush should not be sprayed when the temperature drops below 36 degrees F.

3/The water miscible, low-volatile ether ester form of the suggested herbicide should be used. Examples include propylene glycol butyl ether ester and butoxy ethanol ester.

Table 32. (Cont.)

4/Pounds of active material in terms of acid equivalent (a.e.). For aerial application, 5 to 10 gallons of solution per acre have given good results. For hand or power sprayers 50 to 150 gallons per acre are needed to get good coverage depending on height and density of the brush. One gallon of light summer oil or diesel oil per acre should be added to get better kill where no conifers are involved. If conifers are present and are to be saved, not more than 1 lb./A of 2,4,5-T should be used; 2,4-D can be substituted for Douglas-fir areas. To kill undesirable hardwood trees, 1 gallon of herbicide (4 pounds acid equivalent) should be used to 10 or 12 gallons of low grade diesel oil or 1 gallon oil plus 10 gallons of water. Enough solution should be applied per tree to fill the frill of the completely girdled trunk near the root crown.

5/Percent top kill (100/) and the percent root kill (/100) based on best kill obtained. Where top or root kill is less than 100 percent, the brush should be re-treated if a heavier kill is needed.

6/See references for more details. The treatments indicated are based mainly on the studies cited and interpretation of the results.

7/Indicates treatment and expected results are mainly a "best" estimate.

After 2 years there were no differences in survival of seedlings or incidence of brush reinvasion among the 6 methods.

Regardless of initial brush removal, however, most pine plantation sites in California, over a longer period of time, require additional brush control treatments (Bentley, 1967). The effect of regrowth is not apparent until after the third year.

Table 33 suggests times and dosages for either method based on Bentley's (1967) findings. The kind and rates of sprays are less important than number.

Table 33. Suggested spray schedule for brush regrowth following burning or mechanical site preparation.

Herbicide	Time of spray treatment First [1] late July - Aug.	Second Sept. 1	Third Sept. 1
	------------ pounds per acre	-----	
2,4-D	4	-	-
2,4,5-T	-	3	2
3/1 2,4-D - 2,4,5-T (brush killer) [2]	4	-	-

[1]Assumes spraying before planting. If first spraying is scheduled after planting, 4 lbs. a.e. 2,4,5-T in early September after tree buds have hardened is recommended.

[2]Above 3,500 ft. elevation.

A spray volume of 10 gallons per acre is recommended for helicopter spraying; 20 to 25 gallons for ground rigs. Double coverage of an area is necessary for helicopter applications to ensure adequate coverage (Bentley and Estes, 1965). Half of the dosage should be applied during each coverage.

Followup Chemical Treatment

After mechanical site preparation or burning, herbicides may be necessary as a follow-up treatment where viable brush seeds have germinated or sprouts reinvaded. Chemical treatment may be applied either before or after tree planting. Since young trees may be injured or killed by some chemical treatments, we recommend that the suggestions under "Release of Established Trees" be followed.

Gratkowski (1961) found that a combination treatment of spray-burn-spray gave good results in Oregon. In July 1955, an 80-acre brushfield composed mainly of greenleaf manzanita and mountain whitethorn was sprayed with 2,4-D at a rate of 3 pounds acid equivalent plus 1.5 gallons diesel oil per acre. Almost every species resprouted. In late September, 1956, the brush was burned. Extensive resprouting occurred again, along with about 10,000 new brush seedlings per acre. A respray in 1958 killed about 90 percent of the new brush. A second respray in 1959 destroyed almost all the remaining brush on the area.

Brush should be sprayed before it becomes increasingly resistant to chemical treatment and before it becomes a serious fire hazard when killed.

A schedule for burn or mechanical preparation followed by one or more sprayings is recommended by Bentley (1967). Brush regrowth appears to be more of a problem on heavily bulldozed old brushfields than on timber burns; the regrowth originating primarily from brush seedlings. Three sprays over a period of 5 or 6 years may be necessary on cleared old brushfields, and one or two on timbered burns. The first spray may be before seeding or planting, the remainder after if necessary; or all three may follow seeding or planting. The schedule will depend on how rapidly brush reinvades. Burning followed by a fall spraying of 4 pounds a.e., 2,4-D or 1/1 2,4-D - 2,4,5-T mixture was effective in controlling mountain misery in the central Sierra Nevada (Adams, 1969).

Release of Established Trees

One of the more important forestry uses of selective herbicides is to release young trees from competing brush. Small-scale tests on Stanislaus Experimental Forest indicated that young sugar pines could be safely sprayed with 2,4-D and 2,4,5-T in spring, before the start of growth and in fall after top growth had been completed (Schubert, 1962; Baron, Stark, and Schubert, 1964). A total of 160 trees growing in clumps of whitethorn were treated during an 8-month period at a rate of 10 trees per month with 2,4-D and 10 with 2,4,5-T. Each tree-brush clump was drenched with a mist spray at the rate of 200 p.p.m. of acid in water. Trees sprayed during the growing period were damaged more severely by 2,4-D than by

2,4,5-T (table 34). The damage was restricted mainly to the new growth on both terminal and lateral shoots (fig. 57 and 58).

In another study, young sugar pines treated with 2,4,5-T in water dosages of 1/4- to 1-pound acid equivalent per acre showed no serious damage, but rates of 2 and 4 pounds acid equivalent per acre resulted in higher mortality (table 35) and reduced growth (Schubert, 1962; Baron, Stark, Schubert, 1964). Six 1/10-acre plots of sugar pine in dense whitethorn were sprayed in late September. Four of the plots had some ponderosa pines and incense-cedars. None of the incense cedars was killed.

Table 34. Effect of 2,4-D and 2,4,5-T on young sugar pines growing in clumps of mountain whitethorn, by month of application.

Year and month	Average damage rating [1]			
	Trees		Brush	
	2,4-D	2,4,5-T	2,4-D	2,4,5-T
1958:				
July	2.2	2.4	1.4	3.6
August	1.6	.2	2.0	3.2
September	.2	.0	1.8	2.4
October	.0	.2	.4	3.2
November	2.6	.0	2.0	1.2
1959:				
April	.0	.0	.0	3.0
May	2.5	.4	3.2	4.0
June	2.6	1.6	3.0	3.2

Source: Schubert (1962).

[1] 0=none; 1=slight; 2=moderate; 3=severe; 4=killed.

Figure 57. Undamaged sugar pine treated with 200 p.p.m. of 2,4,5-T in September, Stanislaus Experimental Forest.

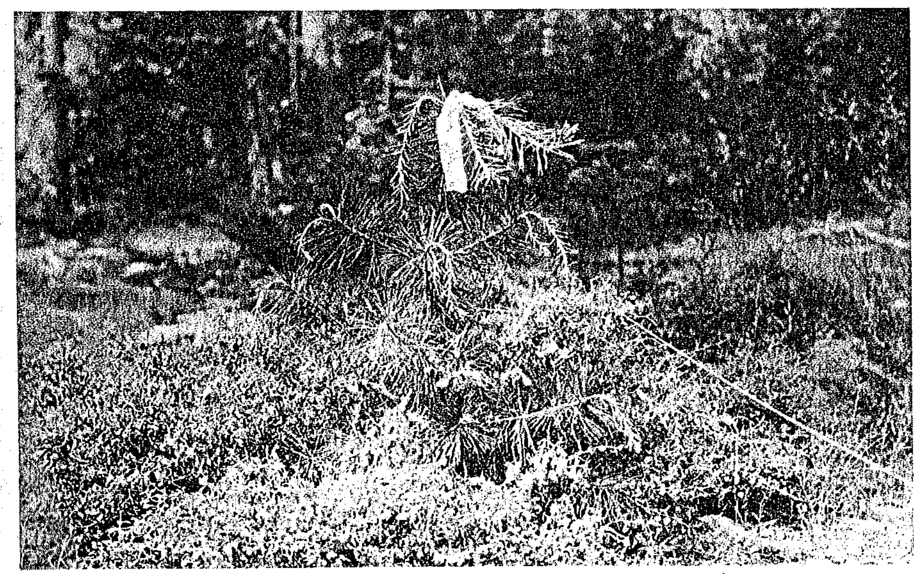

Figure 58. Severely damaged sugar pine treated with 200 p.p.m. of 2,4-D in July, Stanislaus Experimental Forest.

Table 35. Amount of first-year kill for pines and mountain whitethorn treated with different amounts of 2, 4, 5-T on September 24, 1959, Stanislaus Experimental Forest.

Amount of herbicide (rate a.e.lb./A)	Sugar pine	Ponderosa pine	Mountain whitethorn
		Percent	
¼	0	0	0
½	0	0	25
1	4	-	50
2	15	-	60
4	55	75	80

Source: Schubert (1962).

Older ponderosa and Jeffrey pines in a manzanita brushfield at Mount Shasta showed little or no damage when sprayed with 2,4-D and 2,4,5-T early in spring or in September - - even at a rate of 4 pounds acid equivalent per acre (Schubert, 1962). However, the trees were damaged by these herbicides when treated during the growing period.

In Oregon, ponderosa pines fully exposed to sprays of 2,4-D at rates of 2 pounds or more acid equivalent per acre were severely damaged or killed, but a 1-pound rate caused only slight damage (Dahms, 1955). Dahms (1961) later found that ponderosa pine can tolerate about twice as much 2,4,5-T as 2,4-D and about twice as much of either chemical in water as in an emulsion containing 1 gallon summer oil per acre. Treatments in July did the most damage to terminal buds, and spraying in late September did the least damage.

Dahms (1955) has also suggested that Douglas-fir, lodgepole pine, Port-Orford-cedar, western white pine, grand and white firs, and Sitka spruce could be treated at a rate of 1-pound acid equivalent per acre of 2,4,5-T without serious damage. The propylene glycol butyl ether esters of 2,4,5-T were reported to cause less damage than butoxy ethanol esters (Krygier and Ruth, 1961).

Gratkowski (1961) found that Douglas-fir was more resistant thar sugar and ponderosa pines to 2,4-D and 2,4,5-T. In his study Douglas-fir was about equally resistant to both chemicals. Since a number of brush or hardwood species commonly associated witl Douglas-firs are more susceptible to 2,4-D, this herbicide may b used where Douglas-firs are to be released from competition witl tanoak and madrone.

Rates of 2 to 3 pounds acid equivalent 2,4,5-T per acre (tabl 32) are recommended as selective follow-up sprays for young brusl regrowth (Bentley, 1967; Bentley and Estes, 1965). A 4-pound rat has been used successfully to control 2-year brush regrowth in som areas; however, in other areas damage to pines has resulted. Heavie dosages should not be applied on a large scale until experience witl small scale tests show them to be safe.

Some brush regrowth can be tolerated. An effective method fo determining the amount of regrowth and other stages of competin vegetation is to obtain their per acre cubic foot volume (Bentley 1967). This volume is found by computing the product of the mear crown height of each plant by the square feet of crown cover Bentley (1967) has recommended that over a period of 5 years brusl volumes up to 10,000 cubic feet per acre can be tolerated.

FULL SITE PREPARATION

The success or failure of almost every plantation in Californi can be related to the type and thoroughness of the site preparatior which preceded the planting (fig. 59).

Of three basic methods of preparing a planting site, mechanica clearing will require the least amount of follow-up treatment. A "chemically prepared" area generally will require some additiona treatment. A burned site will be intermediate, with some area requiring no additional work, while others may require complet removal of the dead unburned aerial portion and the stumps and chemical follow-up treatment.

The following treatments are suggested as a general guide t provide best growing conditions for planted seedlings or seedling from direct seeding. The treatments consider the best combination of the three basic site preparation methods, mechanical, burning an

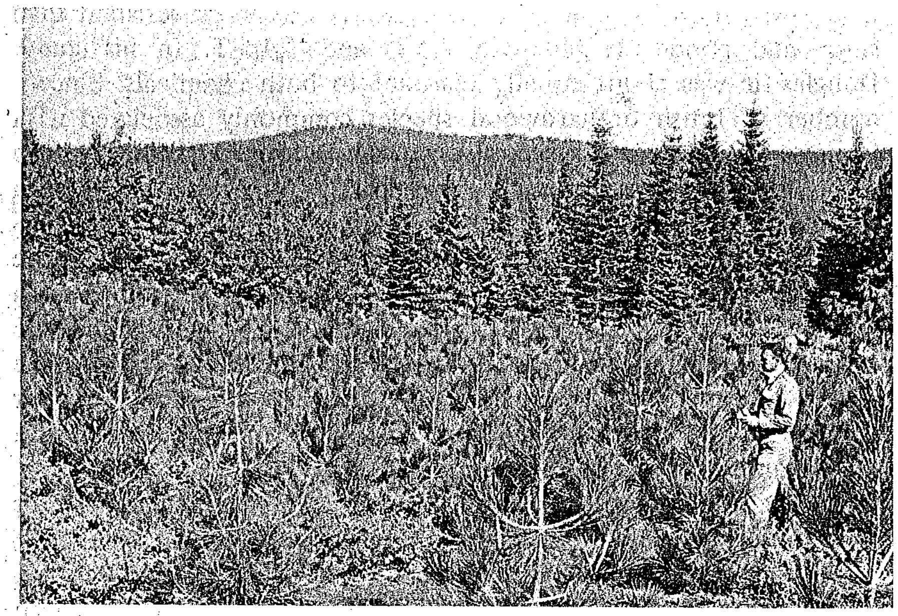

Figure 59. Vigorous young stand of ponderosa pines on an area following mechanical eradication of the mountain whitethorn. No follow-up treatment was needed, although brush was still present.

chemical. The actual treatment or treatments applied should be those which will do the best job at the lowest cost (treatment to be matched with corresponding condition):

Condition	Treatment
1. New cut-over area:	1. None may be needed if slash disposal is part of logging operation. If not:
a. No brush or grass understory.	a. Hand or machine pile slash and burn.
b. Brush understory.	b. Mechanical eradication of brush, pile and burn with logging slash.
c. Heavy grass understory.	c. Mechanical eradication or kill with chemicals.
2. Old cut-over area:	2. Usually will require special site preparation. If needed:

Condition	Treatment
a. Grass covered.	a. Mechanical eradication of grass and other herbs or kill with chemicals.
b. Brush covered.	b. Mechanical eradication of brush, pile and burn with logging slash.
3. New timber burn: (1 year or less)	3. May not require special site preparation. If needed:
a. No brush.	a. Machine pile logging slash and burn.
b. With old brush.	b. Mechanical eradication of brush roots.
4. Old timber burn:	4. Will usually require site preparation.
a. Grass with little to no brush.	a. Grass and other herbaceous vegetation usually present. Mechanical eradication or kill with chemicals.
b. Brush covered.	b. Mechanical eradication. Follow with chemicals if needed.
5. New brushfield:	5. Will require site preparation.
a. Brush small and scattered.	a. Kill brush with chemicals.
b. Brush large and dense.	b. Mechanical eradication, or burn after mashing. Follow with chemicals.
6. Old brushfield:	6. Will require site preparation.
a. Brush light and scattered.	a. May be chemically killed if dead tops do not interfere with planting.
b. Brush heavy and dense.	b. Mechanical eradication of brush, or burn after mashing. Follow with chemicals.

7. Grassfield:	7. Will require site preparation.
a. Grass light and scattered.	a. Kill grass with chemicals.
b. Grass heavy and dense.	b. Mechanical eradication of grass or kill with chemicals.

The specific treatments may vary from those indicated above depending on the species composition, size, and density. If grass or brush cover is sparse, easy to kill, and the dead materials do not interfere with planting or seeding, a chemical treatment may produce the desired results. If the competing vegetation is heavy, mechanical eradication is best.

COSTS OF SITE PREPARATION

Site preparation costs have always evoked mixed opinions from forest managers. Some contend that planting costs are already too high without adding another $40 or $55 an acre for site preparation. On the other hand, many foresters agree that without full site preparation stocking will be too inadequate to yield a fair return on their investment. Hallin (1956) indicated that planting and site preparation must be well done, and that money saved in these two jobs is pointless if too few trees are established to return the expected yields. He showed that reforestation costs of $86 per acre would yield an interest rate of 6 percent on the best quality land.

The costs of site preparation may be computed in several different ways. They can be shown as a separate item for site preparation or be included in the total planting cost. They may be shown on a basis of per acre, per thousand trees planted, or per thousand trees surviving. When presented as a separate item, the costs of preparing the site may seem to be unreasonably high, and to some managers might appear as a cost item they cannot afford. When included as one of the items in the total planting cost, the savings on the other items may greatly offset the high costs of preparing the sites. Similarly, site preparation costs may appear high when expressed on a per thousand tree planted basis. However, when shown as on a per thousand survival basis, these costs may suggest that forest managers can afford to invest money on site preparation.

Buck (1961) reported that in 1956 the average planting costs on the National Forest was $55.14 per acre, with a survival of 45 percent, so that the cost would be $188.51 per thousand surviving trees. In 1966, costs per acre were $65.76 per acre with a survival of 85 percent, for a cost of $154.73 per thousand surviving trees. In addition to a higher survival rate, machine planting lowers the cost on prepared sites. Another way in which cost has been lowered is to plant fewer trees. This reduction is possible because of higher survival rate on prepared sites.

Site preparation costs will vary for different site conditions. On fresh cutover timber lands, the cost of slash disposal and site preparation combined may be as high as $70 an acre. During a 5-year period the cost of slash disposal and site preparation at Blacks Mountain Experimental Forest ranged from $7.91 to $50.58 per acre of regeneration area, for a stand of ponderosa pine that averaged about 20,000 board feet per acre (Gordon, 1956). In a virgin sugar pine-white fir stand of about 88,000 board feet per acre on Stanislaus Experimental Forest, the combined slash disposal and site preparation costs per acre of regeneration area for 2 years was $70.90 the first year and $45.46 the second (Gordon, 1956; Gordon and Cosens, 1952). The lower cost the second year was the result of increased experience and of accepting a less complete job of slash disposal. Based on volume cut, the costs ranged from $0.04 to $0.44 per thousand board feet at Blacks Mountain and from $0.27 to $0.64 at Stanislaus.

Cost for site preparation by burning or chemical treatment varies considerably. The amount of pretreatment and follow-up treatment needed will govern the costs, which may range from $15 to $50 an acre.

Contract costs of helicopter spraying for brush control on National Forests [20] in 1965 ranged from about $7.00 to $13.00 an acre, with the contractor supplying the herbicides. In established pine plantations on National Forests the cost of initial spraying with two follow-up sprayings ranged from $21 to $36 an acre, depending

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[20]Regional Forester, California Region, U. S. Forest Service, San Francisco, California 1965. Herbicide spray contract costs on several National Forests. (Letter to the State Forester)

on the distribution and age of the brush (Bentley and Estes, 1965).

Low quality hardwoods 12 inches d.b.h. or larger were treated on Challenge Experimental Forest at a cost of about $0.40 per tree. 21/ Each tree was girdled near the base with an axe. The axe frill was filled with a 5 percent solution of 2,4,5-T in diesel oil.

Site preparation costs on private land in California are estimated to be from $8 to $13 an acre for chemical control; $9 for slash burning; and $25 to $75 for bulldozer clearing (Adams, 1963). Depending on the method, kind, and quantity of cover, costs generally range from $15 to $60 an acre (Gilden, *et. al.,* 1968).

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V PLANTING

Planting forest trees has been the most positive way to start a new stand of timber when and where needed. Prompt replenishment of tree growth is needed for a planned system of sustained yeild of forest products. Although natural regeneration has been the preferred way to renew the timber supply, it is often inadequate to meet the demands imposed on present day forestry.

Planting helps shorten the time required to grow trees of a specified size. There need be no time lag between removal of the old crop and start of the new one. However, planting in itself does not always assure the renewal of the next crop. The job must be done right if trees are to live and grow as the land owner requires.

Plant only:

(1) Good vigorous trees,

(2) Trees adapted to the site,

(3) Well prepared areas,

(4) At the right time,

(5) In the right way, and

(6) With proper care and protection.

TRENDS IN PLANTING

Planting in California has increased significantly in recent years (fig. 60). During the first 40 years before 1951, the average annual planting by all agencies combined averaged about 1,600 acres. Since 1950, about 18,000 acres have been planted and seeded annually. An average of nearly 39,000 acres were planted from 1965 to 1967

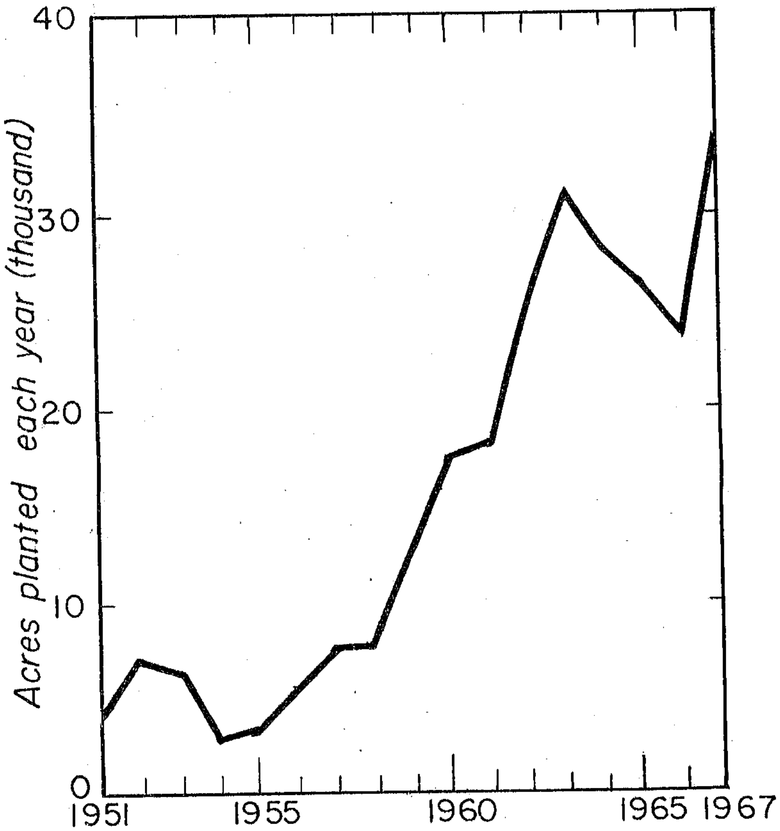

Figure 60. Trend in planting on commercial timberland in California since 1951.

(table 36). By the end of June 1967, about 333,000 acres of commercial forest land had been reforested by planting alone.

The greatest increase in planting and seeding has occurred on National Forests, although efforts on private land have increased substantially since 1951 (table 36). However, before 1951, more acres of private land were planted than of public lands. By 1967, 70 percent of the planted and seeded acres were on public lands.

In addition to the planting on commercial forest lands, another 11,500 acres have been planted as windbarriers on noncommercial

Table 36. Annual forest land planting and seeding in California from 1951 to 1967, exclusive of windbarrier planting, by fiscal years and ownership. 1/

	Public Forest Land							Private Forest Land				
	Federal			Nonfederal				Industry				
Fiscal year	National Forest	Other 2/	Total	State Forest	Other State	Other public 3/	Total	Forest	Other 4/	Other private 5/	Total	All Ownership
	Acres											
Prior 1951	28,336	368	28,704	14	0	1	15	26,424	0	10,082	36,506	65,225
1951	3,690	0	3,690	1	0	1	2	0	65	214	279	3,971
1952	6,948	0	6,948	45	0	0	45	52	42	132	226	7,219
1953	4,960	2	4,962	12	13	27	52	533	22	138	693	5,707
1954	2,287	19	2,306	53	6	36	95	123	40	232	395	2,796
1955	3,045	0	3,045	66	96	33	195	810	40	356	1,206	4,446
1956	4,160	0	4,160	54	527	30	611	549	12	482	1,043	5,814
1957	7,968	32	8,000	53	181	30	264	194	40	839	1,073	9,337
1958	6,892	16	6,908	49	32	51	132	632	30	1,157	1,819	8,859
1959	9,472	185	9,657	49	88	78	215	649	50	2,563	3,262	13,134
1960	14,088	261	14,349	61	38	37	136	4,187	214	2,484	6,885	21,370
1961	14,580	537	15,117	31	59	71	161	3,186	211	2,339	5,736	21,014
1962	22,988	512	23,503	16	62	92	170	3,836	206	3,479	7,521	31,194
1963	25,892	1,819	27,711	27	60	40	127	3,719	65	3,329	7,113	34,951
1964	20,931	3,689	24,620	38	148	190	376	6,883	117	2,295	9,295	34,291
1965	18,569	3,890	22,459	173	5	65	243	5,660	2,281	3,487	11,428	34,130
1966	22,880	2,285	25,165	112	60	76	248	7,620	923	4,695	13,238	38,651
1967	27,357	2,518	29,875	111	29	232	372	7,206	311	5,651	13,168	43,415
Total	245,043	16,136	261,179	965	1,404	1,090	3,459	72,263	4,669	43,954	120,886	385,524

1/ Data based on planted and seeded acreages reported in Tree Planters' Notes Nos. 9, 13, 15, 19, 23, 27, 30, 34, 39, 44, 49, 56, 62, 68, 74, 80, and Vol. 18, No. 5.
2/ Includes Indian and Bureau of Land Management lands.
3/ Includes lands owned by towns, counties, and public schools.
4/ Includes lands owned by mining, railroad, water and power companies.
5/ Includes lands owned by persons, clubs, associations, and private schools.

forest lands (U. S. For. Serv., 1967b). All but 431 acres of the windbarrier planting has been on private land.

The trend in planting success has been upward. According to the Forest Service criteria of 200 trees or more per acre for acceptable stocking, successful plantings have risen from 15 percent before 1946 (Fowells and Dunning, 1948) to 31 percent in 1952 (Zillgitt, 1958) to more than 85 percent in 1959 (Buck, 1959).

In addition, the loss ratio of planted acres has decreased in the past 20 years. For a plantation to be considered lost, it must have less than 100 trees per acre.[22] In 1944, 28 percent of the planted acres were rated as lost. By 1964 only 15 percent had less than 100 trees per acre.

Trees are counted on National Forest plantations at the end of the first and third years after planting. Only borderline plantations are reexamined at the end of the fifth year. A similar plantation examination schedule is followed on lands of other ownership. Therefore, a plantation may be rated as "lost" during any one of the three examinations.

In Forest Service Region 5, plantations with 100 to 199 trees per acre may be fill-in planted to raise stocking to acceptable levels, while those with less than 100 trees are to be replanted if possible.[23]

WHERE TO PLANT

Where to plant is decided by land managers, staff members in charge of regeneration, foremen of planting crews, and individual members of a planting crew. The land manager decides which areas will be planted. His decisions are based on (1) up-to-date planting surveys, (2) timber site quality maps, (3) soil vegetation maps, and (4) available funds and planting stock. He usually will plan to plant the best quality lands first, where his available money, manpower, and trees will do the most good in the long run.

[22] U. S. Forest Serv., Calif. Region. Timber Management Handbook, Chap. II - Silvicultural Practices. San Francisco, Calif., 1957.

[23] See footnote 22.

The responsibility of the individual member of a planting crew is to select the best spot to plant each tree. He will follow established guidelines, instructions from the crew boss, and common sense.

Plant Unstocked Areas First

Since both nursery stock and finances are limited, planting should be restricted to the backlog of unstocked land, plus whatever new planting opportunities develop as a result of fires or timber harvesting.

Fill-in planting of poorly stocked seedling and sapling stands may be considered as a second choice if expected returns are estimated to be greater than from the available unstocked land. In general, fill-in planting on areas occupied by pole timber would be a poor third choice.

Almost all of the unstocked commercial timberlands is in the northern two-thirds of the State (fig. 61). About 58 percent of the unstocked land occurs in the Sierra-Cascade region, with most of the remaining portion in the northern coast. Less than 1 percent of the unstocked land is in the southern California subregion. Ownership of the unstocked forest land in 1952 was almost equally divided between private and government (table 37).

Location of Past Plantings

Since most of the unstocked forest land is in the northern two-thirds of the State, the major planting effort would be made there. Although all planting records are not sufficiently detailed for an exact breakdown by subregions, inferences may be drawn from the records of National Forest planting and some private planting during the past 60 years.

Most of the planting on National Forests has been in the Sierra Nevada-Cascade ranges (table 38). Except for the Klamath National Forest, very little planting has been done in the Coast Range Pine and Redwood–Douglas-fir subregions by the U. S. Forest Service. Only about 1.6 percent of the planting has been done on the three National Forests in southern California.

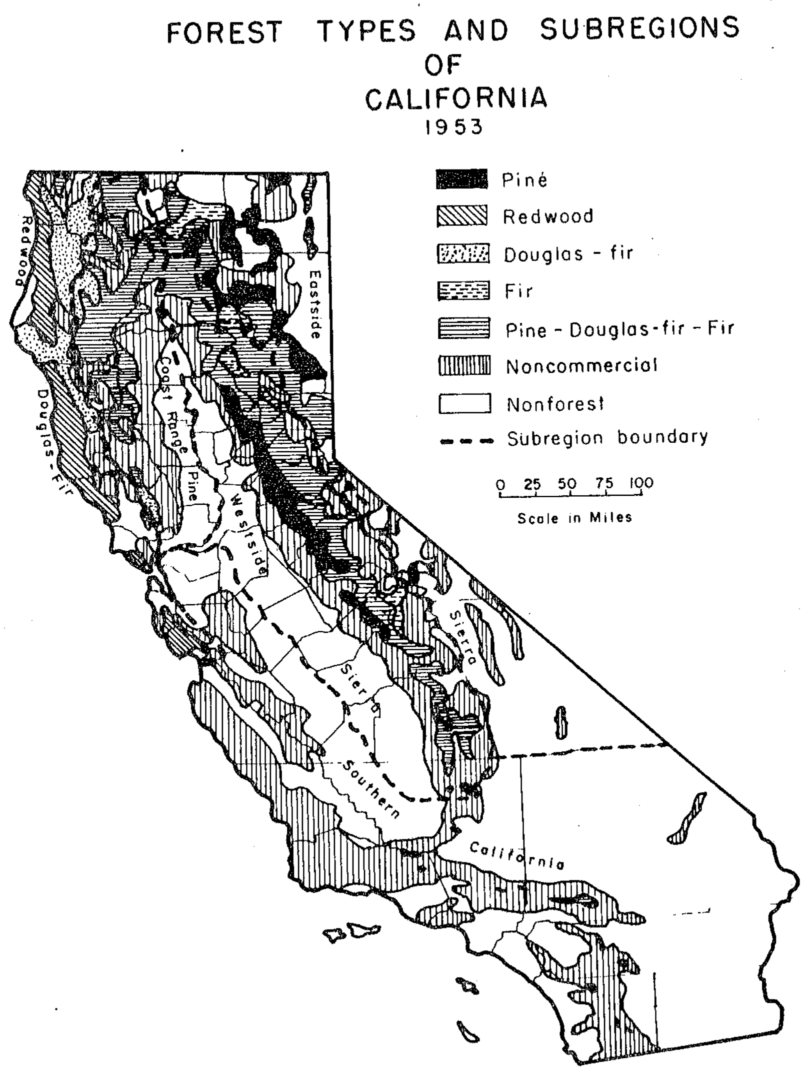

Figure 61. California forest types and subregions.

Table 37. Ownership of unstocked commercial forest land in California by subregions, 1953. 1/

Subregions	National forest	Other federal	State, county and municipal	Private
	Percent			
Eastside Sierra Nevada	15.28	0.37	0.09	8.33
Westside Sierra Nevada	13.06	1.47	.19	18.93
Coast Range Pine	8.19	1.14	.24	6.25
Redwood-Douglas-fir	6.20	1.23	.71	18.03
Southern California	.10	--	--	0.09
Total	42.83	4.31	1.23	51.63

Source: Forest statistics for California. U. S. Forest Serv., California Forest & Range Expt. Sta., Forest Survey Release 25, 66 p., illus.

1/ No recent data available.

Most of the planting on private forest land also has been in the northern part of the State. From 1923 to 1931, 10 forest companies planted more than 12.7 million trees on 26,423 acres: 14,338 acres in Humboldt County, and 12,085 acres in Mendocino County (table 39). Planting by water, power, forest, and other companies during recent years has been done in most of the timbered counties. Some companies with an active planting program include:

1. American Forest Products Corporation (formerly Calaveras Land and Timber Corporation and Winton Lumber Company)
2. Arcata Redwood Company
3. Georgia Pacific Company (formerly Hammond Lumber Company and Rockport Redwood Company)
4. Masonite Corporation
5. The Pacific Lumber Company

6. Pickering Lumber Corporation
7. Kimberly-Clark Corporation (formerly Ralph L. Smith Lumber Company)
8. Boise-Cascade Corporation (formerly Union Lumber Company)
9. Simpson Timber Company
10. Soper Wheeler Company
11. Southern California Edison Company
12. Southern Pacific Land Company

Table 38. Summary of plantings on National Forests in California before July 1967.

National Forest	Total planted	Proportion planted by each forest
	---- Acres ----	---- Percent ----
Angeles	1,176	0.51
Cleveland	439	0.19
El Dorado	9,934	4.29
Inyo	738	0.32
Klamath	38,083	16.44
Lassen	20,165	8.71
Los Padres	609	0.26
Mendocino	4,690	2.03
Modoc	22,584	9.75
Plumas	19,043	8.22
San Bernardino	1,880	0.81
Sequoia	7,040	3.04
Shasta-Trinity	35,073	15.14
Sierra	11,319	4.89
Six Rivers	19,304	8.34
Stanislaus	19,122	8.26
Tahoe	20,390	8.80
Total	**231,589**	**100.00**

Source: Data from 1967 annual planting report by the Division of Timber Management, California Region, U. S. Forest Service, San Francisco, California.

Table 39. Acreage and number of trees commercially planted in Humboldt and Mendocino Counties, 1923-1931.

County and lumber company	Area planted	Trees planted
	Acres	Number
Humboldt:		
Pacific	1/ 5,814	3,493,990
Little River Redwood	3,299	1,285,010
Hammond	2,825	1,120,600
Northern Redwood	2,000	763,000
Dolbeer-Carson	400	150,000
Subtotal	**14,338**	**6,812,600**
Mendocino:		
Union	5,150	2,551,000
Mendocino	1,666	797,000
Glen Blair	100	47,000
Caspar	3,325	1,587,970
Albion	1,844	920,000
Subtotal	**12,085**	**5,902,970**
Total	**26,423**	**12,715,570**

Source: Person (1937).

1/ 297 acres of this area was planted twice.

Numerous Christmas tree plantations have been started since 1950. Many private companies, as well as individuals, are growing Christmas trees on commercial and noncommercial timberlands in California.

Plant Best Sites First

All the best site lands should be planted before planting is done on lower site quality lands (fig. 62). High site quality lands offer the best opportunity to produce wood products at the lowest costs. Tree survival, growth, and quality are the highest and costs the lowest.

Site quality is an expression of many different factors, including soils, climate, slope, aspect, and others. Often in delineating areas as to site quality, small local differences, too small to show as separate units, are included within the boundaries of site quality classes. Therefore, within these broad areas, local factors may have a marked influence on establishment of reproduction.

Many forests have been delineated into units based on the Dunning site classes (Dunning, 1942) or some other system. In terms of Dunning's classes, first priority planting areas would be sites A-200 and I-175. Second priority ones would be sites II-150 and III-125. Sites IV-100 and V-75 are the poorest areas for initial efforts. Areas, in which Dunning site classes may not be appropriate, can be divided into three or four site quality classes, according to local conditions, with site 1 as the best available and site 4 the poorest.

Fowells and Dunning (1948), in their survey of National Forest plantations which had been rated as successful, reported that 74 percent of the plantations on high quality sites had a stocking of 200 or more trees per acre compared to 44 to 45 percent for medium and low quality sites (table 40). The tree vigor on the high quality sites was also considerably better than on the medium and low sites. Only 18 percent of the trees on the best sites were of low vigor; whereas, 35 to 36 percent of the trees on medium and low sites were growing slowly.

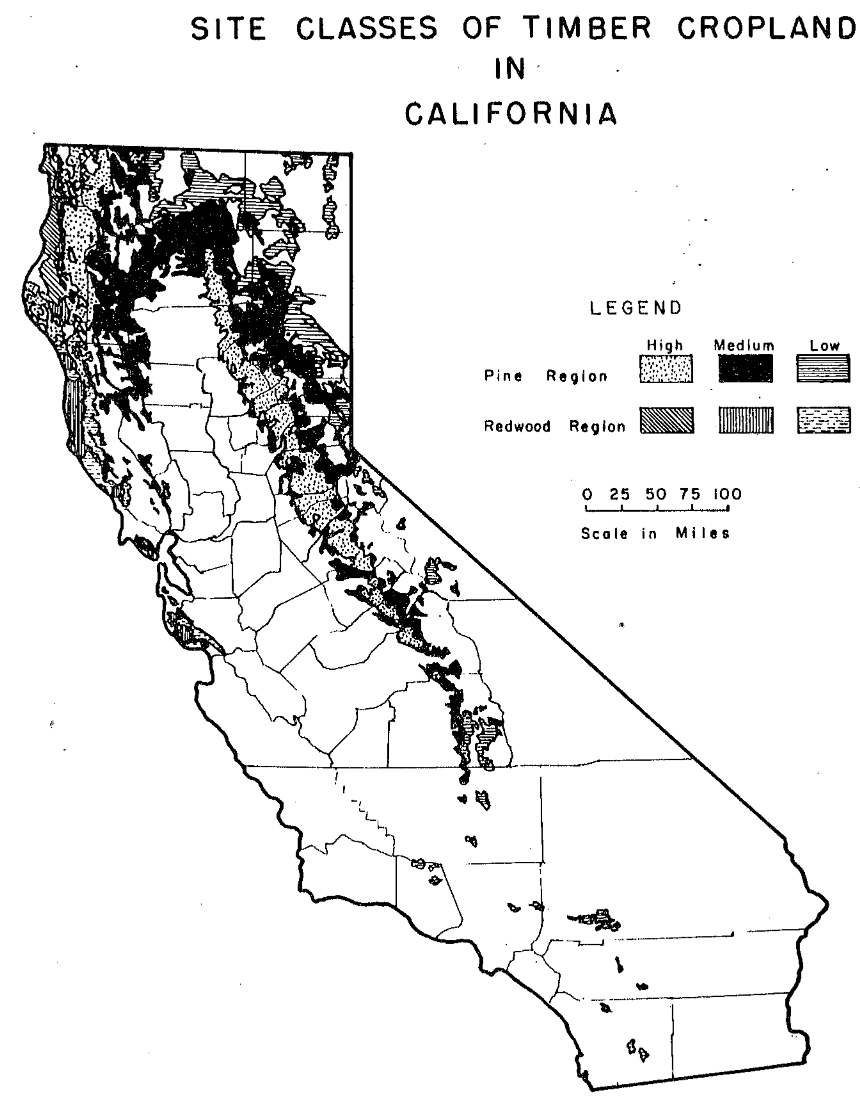

Figure 62. California timber cropland site classes.

Table 40. Distribution of plantation acreage in three site quality classes, by 100-tree stocking classes.

Site quality	Stocking, trees per acre				
	0-99	100-199	200-299	300-399	400-499
	Percent				
High	11	15	45	18	11
Medium	16	40	35	9	0
Low	14	41	40	0	5

Source: Fowells and Dunning (1948).

The best sites usually have deep, well drained soils. These soils within different climate regimes support excellent stands of Douglas-fir, redwood, ponderosa, Jeffrey, and sugar pine; with ponderosa and Jeffrey doing better than sugar pine, Douglas-fir and redwood on the drier areas. In Oregon, Tarrant (1947, 1953) found that sugar pine, ponderosa pine, and white fir preferred well drained soils on north slopes, whereas lodgepole pine was usually found on poorly drained soils. Howell (1931) indicated that ponderosa pine could not endure any excess soil moisture and that it should not be planted on lodgepole pine sites. Show (1930) reported that efforts to establish sugar pine on the lava-ash soils in the McCloud area resulted in almost universal failure, but had high survival on clay or loam soils.

Some soil series have been classed as good forest soils while others are noted to be poor ones. Roy (1957) listed several soil series in northwestern California as good and poor soils for Douglas-fir and redwood planting. Among those indicated as good forest soils were: Hugo, Josephine, Melbourne, Mendocino, Empire, Sites, and Larabee. Poor soils included Tyson, Dubakella (serpentinaceous), Hoover (shallow), Laughlin, and Hugo (shallow phase). Cooper (1961) reported good natural Douglas-fir reproduction in Josephine, Mendocino, and Sites soils, but found only sparse reproduction in Hugo, Melbourne, and Masterson soils. The deep phase of the following soils have also been associated with good timber sites:

1. Aiken
2. Arnold
3. Auburn
4. Butte
5. Coarsegold
6. Cohasset
7. Gleason
8. Goldridge
9. Holland
10. Mariposa
11. Olympic
12. San Andreas
13. Sierra
14. Siskiyou
15. Underwood

Often the soil in a particular area is unknown, either unclassifie by soil scientists or unfamiliar to the local person in charge o planting. Soils have been identified and mapped for some foreste areas. Soil maps can be purchased from the U. S. Forest Service o the California Division of Forestry for use in selection of goo planting sites. Where there is any doubt as to the true potential o any soil, the best indication can be obtained by examining th growth of nearby trees or stumps.

In general, survival of planted trees has been best on gentle nort slopes where moisture is adequate (table 41). South slopes ar generally the driest, west and east slopes next driest (Kummel, *et al.* 1944). Drought-resistant trees, such as ponderosa, Jeffrey pine, an incense-cedar, will normally do better on the warmer dry sout slopes than will sugar pine, Douglas-fir, and the true firs. Sisch (1958) reported that north slopes at elevations above 4,000 offere the best sites for planting in southern California.

Many natural openings in timber or brush stands are ofte unsuitable for tree planting. These openings may have a high wate table, poor air drainage, or some other condition detrimental t trees. In areas with poor soil or air drainage, young trees may b damaged, stunted, or killed. Frost damage to growing terminals an frost heaval are frequently observed where trees are planted i depressions or openings surrounded by taller vegetation Furthermore, some natural openings may be the result of growt inhibitors or toxins given off by the native vegetation (Jameson 1961).

Table 41. Survival of plantings in 0.1-acre plots, milacre quadrats, and company records by exposure.

Exposure	Survival 0.1-acre plots	Milacre quadrats Survival	Milacre quadrats Basis, quadrats	Company data
	------- Percent	------	Number	Percent
North	47	42	679	63
South	29	13	906	26
East	44	17	141	57
West	24	23	124	48
Level	0	13	75	–
Total or average	35	24	1,925	44

Source: Person (1937).

Selecting the Best Spot to Plant

If an area selected was unsuitable for reforestation, then even the best planting job cannot correct the mistakes. Similarly, plantations on the best areas may fail if the individual members of a planting crew do not adequately perform their job.

Each member of a planting crew is responsible for selecting the best spot to plant each tree (Kummel, *et al.,* 1944). The following guidelines apply mainly to hand planting, but should be observed in machine planting where applicable:

1. Select a spot where the seedling may benefit from the shade cast by a stump, a log, or rock–provided it is not too far out of line. However, do not select a spot too close to stumps or logs where loose bark may slough off and smother the tree. Roy (1955) found that small seedlings were killed by large sheets of bark which had sloughed off cull Douglas-fir logs. Bark from cull logs of other species may do the same.

2. Select a spot with good drainage, but do not plant o hummock. These small mounds often have dry centers and p moisture holding capacities. Depressions should also be avoid except in areas where drainage is good. Trees planted in d depressions may be buried with silt.

3. Do not plant closer than 5 feet to live grass or low brush, within 10 feet of saplings or 50 feet of large trees. Trees plant closer than these distances will have difficulty competing for s moisture with the adjacent established vegetation.

4. Do not plant in holes containing dry slash or other debris. T reason for not planting in a dry hole is obvious. Even under m conditions it is not advisable to have undecomposed organic ma which may lead to a nitrogen deficiency problem.

5. Plant trees in favorable spots rather than in a fixed geome pattern. In other words, the spacing should vary to take advantage good planting spots. However, the average spacing should reasonably close to the designated spacing so that the right num of trees are planted per acre.

Selection of a favorable location for the planting spot of means the difference between success and failure.

WHEN TO PLANT

The best time to plant forest trees in California has genera been in early spring. However, late fall and winter planting have times produced equally good results and may be preferred to spr planting in some areas. With respect to time of planting, three m factors or conditions have been found to affect survival: (1) t physiological condition of the planting stock; (2) the amount of s moisture available to the plant; (3) and the weather conditi during and after planting. Any one of these three conditions may limiting and at times all three may jointly affect planting succ (Kummel, *et al.*, 1944).

Condition of Planting Stock [24]

According to Toumey and Korstian (1949) "planting should done after growth ceases in autumn and before growth starts

[24] Stock quality as related to physiological condition was covered earlier in this report.

spring." This general guide was followed in California for about 50 years of planting. Trees were frequently planted from the first week in October until deep snow or frozen ground halted planting in late November or December. Planting was then resumed in spring when the ground was free of snow and continued until it was "too dry to plant." Plantation failures were common under this planting schedule and lack of proper site preparation.

Many reasons were advanced for these "unaccountable" failures. One of the reasons given was the poor physiological condition of the planting stock. For example in the late 1930's, Dunning, Fowells, Kirk, and others indicated that the heavy mortality of some fall-planted trees "may have been caused by the poor physiological condition of the trees when they were field planted rather than some other factors." [25] Since research plantings made late in the fall almost always had high survival, they believed that many plantings on National Forests were made before the trees had completely "hardened-off."

The first test of different planting dates in fall and spring was made with transplant stock at the Feather River Nursery, near Quincy, California. [25] Freshly lifted ponderosa and Jeffrey pine 1-1 transplants from the Durbin and Feather River Nurseries were transplanted at different dates in fall 1941 and spring 1942. The 2-year-old trees from the Durbin Nursery were segregated into two groups–those with terminal buds and those without. Very few trees from the Feather River Nursery had terminal buds, so only those without buds were used in the study. The transplant beds were thoroughly watered before fall planting started, but received no further watering during the study–to simulate conditions which may be found on a well-prepared planting site without vegetative competition for moisture.

Although the analysis at the end of the first growing season indicated significant differences in survival, the results of the study did not demonstrate conclusively that the physiological condition of

[25]From unpublished progress reports on file at the U. S. Forest Service, Pacific Southwest Forest & Range Experiment Sta., Berkeley, California.

the planting stock was one of the main reasons for the man plantation failures, although the September lifting from Feathe River Nursery was evidently too early (table 42). Furthermore, sinc the study did not demonstrate poor survival during the "normal" fa and spring planting seasons, there was no sound reason to change th planting schedule. Furthermore, the study did not test planting stoc under the normal high moisture stresses that prevail under fiel conditions.

Table 42. First-year survival of 1-1 planting stock from tw nurseries transplanted at different dates in Feather Riv Nursery, 1941-1942.

Planting date	Durbin Nursery				Feather River Nurser	
	Jeffrey pine		Ponderosa pine		Jeffrey pine	Ponderos pine
	Buds	No buds	Buds	No buds	No buds	
	Percent [1]					
September 25	87	94	87	81	77	40
October 9	88	81	92	90	98	87
October 23	92	83	85	85	94	96
November 6	100	98	92	98	100	98
March 24	100	98	100	98	90	98
April 7	–	–	–	–	100	100
April 25	–	–	–	–	94	92
May 5	–	–	–	–	94	96
May 19	–	–	–	–	94	87
June 2	–	–	–	–	54	52

[1]A difference of 13 percent in survival is statistically significant. Each statistic is based 52 trees (total tree basis was 2,080).

Since planting success continued to be low, it was decided i 1955 to take a new look at the physiological condition of pondero pine seedlings at different times of the year. Results of the mo recent studies and recommendations arising from them are describe in the chapter on nursery practices.

It can be expected that under field conditions, both the root-regenerating potentials and survival will be lower than the results indicated by the greenhouse or nursery studies. The success of fall planting depends on the seedlings' physiological potential to resume root growth when conditions are (or become) favorable. Since soil moisture and root-regenerating potentials are low, all plantings made in early fall may fail. Plantings made in late fall or early winter have higher probability for success. The success of a spring planting depends on the seedlings' physiological potential to start or continue active root growth soon after planting. Seedlings with high root regenerating potential in the nursery were better able to survive in soils with a moisture content less than field capacity (Stone, 1967). Any delay in planting after the area becomes plantable in spring will reduce the chances for success. Long delays may result in total failures unless late spring rains restore soil moisture to near field capacity. [26]

Soil Moisture

Soil should be wet down to at least 1 foot before tree planting is started in the fall. To wet the soil to that depth requires from 1 to 2 inches of rain, depending on the dryness and kind of soil and the interval over which the rain falls. The probabilities of getting ½-inch to 4 inches of rain during each month are shown in figure 63 for the Feather River Station. The probability of getting 2 inches of rain by the first of October was only 33 percent. By the first of November, it was 56 percent. However, the probability of having enough moisture in the soil was only 44 percent for November 1, based on at least 2 inches of rain within a 30-day period (fig. 64). Therefore, based on the daily precipitation records at the Feather River Station, there would be only a 50-50 chance that planting could be started by the first week of November, even if the planting stock was physiologically ready for field planting.

The rapid decline in probability for adequate moisture in May also suggests a cessation of planting before stock becomes unsuitable for planting (fig. 64).

[26] See proposed nursery lifting and storage schedules elsewhere in this report.

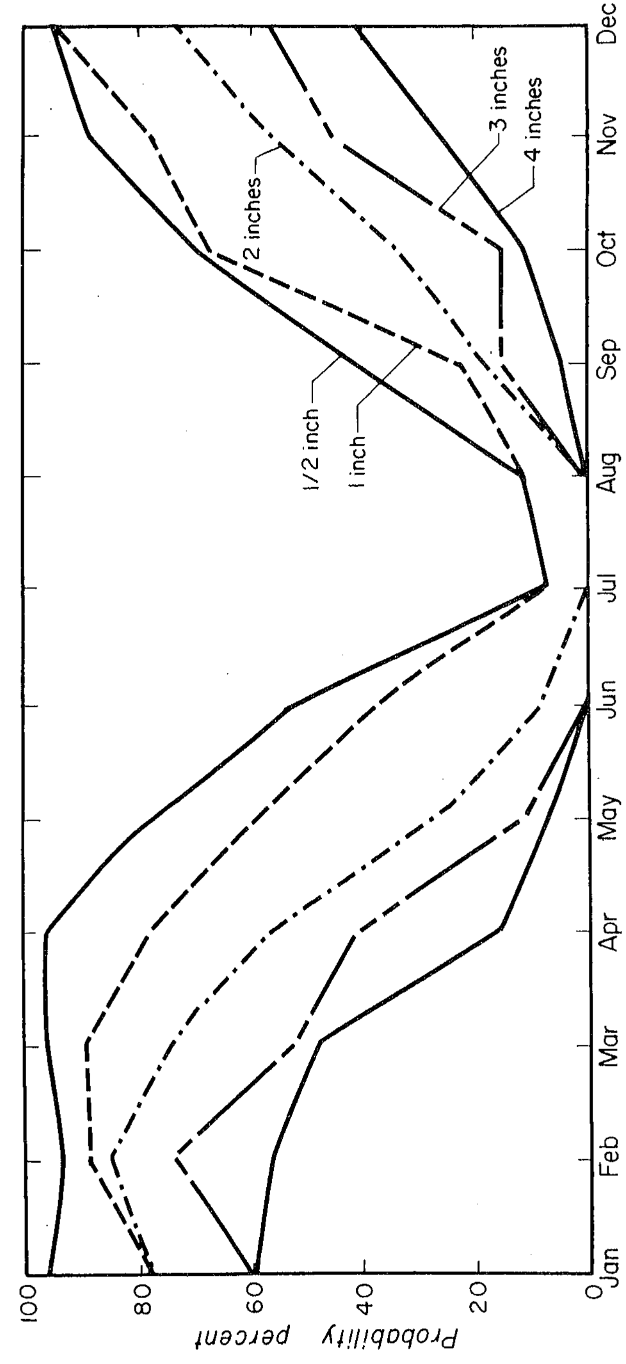

Figure 63. Probability of getting various amounts of precipitation each month at Feather River Station, near Quincy, California (Basis: 1912-1938).

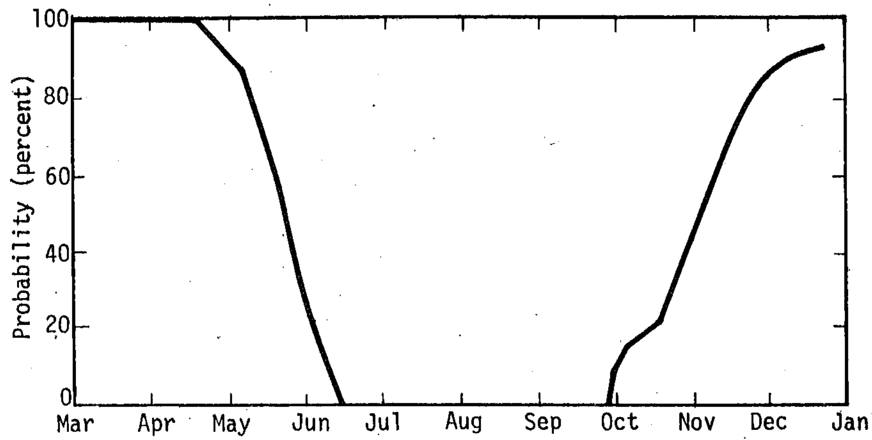

Figure 64. Probability of adequate soil moisture for tree planting in spring and fall at Feather River Station, near Quincy, California (Based on precipitation records from 1912-1938).

After the trees are well established and making active root growth, their moisture requirements are considerably less than at time of planting. For the first 2 to 4 weeks after planting, root growth in the field is slow. Therefore, soil moisture is rapidly depleted by the plants within the restricted area occupied by the roots. After the roots start active growth, soil moisture is drawn from an area which continually increases.

Weather Conditions

Elements of weather other than precipitation also have a marked affect on planting success. An extended warm, dry period in fall or spring, shortly after planting, can cause serious losses. An open winter has often lead to considerable frost heaving of fall planted trees, particularly at the higher elevations. When the ground is frozen, strong winds rapidly desiccate planted seedlings. Warm periods in winter were believed to result in plant damage or death by activating new growth which was later killed during a severe cold snap. However, the probability of growth during the winter is low, according to Hellmers (1959), who found that the photoperiod, not temperature, controlled bud bursting. Fowells (1941) reported that growth on conifers started at significantly later dates with each

2,000-foot rise in elevation. This condition suggests that when day-length is adequate, growth is controlled by temperature.

Strong desiccating winds have also been reported to cause heavy mortality in southern California (Sischo, 1958) and along the coast in the redwood belt (Person, 1937). Strong, dry winds probably have caused mortality in many other areas also. Planting should never be done during periods of strong winds.

Early, deep snows during fall, and late snows in spring also have had an adverse effect on the planting program. When snow occurs in the fall it may completely halt further planting. Late spring snows may delay planting beyond the optimum planting season. Thus the combined effects of adverse weather may in some years seriously reduce the number of planting days available, both during the fall and spring planting season. When only a few thousand trees are to be planted, this limited planting season may have little or no adverse effect on the regeneration program. However, for a large planting program it may prove disastrous. Since weather conditions are unpredictable, every good planting period during late fall, winter and early spring must be used.

Spring and Fall Planting Experience

In general, records of past planting in the Sierra Nevada indicated that spring-planted trees were best. The average survival for the period 1929-1939 by National Forests was:

National Forest:	Spring	Fall
	- - - Percent- - -	
El Dorado	72	22
Lassen	51	43
Modoc	59	29
Plumas	36	24
Shasta	82	55

There have been times when the survival of fall-planted trees was as high as for spring-planted trees. Ponderosa pines planted in November 1949 and April 1950 on Stanislaus Experimental Forest had a second-year survival of 84 percent for both fall and spring. A

Feather River, ponderosa pines planted on December 6, 1938 had a survival of 91 percent compared to 98 percent for March 31, 1939. In the 1941-1942 season, ponderosa pine planted on November 6 had a first-year survival of 98 percent compared to 100 percent for April 7 planting. All of these comparisons involved planting dates in fall and spring when the trees should have been in a good physiological condition for planting. Ponderosa pines planted on September 25, 1941, had only 40 percent survival at the end of the first growing season compared to 52 percent for trees planted on June 2, 1942.

In recent years, most plantings in California have been made in spring. For example, almost 80 percent of the ponderosa and Jeffrey pine plantings on National Forests from 1958 through 1960 were made during the 3-month period of March through May and about 75 percent of the Douglas-fir plantings in February, March, and April. Most of the plantations with the other species were also planted during these months. A similar schedule was followed on private and nonfederal public lands.

Suggested Planting Seasons

The best times to plant will necessarily vary for different regions in California. Even within regions, the best time to plant will vary by elevation and general aspect. To date, the best results have been obtained from late fall, winter, and early spring plantings. The poorest have been early fall and late spring. Within the optimum planting periods for each location, the physiological condition of the trees and the available soil moisture will also affect the planting schedule.

Data gathered for almost 14 million trees planted on about 28,000 acres of National Forests throughout California during 3 consecutive years, and recommended planting dates in published reports have been incorporated to suggest planting seasons for the three major planting regions in California:

1. Southern California

The best time to plant is in January, February, or March, when the soil is generally moist, with the possibility of several rains before

drought periods. Snow storms may prevent planting at the high elevations in January and February but snows seldom interfere wi planting in late March or early April.

Areas at the lower elevations and on slopes with a southe exposure should be planted first.

Planting is not recommended during December except protected areas if soil moisture is adequate. Strong desiccating win in December can kill seedlings (Sischo, 1958). Winds also occur lat in winter and in early spring, but are not as frequent or as damagi as in December.

2. Central and Northern Coastal area

This area begins with the Los Padres National Forest in the sou and extends to the Oregon border in the north. It extends from t coast on the west to the base of the east slopes of the Coast Range The area is large but each planting chance is comparatively sma because of variable topography. Therefore, the time schedule shou be geared to plant first those areas which open up and dry out ear and to plant next those areas which open up and dry out last.

In general, plantings made from January through April have t highest probability for success. Roy (1957) recommended planti the areas near the coast, any time after the fall rains have thorough wet the soil. However, the physiological condition of Douglas-fir ma not be suitable before December 1 (Todd, 1964). Areas furth inland should be planted as early as possible in the spring. Sin south and west slopes dry out earliest, these slopes should be plante before the east and north slopes.

In a small scale study near Eureka, best survival of Douglas-f was for trees planted in February and March; and, at the Jackso State Forest, planting during late December through February ga better survival than earlier or later plantings (Stone, *et al.*, 1961 Test plantings by Fritz and Rydelius (1966) indicated January an February were best for a similar site. Planting during the perio 1922-27 on private lands in Humboldt and Mendocino Counties wa done mainly from December to February (Person, 1937). Surviv after 5 to 9 years was 32 to 36 percent–high enough for adequa stocking.

3. Sierra-Nevada Cascade Range Area

This area begins with Sequoia National Forest in the south and includes Modoc National Forest in the north. The variable topography and climate influence the planting schedule for specific locations.

In general, spring planting has been the most successful. The highest initial survival has been for plantings made from February through May. Planting on any specific area should begin as early as possible after the first of the year and stop about mid-May. If soil moisture gets low, planting should be stopped earlier. If there are late spring rains, the planting season may be extended; however, no planting should be done after June 1. Again, south slopes should be planted first–followed by west, then east, and last north slopes.

Some areas will have to be fall planted, particularly those at high elevations which may be inaccessible until too late in spring for planting. Large planting programs may also make it necessary to spread the workload. Two main factors control the beginning date for fall planting: (1) physiological condition of the stock, and (2) sufficient soil moisture for planting. The earliest that stock will be suitable for planting is about the first of November, and this stock would be only from a cold climate nursery (see Chapt. III). In most years November 1 coincides with a time when there would be about a 50-50 chance that soil moisture would also be adequate. High elevation areas could be planted first before they are snowed-in and then planting could be continued at lower elevations.

Areas below the deep snow zone may be planted during late fall and winter while conditions are favorable. Although planting in the snow is not generally recommended, planting can be done successfully if the ground is not frozen. The snow must be removed from the planting spot before the hole is dug, and none should be pushed into the hole while planting the tree. A "mulch" of snow may be placed around the planted tree.

Gilden, *et al.*,(1968) have recommended similar planting dates in six areas of the state (fig. 65).

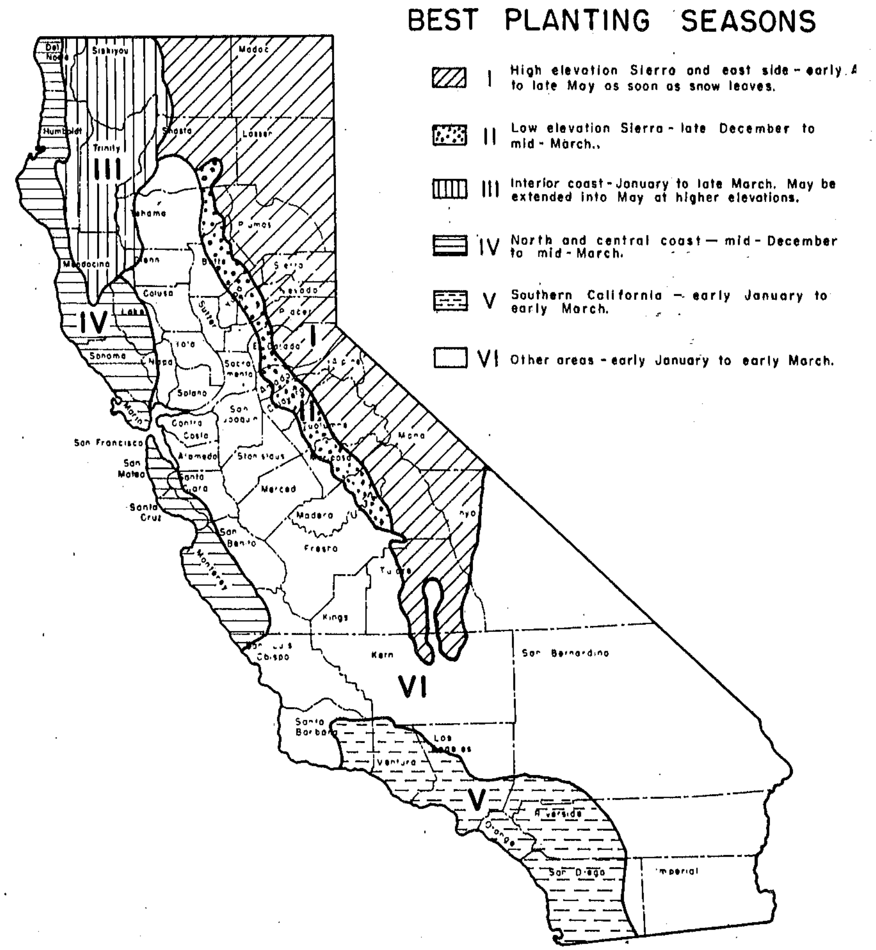

Figure 65. Best California planting seasons.

WHAT KIND OF STOCK TO PLANT

The ultimate success of each plantation will depend on the ki
of stock planted. The stock must be of the right seed origin, age, si
and quality best suited for the particular area. Often a choice can
made from several suitable alternatives. However, a wrong choi
may lead to failure.

Planting stock from a local seed source is recommended (see Chapter II). Non-local source planting stock should be adequately field tested in the local area before it is used on a large scale. When ordering planting stock, the seed zone and elevation should be specified in the request.

Age and size classes of nursery stock that are most suitable for planting were described in some detail in Chapter III.

Most stock is produced for timber production. Almost all the trees grown at the two Forest Service Nurseries are planted on federal lands for timber production. Seedlings from the two State District nurseries are used mainly to reforest State and private timberlands and for Christmas tree production. In recent years over a million trees have been planted annually on private lands for Christmas trees.[27] The potted trees from the State Nursery at Davis are planted primarily for roadside and public land beautification, as windbarriers, and for erosion control on State or private lands.

Species to Plant

Generally, the species to plant on a particular area should be the same as those that have previously grown there. Trees of a different species often fail unless the introduced species are adapted to the environment. Native species have been used in almost all plantings for timber production in California.

Most of the trees planted for timber production have been ponderosa and Jeffrey pines. These two species account for about 80 percent of the trees planted. Other species in descending number planted were: redwood, Douglas-fir, and sugar pine. These five species probably account for 95 to 98 percent of all the trees planted on commercial forest land by all agencies.

In the Redwood--Douglas-fir region, redwood leads Douglas-fir in numbers of trees planted. Most of the redwoods were planted during the period 1923-32, with very few since then. Douglas-fir is now the leading species in that region. The U. S. Forest Service Humboldt

[27]Adams, Ronald S. Planting stock distribution in California. 1967. (Report on file in State Forester's Office, Sacramento, Calif.)

Nursery has an annual capacity of 8 million Douglas-fir seedlings; tl may soon rank Douglas-fir first in the number of trees planted California.

Gilden, *et al.*, (1968) have suggested species to plant in northe California from a schematic profile from the coast to the Nevac border (fig. 66). Species include those suitable for Christmas trees.

In recent years, two hybrids have been produced for plantings c National Forests. During the 1966-67 planting season, 14,0(knobcone x Monterey pine hybrids were shipped for planting. The knobcone x Monterey hybrids are planted at low elevations sin they are susceptible to freezing.

During the same year, over 6,000 Jeffrey x Jeffrey x Coult pine hybrids were shipped to various forests, to be planted where tl pine reproduction weevil *(Cylindrocopturus eatoni Buch.)* h seriously damaged Jeffrey and ponderosa pines. Resistance to th insect pest was demonstrated on small test plantings in the Shas brushfield (Shasta National Forest) and the Big Springs brushfie (Lassen National Forest), where weevil damage had been severe, ar in the McCloud Flats area (Shasta-Trinity National Forest), whe damage had been very light (Hall, 1957, 1959). Damage has bee lighter to the hybrid pines than to Jeffrey pine (table 43).

Six pine hybrids were planted on Stanislaus Experimental Fore to test their performance at high elevations. At the end of the fir 10 years, the hybrids with Jeffrey and ponderosa pines compare favorably with native Jeffrey pine and ponderosa pine (table 44 The western white x eastern white pine hybrid, planted at only o location, did very poorly. All of the knobcone x Monterey F hybrids were killed by low temperatures, which occasionally drc below -10° F. in winter and below 20 °F. in May and June.

The low survival of the conifers of ponderosa pine parentage i Plot 2 of the experimental forest (table 44) was caused mainly t porcupines. Damage to ponderosa pines was extensive, with 2 to 3 percent of the trees killed. Damage to the Jeffrey pine and Jeffrey Jeffrey x Coulter pines was very light even though 78 percent ha some injury. In Plot 1, only 7 of the 600 trees had porcupir damage--all ponderosa pines. No porcupine damage occurred on Pl 3.

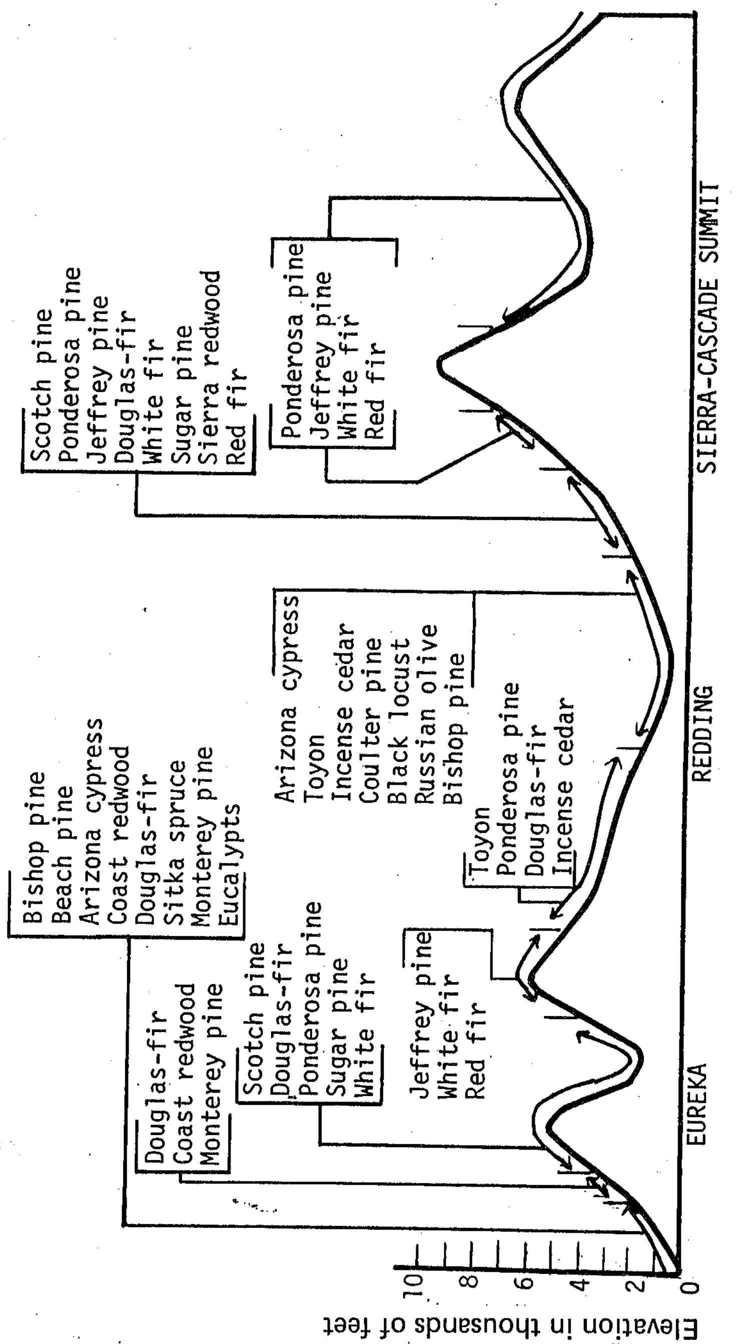

Figure 66. Species suitable for timber and Christmas tree reforestation in northern California, as suggested by Gilden, *et al.*, (1968).

Table 43. Total mortality caused by the pine reproduction weevil during an 8-year period, northern California.

Location	Mortality of Jeffrey pine	Mortality of Hybrid
	- - - - - - Percent	- - - - - - - - -
Mt. Shasta [1]	64.0	7.3
Big Springs [2]	23.7	4.2
Total	43.0	5.7

Source: Hall (1959).

[1] Based on 200 each.

[2] Based on 100 each.

Although the ponderosa pine hybrids survived and grew well, they all suffered more snowbend than the native ponderosa pines (Stark, 1964). The native Jeffrey pines suffered almost no damage, and the snow damage to the Jeffrey x Jeffrey x Coulter hybrid was rated as "slight" (less than 5° lean).

Unstocked areas within various timber types will generally dictate species requirements. In 1952, most of the unstocked land was in the Pine–Douglas-fir--fir timber type and the least in the true fir type. Pine is one of the best species to plant on at least 70 percent of the idle land. Douglas-fir is native to about 56 percent of the area and redwood to 12 percent. Sugar pine, white fir, red fir, and incense-cedar are suitable for planting on at least half of the area along with other minor species and tested hybrids.

Subregional Species Planting Guides

Since the early 1900's considerable experience has been accumulated which can serve as a basis for species preference for planting in different parts of California. In general, the best species to plant are those indigenous to the immediate vicinity. Species not native to the area should not be used to establish forest plantations until definitely proved to be superior to native stock. Management objectives and markets must be considered also. Therefore, these factors that determine the choice of species should be considered:

Table 44. Tenth-year survival, average height, and height of tallest tree in the hybrid test planting plots on Stanislaus Experimental Forest. [1]

Plot number and item	*Pinus ponderosa*	*P. jeffreyi*	*P. jeffreyi* x (*P. jeffreyi* x *P. coulteri*)	*P. ponderosa* x *P. ponderosa* var. *arizonica*	*P. ponderosa* x *P. engelmanni*	*P. ponderosa* x *P. ponderosa* var. *scopulorum*	*P.* X *attenuradiata* x X attenuradiata (F2)	*P. monticola* x *P. strobus*
Plot No. 1: 2/								
Survival (pct.)	69	93	86	87	80	84	0	-
Average height (ft.)	9.1	9.1	11.4	10.2	8.3	8.7	0	-
Height of tallest tree (ft.)	15.2	13.8	16.1	16.6	13.6	16.3	0	-
Plot No. 2: 3/								
Survival (pct.)	61	89	84	64	39	5	0	9
Average height (ft.)	6.3	9.9	9.6	7.1	6.4	4.2	0	3.1
Height of tallest tree (ft.)	10.7	15.6	13.2	11.3	9.8	5.9	0	5.8
Plot No. 3: 4/								
Survival (pct.)	60	49	49	54	48	46	-	-
Average height (ft.)	5.8	4.5	4.3	4.4	4.8	5.9	-	-
Height of tallest tree (ft.)	9.3	9.0	7.3	7.7	7.5	10.6	-	-

1/ Trees were planted in spring 1950, measured fall 1959. 100 trees of each planted at each location.

2/ Located on south slope at elevation of 5,350 feet on Holland Sandy Loam.

3/ Located on north slope at elevation of 5,200 feet on Holland Fine Sandy Loam.

4/ Located on north slope at elevation of 6,400 feet on Olympic Sandy Loam.

1. Closeness of correlation between the several site factors of the area and the silvical requirements of the species.

2. Suitability of the species for the particular objectives of management.

3. Adaptability of the species to management under the required silvicultural system.

4. The effect of the species on the particular site.

5. Cost of reproduction, rate of growth, and resistance to injury.

6. Expected future market requirements and the economic utilization of the species.

Eastside Sierra Nevada--Ponderosa and Jeffrey pines are the most abundant and valuable species in this subregion. Other native and important species are California red fir, white fir, Douglas-fir, and sugar pine. Lesser important species include incense-cedar, lodgepole pine, and western white pine.

Ponderosa and Jeffrey pines have been the most frequently planted, with lesser amounts of white fir and red fir. Ponderosa pine does best on moist sites with deep, well-drained soils. Jeffrey pine generally occurs at higher elevations than ponderosa pine; however, there is considerable intermingling of both species over a rather wide transition zone. Where the two species grow together, Jeffrey pine should be planted on the drier, more exposed sites. Neither of these two species should be planted in poorly drained areas. Jeffrey pine should be planted in areas with high porcupine populations as they are less damaged than ponderosa pines.

Sugar pine and Douglas-fir generally have been more successful when planted on northern slopes where moisture conditions are more favorable to their growth. Sugar pine seedlings have been severely damaged by freezing (Schubert, 1955, 1956). Areas which may be frost pockets should be avoided. Douglas-fir should not be planted in locations with poor air drainage. In addition to avoiding frost pockets, sugar pine should not be planted in areas where there is a risk of blister rust.

Very few true firs, lodgepole pines, or knobcone pines have been planted. White fir should be planted at the lower elevations and red fir at the higher ones.

Westside Sierra Nevada.–In terms of timber volume, white fir ranks first, followed in descending order by ponderosa and Jeffrey pine, California red fir, sugar pine, and Douglas-fir (U. S. Forest Service, 1954). Lesser important species include incense-cedar, Sierra redwood,lodgepole pine, knobcone pine, and western white pine.

As in the Eastside Sierra Nevada subregion, ponderosa and Jeffrey pines have been the most frequently planted, with lesser amounts of sugar pine, white fir, red fir, and Sierra redwood. Ponderosa pine should be planted on the moist sites with deep, well-drained soils. However, ponderosa pines should not be planted on wet lodgepole sites as their tolerance for excess moisture is low.

Jeffrey pine usually has had a higher survival rate than ponderosa pine, whenever the two were planted on the same area. Jeffrey pine has been rated as more drought-resistant than ponderosa pine (Stone, 1957), and therefore would be preferred to ponderosa pine on the drier sites where both are native. Jeffrey pine grows at higher elevations than ponderosa pine and has been recommended for planting in areas above 6,000 feet in northern California (Corson and Fowells, 1952). Ponderosa pine is preferred for planting below 4,000 feet. Both species can be planted in the transition zone between 4,000-6,000 feet.

Planting sugar pine and Douglas-fir should be restricted to the same kinds of areas described under the Eastside Sierra Nevada.

Survival of sugar pine and Douglas-fir has been quite low in the Sierra Nevada region; however, with high quality stock and good planting, high survival should be expected.

White fir and red fir have been planted only to a limited extent in the Westside Sierra Nevada subregion. White fir grows best on moist, cool sites (Sudworth, 1967); however, it is very susceptible to freezing (Schubert, 1955) so frost pockets should be avoided. It is less drought resistant than other species commonly found in the mixed conifer type (Stone, 1957). Red fir is similar to white fir in its site requirements, but generally grows at higher elevations. Best locations for planting both firs would be on north-facing slopes with deep, well-drained soils. First-year survival of 76 percent for white fir and 55 percent for red fir 2-0 stock was reported for plantings on the Latour State Forest (Adams, 1961).

Opportunites also exist for plantings of other coniferous species. Incense-cedar can be planted on west-facing slopes with deep, well-drained soils derived from a wide variety of parent rocks (Schubert, 1957a). Western white pine should do well on a great variety of soils over a broad range of climatic conditions at elevations from 5,000 to 7,500 feet (Wellner, 1962). Sierra redwood grows best on moist, deep, well-drained soils on a wide variety of slopes from low foothills to 7,500 feet elevation (Schubert, 1957b). Lodgepole pines are common on wet flats and poorly drained soils (Tackle, 1959); however, they will do well in better situations also. Knobcone pine also offers opportunities for planting on a wide variety of sites in this subregion.

Monterey pine and the knobcone x Monterey hybrid should be excellent for planting at elevations below 2,500 feet.

Coast Range Pine.–Most species that will do well in the Westside Sierra Nevada subregion can be successfully planted and managed in the Coast Range Pine subregion. Douglas-fir ranks first in terms of volume, with ponderosa and Jeffrey pines second, followed by white fir, sugar pine, and California red fir. Ponderosa and Jeffrey pines are preferable to other species on the more severe sites (Roy, 1957). Douglas-fir sugar pine, and the true firs will probably do better on the moister north slopes wherever the species are native than they would on the drier south slopes.

Redwood–Douglas-fir.–Douglas-fir and redwood are by far the most common species in this subregion (U. S. Forest Service, 1954). White fir ranks third, followed by sugar pine, ponderosa and Jeffrey pine, and California red fir. The best species to plant are Douglas-fir and redwood, with Dougals-fir better than redwood on the drier, more exposed ridges and southerly exposures (Roy, 1957).

Other native conifers, particularly Monterey pine, and suitable hybrids can be planted. Experience with Sitka spruce and Port-Orford cedar in Humboldt and Mendocino Counties indicates that these species can be planted on favorable sites with good success (Person, 1937); however, Port-Orford cedar is not a desirable tree for planting outside its natural range because it is highly susceptible to animal damage, cold injury, and *Phytophthora* root rot (James, 1958).

Southern California.--Ponderosa and Jeffrey pines make up most of the volume, with lesser amounts of white fir, sugar pine, and other conifers (U. S. Forest Service, 1954). Sischo (1958) indicated that at elevations about 4,000 feet, Coulter pine, bigcone Douglas-fir, deodar cedar, and knobcone pines are suitable for planting on the drier sites. On the more favorable sites sugar pine, incense-cedar, deodar cedar, Jeffrey pine, ponderosa pine, and white fir may be suitable for planting.

In general, survival of planted trees has been quite variable, usually low, depending on location, site conditions, quality of planting stock, and season planted; however, some survivals of over 50 percent have been reported for most species (Sischo, 1958). A small plantation of deodar cedars planted in 1930 at Tanbark Flat, Angeles National Forest, had 56 trees, of the original 60, living in 1960; the codominant trees averaging 62 feet tall (Lanner, 1961).

The Los Angeles County Department of Forester and Firewarden has had considerable success with Jeffrey and Coulter pines at the 5,000 foot elevation and above, where brush was completely removed and side hills terraced (fig. 67). [28] Survival has been better than 95 percent.

PLANTING METHODS

Before 1958 all commercial forest planting in California was done by hand tools. Then, as now, bare-root stock was used exclusively, except in small special planting projects in southern California, generally on recreation areas and elsewhere for Christmas tree production, in the Bay Area on land owned by local water companies, and in roadside planting, where potted stock was planted. Beginning in 1958, power tools, such as soil augers and planting machines, came into use in a number of commercial tree planting projects. Augers had been used for several years before then, for roadside plantings by the State Division of Highways.

[28] Van Wagner, R. M. Reforestation in Los Angeles County. (Personal communication, 1967).

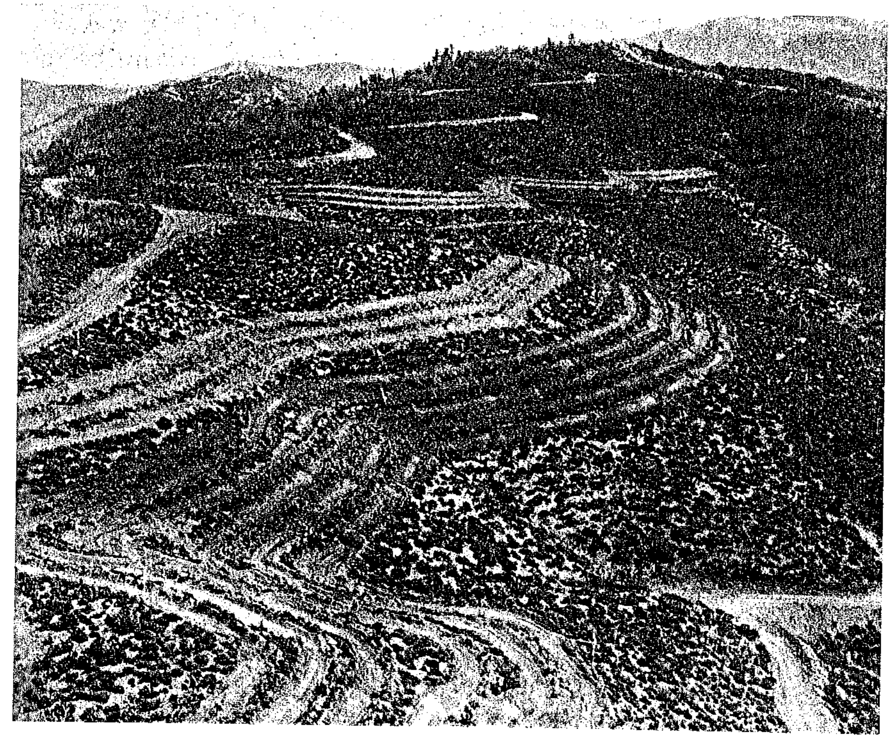

Figure 67. Terraced slopes in Los Angeles County. (R. M. Van Wagner, L. A. County Dept. of For. & Firewarden photo).

Hand Tools

In the Sierra Nevada subregions, much of the planting has been with a mattock--the Western Pattern Planting Tool--and the side-hole method (Corson and Fowells, 1952). The side-hole method was also used in the early days of the Redwood--Douglas-fir subregion.[29] Other tools and methods have been tried on different sites. We have found no report to show that the mattock and side-hole method are superior. Show (1930) reported on three methods of planting and found no difference in survival with the center-hole, side-hole, or single-slit method. In recent years, trees have been planted successfully with the bar method on light soils.

[29] Gibbs, Wm. H. Redwood reforestation by the Casper Lumber Co. 1931. Report on file with the California Division of Forestry.

Proper attention to details in planting is perhaps of greater importance than the method itself (Kummel, *et al.*, 1944). Wakeley (1954) indicated that depth of planting and proper closure of the planting hole had a much greater effect on survival than all the other "errors of planting" that have often been reported to cause mortality.

The proper procedures to follow are:

1. **Prepare spot.**–Clear away litter and dry soil from a spot 12 to 15 inches square. Omission of this step has been a common source of failure.

2. **Dig hole.**–Dig a hole with the back side of the hole at the upper edge of the cleared space. Make the hole not less than 10 inches deep and the rear wall of the hole vertical or nearly so. The hole must be deep enough to plant the trees without curling up the root at the base. Shallow holes are a common fault in planting.

3. **Remove ONE tree** from the planting bag or tray **after** the hole has been dug. If more than one seedling is removed at a time, the fine roots may dry out before the seedling can be planted. A seedling may be killed by exposure of less than 3 minutes. Keep trees in planting bag or tray covered and moist.

4. **Set tree**–Suspend the tree so roots are against the vertical rear wall of the hole. Hold the plant so it will be set at about the same depth or not more than an inch deeper than it grew in the nursery and spread the roots out fanwise. Wakeley (1954) found that shallow planting often resulted in plantation failures, whereas planting the tree an inch or so deeper than the original ground line on the seedling did not lower survival.

5. **Fill hole**–Holding the tree in position with one hand, fill half the hole with **moist** soil and pack with the other hand. Complete filling the hole with moist soil and pack this firmly in place. The hand is recommended for packing the soil in the lower half of the hole. The upper half of the hole can be packed with the feet or planting tool, but care must be taken to avoid damaging the tree. Filling the hole with moist soil and proper packing are essential if the plant is to survive the summer drought.

6. **Mulch**–Push loose dry soil and litter around the base of the tree to help reduce evaporation of soil moisture. Person (1937) reported that the practice of placing pieces of slash on the south side of the newly planted redwoods improved survival.

Selection of a favorable location for the planting spot often means the difference between success and failure. Favorable locations are on the north side of rocks, stumps, logs, and small clumps of brush. Unfavorable locations are on mounds or ridges of loose dry soil or ash, rocky areas with little soil, depressions, deep accumulations of trash, close to stumps or logs with loose bark, within 2-3 feet of living brush or closer than one-half the height of an established tree. Person (1937) attributed the success of some of the redwood planting to the practice in some areas of planting on the north side of pieces of large slash. When the area was later grazed only the trees planted in the locations close to the large slash escaped injury from trampling and browsing.

In the Redwood--Douglas-fir area, various tools may be used, depending on the soil (Roy, 1957). The planting bar is used by most contract planters and is suitable for most soils. The Western Pattern Planting Tool is also recommended as a good all-purpose implement for any type of soil. During the large planting program in Humboldt and Mendocino Counties, the slit-hole and side-hole methods were used with apparently equal success (Person, 1937). The slit or hole was made either with a small planting mattock or a narrow planting spade. General steps to follow in planting are the same as those described for the Sierra Nevada. Particular care should be taken to avoid planting close to large Douglas-fir cull logs with loose bark (Roy, 1955).

In southern California, shovels, planting bars, and mattocks are commonly used for planting. Tests were conducted with these three tools at two different areas to evaluate their effect on survival (Sischo, 1958). On the Cuyamaca plot, survival of the trees was the same for all three tools–90 percent with each. On the Riverside plot, survival was 90 percent with the shovel used to dig a round hole; 76 percent with the planting bar used to dig a slit-hole; and 67 percent with the mattock used with a side-hole method of planting. The planting rates were: 36 per hour with the shovel; 42 per hour with the planting bar; and 50 per hour with the mattock. On a man-hour–tree-survival basis--there was no significant difference in the three methods. However, with the planting bar or mattocks, more trees could be planted per acre to compensate for the fewer surviving trees per acre to obtain the same stocking at a slightly higher cost for planting stock. The only difference recommended for planting in southern California from the other two regions is the construction of a shallow basin around each tree to trap more water during the infrequent rains characteristic to that region (Sischo, 1958).

Powered Hole Diggers

A tractor-powered planting hole digger may offer some improvement in California over the conventional planting hole method, particularly where certain kinds of competing vegetation cover the planting site. For example, survival on the Groveland District of Stanislaus National Forest, was significantly higher for trees planted in holes prepared by a tractor powered digger (fig. 68)

Figure 68. This mechanical planting hole digger was designed by Roland Rotty and developed by the U. S. Forest Service San Dimas Equipment Development Center.

(Rotty, 1958b) than in holes dug by hand (Schubert and Roy, 1959). On one of the plots which was covered with mountain misery, first-year survival of bareroot stock was 75 percent for seedlings planted in the holes dug mechanically, compared to only 36 percent for seedlings planted in holes dug by the planting hoe. At the end of 3 years, the survival was 54 percent compared to 11 percent in favor of the powered hole digger (table 45). The average third-year survival for all plots was 85 percent for the powered digger compared to 51 percent for hand tool. Growth also was greater on trees planted in mechanically dug holes. Therefore, these trees would have an advantage over trees planted in hand-dug holes in gaining dominance over brush.

Table 45. Comparison of survival and growth of 1-0 ponderosa pine stock planted in holes dug with a tractor powered digger and a planting hoe near Groveland, Stanislaus National Forest.

Planting method and plot number 1/	Survival 2/		Average growth
	First-year	Third-year	Surviving trees
	- - - - - Percent - - - -		Inches
Mechanical hole digger:			
Plot 1	100	100	15.8
Plot 2	100	100	18.8
Plot 3	75	55	12.6
Average	92	85	16.3
Planting hoe:			
Plot 1	54	46	12.4
Plot 2	100	96	17.2
Plot 3	36	11	12.6
Average	63	51	15.5

1/ Plot 1 had a light cover of small brush. Plot 2 was bare mineral soil. Plot 3 had a heavy cover of mountain misery sprouts.

2/ Based on 28 trees per plot per planting method.

The tractor powered digger offers considerable promise for planting on gentle slopes or flat areas which are free of rocks and roots. Further development and field testing are required, however, to improve the design and operation before the machine can be recommended for general field use. At Groveland, for example, the production rate was only 480 trees per 8-hour day--no more than a man can dig and plant in the same period with a planting hoe. Furthermore, the model did not perform adequately on either steep slopes or areas with large rocks or roots.

Two types of hole diggers used more widely in California--the Little Beaver and Lucky J--are suitable for operation on a wide variety of planting area conditions (figs. 69 & 70). The Little Beaver post-hole auger and augers mounted on chain saw engines can be used practically any place where a man can walk. They can dig a 4-inch diameter hole to any depth needed for tree planting. On a good site, one man with an auger can dig enough holes for a 3- to 4-man planting crew. Up to 750 trees per man-day have been planted with the Little Beaver (Buck, 1961). The other type of auger is capable of like production. Survival comparisons have not been made

Figure 69. Hand planting in holes dug with the Little Beaver post-hole digger.

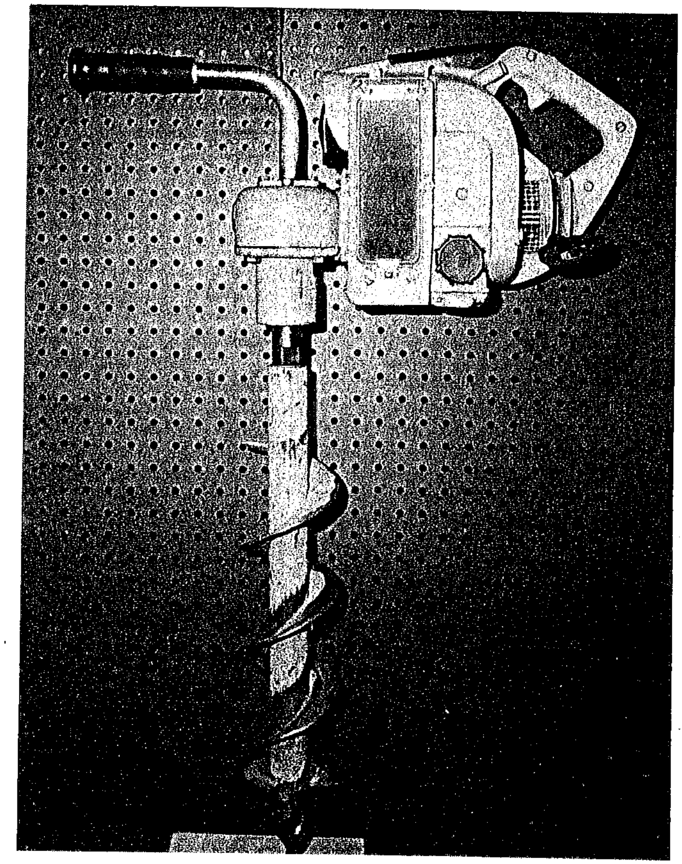

Figure 70. Lucky J tree planting auger.

statistically. However, in areas where the auger has been used, survival has been as high or higher than for hand-tool methods at about three times the rate of planting.

Several disadvantages limit the use of the augers. The main disadvantage is that they cannot operate on areas with many large rocks and roots. Other disadvantages are noxious fumes from the gas engine, frequent breakdowns of some models and operator fatigue. Frequent rotation of planting crew members overcomes the problem of fatigue. One hour at a time on the auger does not cause undue fatigue.

Planting Machines

The first planting machine in California was obtained by the Forest Service in 1949.[30] It was given a thorough workout on the Sheepwell Burn and the McCloud Flat Area on Shasta National Forest. On the Sheepwell Burn the performance was satisfactory, and the survival was as good or better than for hand planting, but on the McCloud Flat Area it was a total failure. Four more machines were purchased the following year; however, attempts to use the machines met with general difficulties, and little further use of them was made until 1958.

In 1951 the machines could be used on only a few areas of gentle slope without rocks, stumps, logs, and other debris. Changes were made in the design, to permit their use in areas which contained small rocks and light debris. Now, areas completely cleared by full site preparation treatment, are planted successfully by machine (figs. 71 & 72). From 3,000 to 4,000 trees can be planted per machine day; however, rates of 2,000 to 3,000 trees per day are more common in cleared areas containing windrowed brush. Second-year survival of machine-planted seedlings was consistently higher than for hand planted ones in a study of 10,000 trees at Mt. Shasta (Baron and Schubert, 1963).

A new machine for planting developed by the U. S. Forest Service Equipment Development Center in San Dimas was introduced in the California Region in 1963 (fig. 73) (U. S. Forest Service, 1967). It promises to overcome many disadvantages of earlier machines. The hitch was developed in the Intermountain Region of the Forest Service.

Machine planting requires the same strict adherence to detail as hand planting. Some of the more important requirements are:

1. **Prepared area**--Remove all herbaceous vegetation, litter, slash, and other debris. Vegetation will use moisture needed for tree growth and interfere with proper operation of the planting machine. Litter, slash, and other debris will also cause improper planting.

[30] Annual Planting Report, Division of Timber Management, U. S. Forest Service Region 5, 1950.

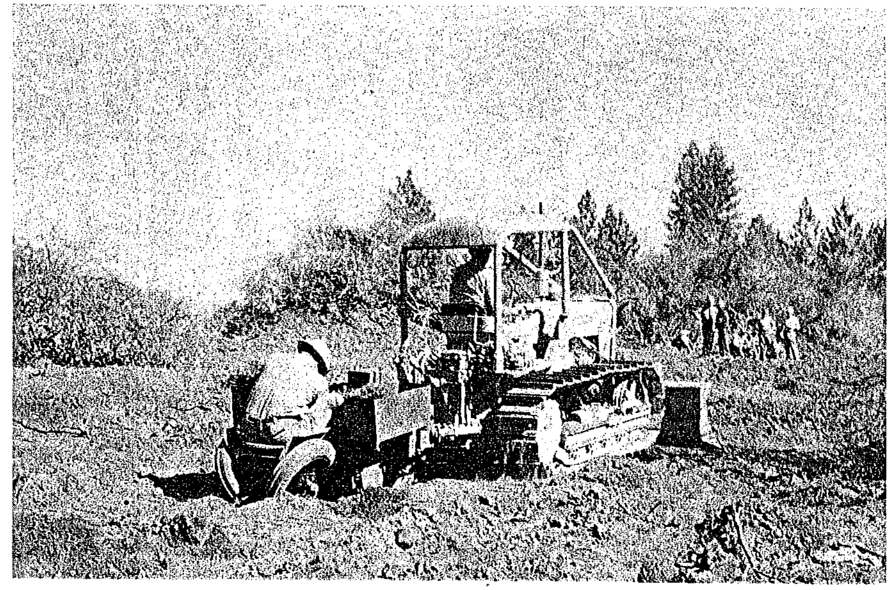

Figure 71. Demonstration planting with a planting machine on Eldorado National Forest, October 1959.

Figure 72. Machine-planted area on Shasta-Trinity National Forest after mechanical site preparation.

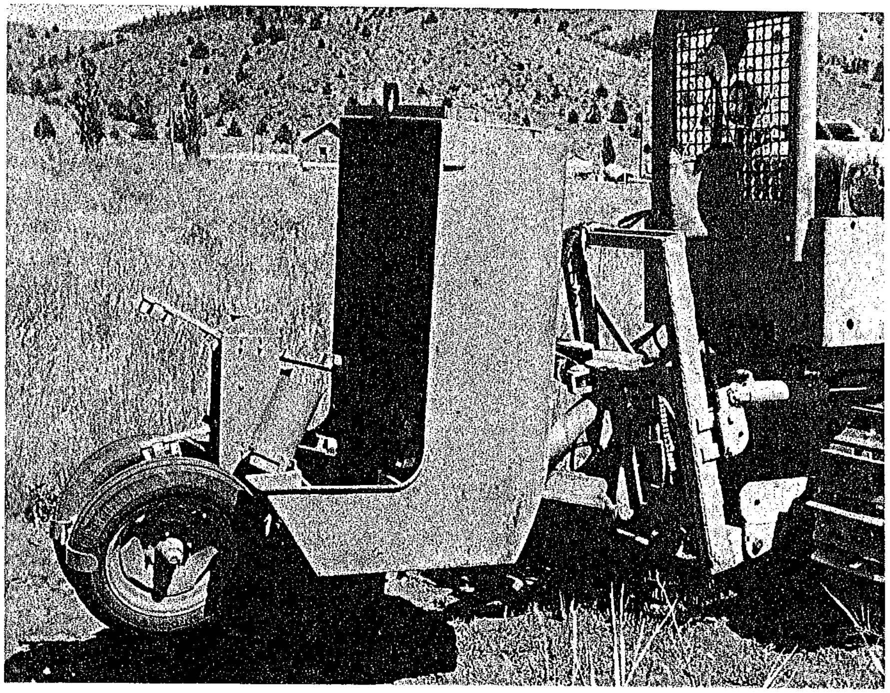

Figure 73. The U. S. Forest Service Equipment Development Center, San Dimas, has developed a planting machine that has several advantages over earlier models.

2. **Soil moisture**–Should be sufficiently high for tree requirement but not too high for proper operation of the planting machine.

3. **Weather**--Should be reasonably calm and humid. Planting should not be done during dry, windy weather.

4. **Planting depth**--Adjust coulter and trencher to make a deep trench so plants are set at proper depth with roots fully extended in a vertical plane.

5. **Pack soil**--Adjust packing wheels to firm soil so trees are set securely in soil and loss of soil moisture is minimized.

6. **Trees in hand**--If packing crate is mounted on the planter, remove no more than 10-15 trees from crate at any one time. When larger quantities of trees are taken, excessive root drying occurs which may kill the trees. Some planting machines have containers that will hold 100 to 200 trees to supply the operator.

7. **Trees in crate**--Insure that roots are kept moist at all times. Excessive exposure to sun and dry air will kill the trees.

8. **Spacing**--Adjust placement of trees in trench to give desired spacing. Avoid setting plants on large rocks, roots, other types of debris, or in shallow trench.

TREATMENTS TO IMPROVE INITIAL SURVIVAL

Many different factors affect the initial survival of field planted trees. In fact, most of the subjects already covered dealt with seedling survival either directly or indirectly. However, the one predominant cause of seedling mortality has been drought. Because of drought, trees must be of highest quality, competing vegetation must be removed, and greater care must be used in selection of the planting spot and in planting the tree. Constant improvements in nursery practices were necessary to produce a better tree; improvements were needed in storage and shipment to reduce possible deterioration in tree quality; and improvements were needed to find better ways to plant the trees so they would survive under drought conditions.

Other treatments have been tried in the field to minimize losses due to drought. Trees have been (1) provided with artificial shade, (2) coated with transpiration retardants, (3) watered the first year or two, (4) roots puddled with a slurry of mud, (5) mulched with various materials, (6) planted in fertilized planting spots, and (7) planted with roots encased in "sandwiches." Some of these supplementary treatments have improved survival, others have not, and some have reduced survival.

Shade

Shade has been found to be beneficial at times but not in every case. In studies on shade, Show (1924, 1930) reported that no shade was required for ponderosa pine, Jeffrey pine, and incense-cedar; whereas sugar pine, Douglas-fir, and white fir did best under half shade. He also indicated that the need for shade was greater on poor than on good sites. Gibbs[31] reported that shades placed on the south, east, and west sides of 1-0 redwood seedlings planted on a south slope was 70 percent as opposed to 22 percent for unshaded ones. Light shade was found to improve survival of newly planted trees of all species in the Southwest (Krauch, 1956; Pearson, 1950). However, heavy overhead shade of any kind was found to be harmful (Pearson, 1950). Pearson (1950) also found that ponderosa pine seedlings require less shade than Douglas-fir, white fir, or Englemann spruce. In a test of 2-0 ponderosa pine, Maguire (1955) reported that the survival of shaded trees was 80 percent compared to 20 percent for the unshaded.

In studies by the Calfiornia Division of Forestry, shade provided by shingles or box shook significantly improved survival of white fir and Douglas-fir (Adams, *et al.*, 1966). Results of shading studies with 1-0 and 2-0 Douglas-fir in two locations showed wide differences (table 46).

Table 46. First year survival of shaded and unshaded 1-0 and 2-0 Douglas-fir planted at the Ben Lomond and Davis Headquarters Nurseries, by survival count date.

	Ben Lomond Santa Cruz Co. (2700 ft.)		Davis Yolo Co. (35 ft.)			
	11-29-63		12-23-63		10-5-64	
	1-0 [1]	2-0 [1]	1-0 [1]	2-0 [1]	1-0 [1]	2-0 [1]
	Percent					
Shaded [2]	96	92	63	86	34	75
Unshaded [3]	34	55	2	25	0	3

Source: Adams, *et al.*, (1966)

1/ Differences in columns are statistically significant at the 1 percent level.
2/ Differences between the Davis shaded age classes are significant at the 1 percent level.
3/ Differences between the Ben Lomond unshaded age classes are significant at the 5 percent level and between age classes in the Davis 12-23-63 count at the 1 percent level.

31/ See footnote 29.

First-year survival of shaded Dougals-fir and redwood in Foundation for American Resources Management plantings near Ft. Bragg, Mendocino County, respectively ranged from 86 to 100 and 81 to 93 percent (Fritz and Rydelius, 1966). There was no difference between half and one-third shade. The results were from different studies covering a 4-year period.

Ruth (1956) indicated that Douglas-fir would withstand up to three-fourths shade without loss in survival; however, growth decreased with an increase in shade (table 47). He also reported that animal browsing was more severe on shaded than on unshaded trees (table 48). In the Redwood Region, Person (1937) found the opposite to be true in that often only the shaded trees escaped animal injury; however, the shaded trees may have been protected by the dead branches while the unshaded were out in the open.

Table 47. Effect of shade on height growth and survival of trees (Douglas-fir) not browsed, Henderson Creek Plantation.

	Third and fourth growing seasons since planting			Fifth growing season since planting		
Shade Class	Trees	Average annual height growth	Survival	Trees	Average annual height growth	Survival
	Number	Inch	Percent	Number	Inch	Percent
Not shaded	5	10.9	100	19	25.0	100
1/4 shaded	37	14.7	100	28	24.6	100
1/2 shaded	57	11.0	98	34	18.2	100
3/4 shaded	48	7.9	100	26	17.0	100
overtopped	14	4.4	68	25	8.0	89

Source: Ruth (1956).

Transpiration Retardants

Various chemicals have been tried in attempts to reduce water loss from plants through transpiration. Maguire (1952) reported good results with vinyl resin latex, but he had no untreated check plants to evaluate the improvement in survival if any occurred. Marshall and

Table 48. Percent of Douglas-fir trees browsed by shade classes.

	Percent browsed	
Shade class	1950	1952
Not shaded	44	6
1/4 shaded	45	8
1/2 shaded	46	17
3/4 shaded	48	30
Overtopped	61	48

Source: Ruth (1956).

Maki (1946) found that seedlings top-dipped in emulsions of lanolin or a commercial paraffin wax transpired 40 percent less moisture in 4 days than untreated plants. Mowat (1961) tried several rates of an emulsified wax on 2-0 ponderosa pine but the treatment did not increase survival. Tests with vinyl latex, emulsified wax, and lanolin at Stanislaus Experimental Forest showed a slight but not significant improvement in rate of survival (Fowells and Schubert, 1955). However, Thomas and Stadel (1948) reported a significantly higher survival of ponderosa pines treated with 1 part wax emulsion to 4 and 6 parts water than untreated seedlings.

Fritz and Rydelius (1966) coated Douglas-fir and redwood seedlings with a commercial preparation, Wilt-Pruf, at the time of planting in the North Coast area. There were no significant differences in survival between treated and untreated seedlings.

Watering Plantation Trees

Few trials have been conducted to determine the benefits derived from watering plantation trees in California. Costs would normally prohibit such practice except in special studies or where trees are planted for purposes other than timber production. At the Institute of Forest Genetics, experimental trees are regularly watered during the first few years after planting. Survival of these watered

trees has been 85-98 percent compared to 5-20 percent for trees on nearby unwatered plots (Weidman, 1943; Weidman and Barriman, 1944).

High survival also was obtained by watering trees during only the first year. In a study conducted by the Institute of Forest Genetics, one plot was located on a moderately dry site at the Institute, altitude at 2,700 feet elevation, and the other on a severely dry site at the Bassi Ranch near Lotus, El Dorado County, 950 feet elevation. Specially selected 2-year-old ponderosa pines with a 15-inch root system were planted on both well prepared sites. All trees were given 7 gallons of water immediately after planting. Thereafter, one-fourth received no further watering; one-fourth were watered on August 22; one-fourth were watered on August 22 and September 21; and one-fourth were watered in early June, June 17, July 12, August 22, and September 21. At each watering 7 gallons of water were poured into a basin around the tree.

Highest survival was reported for trees which had received water five times during the summer (table 49) (Weidman, 1943; Weidman and Berriman, 1944). Very little improvement in survival was attained by two waterings over the one watering, which at best was only about 10 percent higher than no watering. Perhaps both the one-and two-watering schedules would have shown higher survival had the trees been watered earlier in the summer–about July 1 instead of August 22.

In a study at Yosemite Mountain Ranch near Fish Camp, results were not as impressive as at Bassi and the Institute. First-year survival of watered 2-1 sugar pines was higher than the unwatered trees, but the reverse occurred with ponderosa pines (table 50). Unwatered seed spots in the same area had 2 percent higher stocking than those that were watered. The plants were watered in late July and August. Rainfall during June (1.30 inches) and July (0.93 inch) was high; however, it occurred in several storms, which reduced its effectiveness.

Benefits of watering 1-0 planted redwood seedlings at 2-week intervals between mid-July and fall rains were reported by Fritz and Rydelius (1966) (fig. 74). Watering improved survival about 13 percent at the end of the third growing season, in this study near Ft. Bragg.

Table 49. Effect of different watering treatments on survival of ponderosa pine.

Plot location	Year of survival count	Survival when watered different number of times during the first summer			
		0	1	2	5
		Percent			
Institute of Forest Genetics Placerville, California (2,700 ft. elevation) 1/	First	77	83	87	100
	Third	70	80	77	97
	Fourth	70	80	77	97
	Fifth	70	80	77	97
Bassi Ranch, Lotus, California (950 ft. elevation) 1/	First	33	40	43	83
	Second	23	30	33	83
	Third	23	30	33	83
	Fourth	23	30	33	83

Source: Weidman and Berriman (1944).
1/ Based on 120 trees planted at each location.

In southern California, watering during the dry season for 2 or 3 years after planting has been found helpful on many sites, and at low elevations may be essential for successful planting (Sischo, 1958). In plantings where watering is done, a basin is made around each tree. In a study of watering trees planted at forest fire stations in San Bernardino, Riverside, and San Diego counties, trees which were not watered always had lower survival rates than those that were watered (Sischo, 1958). The effect of watering on different schedules was found to vary for different soils (table 51). Bimonthly watering was found to be best for clay soils; weekly watering was best for loam soils.

Table 50. First year survival of transplants and seedlings planted a Yosemite Mountain Ranch.

Stock	Treatment	Basis	Stocking
		Number	Percent
2-1 sugar pine	Watered	96	45
	Not watered	96	25
1-1 ponderosa pine	Watered	96	56
	Not watered	96	69
Pine seed spots	Watered	416	84
	Not watered	416	86

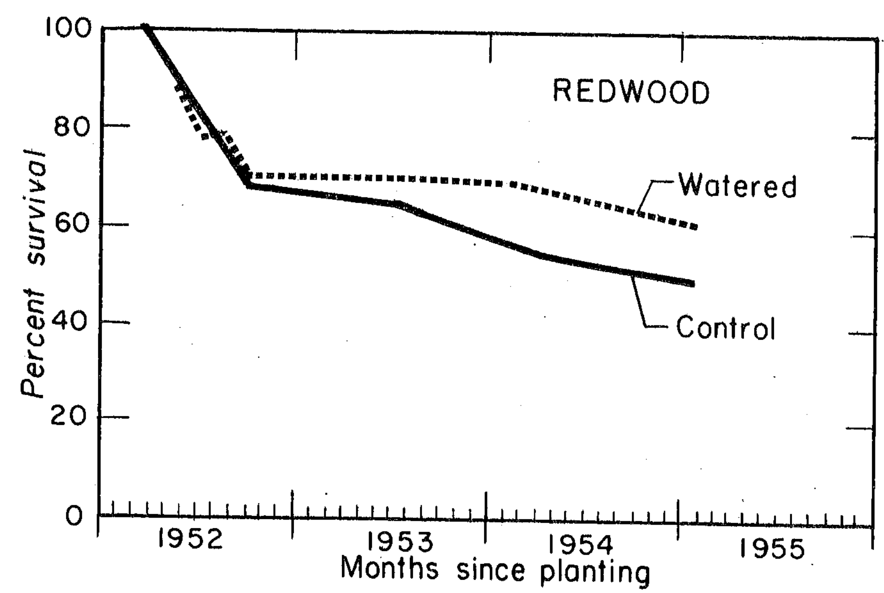

Figure 74. Progress of mortality in a watered and an unwatered redwood row. Watering was not commenced until July 19, 1962, after which, rate of mortality was slowed. Until then mortality followed the pattern of the unwatered (control) row. Note that the first growing season is the most critical. (From Fritz and Rydelius, 1960.)

Table 51. Effect of watering trees on difficult soils in test plots at forest fire stations.

Watering Schedule	Survival on . . . Clay	Loam	Sand-Loam	Average
	- - - - - - - -	Percent	- - - - - - - -	
Weekly	64	41	55	53
Bimonthly	73	26	51	50
Monthly	52	35	37	41
None	31	18	31	27
Average	55	30	43	43

Source: Sischo (1958)

Mud Puddled Roots

We know of only one test in California to evalute the effect of puddling roots on survival and growth of ponderosa pine seedlings (Schubert and Roy, 1959). The third-year survival of 1-0 ponderosa pines with roots puddled in a slurry of forest soil was 99 percent compared to 96 percent for trees with roots not puddled (fig. 75). The average height at the end of the third year was 20.6 inches for the root puddled trees and 19.6 inches for those not puddled (table 52). These slight differences in survival and growth were not statistically significant.

The advantages, if any, of puddling ponderosa pine seedling roots have not been adequately established to recommend it as standard practice. Wakely (1954) has indicated that puddling has increased survival significantly in only one minor instance in the Southeast and decreased it significantly in none. More recent studies in the southern states have shown that there are a number of advantages to using stock with puddled roots (Brenneman, 1965). Under severely dry conditions, as commonly occur in Calfornia, puddling may prove beneficial in some areas but should be adequately tested first.

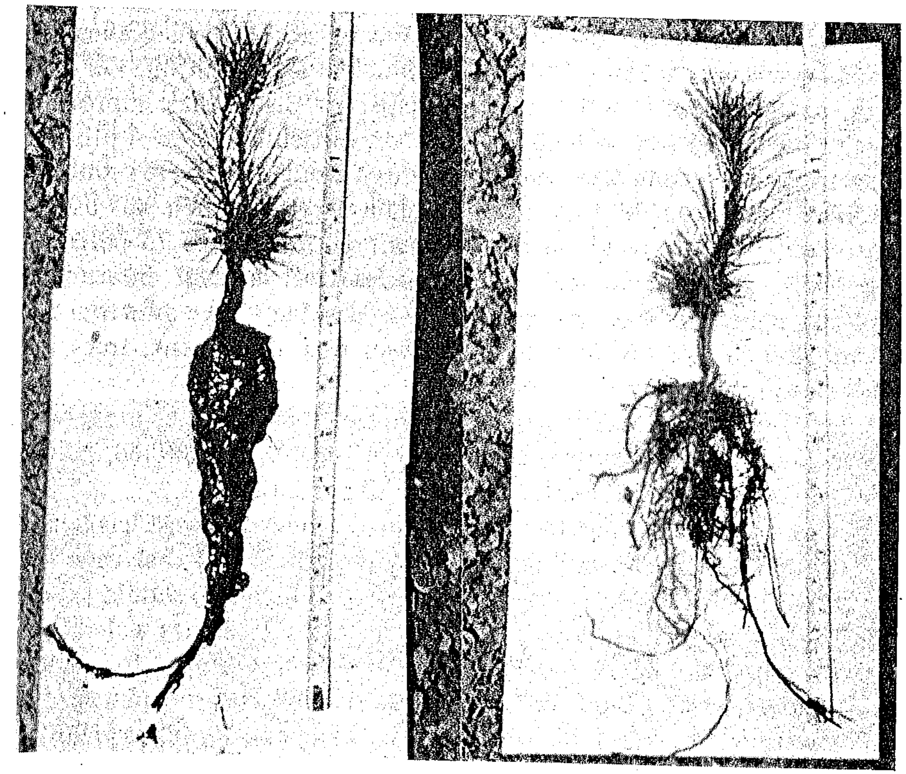

Figure 75. 1-0 ponderosa pine seedlings from the Oakdale Nursery: left, roots puddled in slurry of forest soil; right, roots not puddled.

Table 52. Third year survival and growth of root puddled 1-0 ponderosa pine seedlings.

Root treatment	Survival	Heights Average	Range
	Percent	- - - - - - Inch	- - - - - -
Puddled	99	20.6	10.2-34.8
Not puddled	96	19.6	8.6-36.2

Mulches

Determination of costs for each surviving seedling is necessary in deciding whether seedlings should be mulched after planting. On dry sites, mulching with some kind of paper or plastic has improved survival. Hunt (1963) calculated, that on difficult sites in southern Oregon, per surviving tree costs for planted Douglas-fir were reduced by 10 cents (from 33 to 23 cents) when a paper mulch was used. Untreated trees survived only 10 percent as opposed to 75 percent for those mulched with 27-inch square kraft asphalt interlined building paper. Size of squares had considerable effect on survival. When 18-inch squares were used, survival was 40 percent; trees in 27-inch squares survived 75 percent.

Ponderosa pine also benefited from mulching in other southern Oregon studies (Hermann, 1965). Survival was about doubled; from less than 40 percent to slightly less than 80 percent.

Survival in Christmas tree plantations in the Northwest has been best with black plastic mulch or black paper similar to that used in pineapple fields (Hawkes and Mason, 1962). Mulch size should be at least 24 inches square or a continuous strip 18 to 24 inches wide.

Sawdust, shredded redwood bark, redwood chips, redwood needle litter, straw, sand, roofing paper, clear plastic and pineapple paper were all listed as mulches in tests by Fritz and Rydelius (1966) near Ft. Bragg. Pineapple paper strips and 36-inch by 36-inch squares improved survival more than 15 percent over no mulch. Particle mulches on the other hand, did little to improve survival. Tests in northern Idaho showed that shredded bark mulch failed to conserve moisture, and 3-0 Douglas-fir seedlings survived only 33 percent (Loewenstein and Pitkin, 1961). Seedlings in cultivated plots, however, survived 85 percent. A form of mulch used successfully in Spain is three rocks placed as closely around each planted tree as possible (Rotty, 1958a). This method tried in northern Arizona (Heidmann, 1963b) improved survival significantly on unprepared areas (91 percent vs. 70 percent). This kind of mulch on fully prepared areas, however, was not necessary; respective survival was 95 percent and 94 percent.

Sandwich-Encased Roots

Inserting the seedling roots between two pieces of a stiff water-absorbent, fibrous material (fig. 76), was conceived by Roland Rotty of the Washington Offices, U. S. Forest Service. The hope was that the sandwich material after being soaked in water before use, would provide sufficient moisture for the seedlings until their roots developed sufficiently to insure survival during the rainless summer months.

Field tests in several locations with ponderosa pine and Douglas-fir seedlings have failed to show any improvement in survival

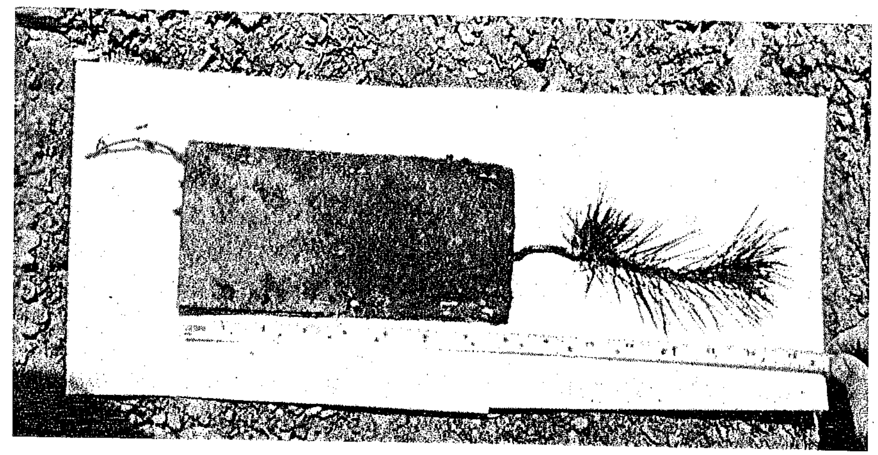

Figure 76. 1-0 ponderosa pine seedling encased in a sandwich, a stiff material with high absorptive capacity, designed by Roland Rotty, Chief, Branch of Tree Planting Cooperation, U. S. Forest Service, Washington, D. C.

(Schubert and Roy, 1959). In the trial at Groveland with 1-0 ponderosa pine, first-year survival was 77 percent for bare-root planting compared to 74 percent for sandwich planting. In the test on the Bogus Burn in northern California, the first-year survival of 1-1 ponderosa pine was 83 percent for bare-root and 53 for sandwich encased roots. The survival of sandwich planted 2-0 Douglas-fir in northwestern California was also lower than for bare-root stock–29 percent for sandwich and 32 percent for bare-root.

Fertilization at Time of Planting

Fertilizers have been used effectively in nurseries; however, their usefulness at the planting area have not been demonstrated. In a greenhouse study, Stone (1958) found that ponderosa pine responded to fertilizers when grown in an Aiken and a Dubakella soil. Vlamis, Schultz, and Biswell (1958) indicated that ponderosa pine seedlings grown in Holland and Salminas soils responded to nitrogen treatment, very little to phosphorus, and no significant response to potassium.

The fertilizer study at Groveland showed no significant differences in survival or growth of 1-0 ponderosa pine seedlings (table 53) (Schubert and Roy, 1959). Pelleted fertilizers, urea formaldehyde formulations, planted with Douglas-fir seedlings increased height growth 42 percent and stem diameter growth 24 percent in Crown Zellerbach studies in the Pacific Northwest (Austin and Strand, 1960). However, in a study at Gualala Redwoods, fertilizers placed in planting holes failed to show any significant difference in survival of 1-0 Douglas-fir seedlings (Adams, 1962). Blanford (1962) reported that fertilization has not been necessary to produce satisfactory growth in Christmas tree plantations.

Table 53. First-year survival of 1-0 ponderosa pine seedlings by fertilizer treatment and planting method; Groveland, 1958.

Fertilizer treatment	Mechanical digger		Planting hoe		
	Bare-root	Sandwich	Bare-root	Sandwich	All
	Percent				
Fertilized	90	26	67	12	49
Not fertilized	93	83	60	64	75
Average	92	54	63	38	62

Source: Schubert and Roy (1959).

Fertilizer pellets increased first year mortality of Douglas-fir and redwood seedlings in experimental plantings near Ft. Bragg (Fritz and Rydelius, 1966). A magnesium ammonium phosphate (8-40-0) placed in planting holes, however, improved second year survival considerably for Douglas-fir seedlings, but there was no appreciable difference between fertilized and unfertilized redwoods.

STOCKING DENSITY

Stand density affects stand development, growth rates, tree form, and quality of individual trees. Precisely, how much effect stand density has on these attributes has not been determined for California species or conditions. Criteria for stocking densities have been set more for control of site quality than for tree quality.

Spacing

The most common spacing used in California has been 8 feet by 8 feet for stocking of about 680 trees per acre. However, as many as 1,200 and as few as 300 trees have been planted at various times during the past 55 years.

During the major planting program in Humboldt and Mendocino Counties, spacing varied from 6 feet by 6 feet to 12 feet by 12 feet with an average close to 8 feet by 8 feet (Person, 1937). In the early plantings in stripped brushfields, trees were planted about 6 feet apart in single rows spaced at about 20 feet for approximately 350 trees per acre (Fowells and Dunning, 1948). Trees planted in wider stripped and block-cleared areas and on fresh burns were usually spaced at 8 feet by 8 feet.

Most recent plantings have generally been at a spacing of 10 feet by 10 feet (Buck, 1961). Some plantings have been at spacings 12 feet by 12 feet. Improved survival, as a result of better planting stock and site preparation, has made it possible to go to these wider spacings and still have adequate stocking.

Several factors should be considered in deciding the proper spacing. If the objective is to grow trees for timber production, a spacing of 10 feet by 10 feet or 12 feet by 12 feet is best (Eversole, 1955).[32] However, the area may be subject to severe erosion and, a spacing of 8 feet by 8 feet or even 6 feet by 6 feet might be advisable. Closer spacing is also recommended for plantations managed for Christmas tree production or where there is a possibility to sell thinnings as small sized products such as pulpwood, posts, or small poles. For Christmas tree crops a spacing of 4 feet by 7 feet or 6 feet by 7 feet to permit use of cultivators between rows is best. For pulpwood or other small sized products, a spacing of 6 feet by 6 feet or 8 feet by 8 feet may be advisable.

Acceptable Plantations

On National Forests in California, an acceptable plantation for timber production has been defined as one having at least 200 live, undamaged trees per acre at the end of 5 years (Zillgitt, 1958). In determining the stocking for an "acceptable plantation" both natural seedlings and planted trees should be included.

To have 200 trees per acre at the end of the fifth year would require a fifth-year survival of: (1) 17 percent for a 6-foot by 6-foot spacing, (2) 29 percent for an 8-foot by 8-foot spacing, (3) 46 percent for a 10-foot by 10-foot spacing, and (4) 66 percent for a 12-foot by 12-foot spacing. First- and second-year survival are now frequently over 80 percent, but no reliable survival values are available for the fifth year. A survival of 66 percent for the fifth year is not unreasonable to expect on better sites for high quality stock properly planted on well-prepared areas. Field personnel will have to determine adequate survival values for their particular areas and plant accordingly.

It must also be remembered that the 200 trees needed for "acceptable plantations" are minimum standards, so a higher stocking may be desirable. These minimum standards are subject to change when data become available, based on yield and quality of timber products from plantations of different stocking densities.

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[32] Buck, John M. Spacings for National Forest plantings, personal communication, 1968.

How to Measure Planting Success

An accurate estimate of the "success" of a planting is necessary. This estimate is used to determine effectiveness of the planting methods, the quality of the planting stock, and to help decide whether stocking is adequate or replanting is necessary.

Several methods to measure survival are used. Whatever the method, it is most important that site differences and differences among the planters are adequately represented in the sample. Such representation is aided by running the sample lines obliquely to both contours and planting lines.

One method is to stake immediately after planting all trees within 3.3 feet of each side of a sample line to provide a basis for future sampling--preferably after the first and fifth growing seasons. Sufficient lines should be run so the number of staked trees is 10 to 15 times the number of acres planted (Roy, 1957). After the first year, natural seedlings that stock spots where the planted trees died should be counted. Natural seedlings that grow within a 4.5-foot radius (about 64 square feet) of the stake are tallied as stocking the spot (Schubert, Heidmann, Larson, 1970). From these data, both survival of planted trees and percent of stocked spots can be computed.

Stocking Density and Yield

The subject of stocking density as it affects quality and yield is currently under investigation for ponderosa pine in the western United States (Myers, 1964). Although the study is not specifically designed for plantations, it does deal with even-aged stands of different stocking levels and size classes on different site quality lands. The results of these studies may provide better stocking guides for future plantations.

In the past, high stocking levels were advocated to gain and maintain control of the area with trees and to encourage early natural pruning. The need for close spacing to crowd out the brush at an early age has been partly, if not completely, eliminated by better initial site preparation and by the use of chemicals to release the trees from brush competition. Crowding of ponderosa pine has not proved to be an effective way to induce self-pruning (Hallin, 1959).

Grah (1960) indicated that an average stocking of less than 170 trees per acre during the first 20 years, results in butt logs with knots larger than 1.5 inches in diameter for Douglas-fir in Humboldt County. These logs would not qualify as peelers in the manufacture of plywood. He further stated that for Douglas-fir grown on an 80-year rotation:

1. Seventy percent of the butt logs will have knots larger than 2.5 inches in diameter and would be graded as No. 3 sawlogs.

2. With average stocking of less than 135 trees per acre during the first 20 years, none of the butt logs would grade higher than no. 3 sawlogs.

3. To minimize the degrading effect of knots on log quality, stands should be grown at densities greater than 170 trees per acre, or should be artifically pruned.

In his study on ponderosa pine in the Sierra Nevada, he found that average limb age and knot size increased with lower densities. At a density of 170 trees per acre, average limb age during the first 20 years was 9 for ponderosa pine compared to 15 or 20 for Douglas-fir. He also found that limbs live longer and reach larger average diameters on south and west than on north and east faces of trees. On the basis of these two studies, he felt that denser early stocking would probably have a greater effect on quality and value in Douglas-fir than in ponderosa pine stands.

In a study conducted near Carson, Washington, Reukema (1959) reported that Douglas-fir planted at a 10- by 10 and a 12- by 12-foot spacing reached merchantability sizes sooner than trees planted at closer spacings (table 54). For the 32-year-old stands, the cubic volume of the merchantable stand for trees grown at 10- by 10- foot and 12- by 12-foot spacings was double that for 6- by 6-foot spacing and almost four times that at the closest spacing tested. No information is available for volume production for different spacings in California.

Table 54. Live stand statistics for 32-year-old Douglas-fir under different spacing on Wind River Experimental Forest (acre basis).

	Stand 1.6 inches d.b.h. and over					Merchantable stand 1/	
		Average tree					
Spacing	Trees	d.b.h.	Height	Basal area	Cubic volume	Cubic volume	International ¼" volume
Feet	Number	In.	Ft.	Sq.ft.	Cu.ft.	Cu.ft.	Bd.ft.
4 by 4	1,728	4.1	38	159.8	3,147	703	309
5 by 5	1,411	4.2	36	136.9	2,559	722	137
6 by 6	1,007	4.9	42	132.5	2,761	1,301	1,141
8 by 8	570	5.8	48	106.4	2,418	1,614	2,817
10 by 10	401	7.5	56	125.0	3,207	2,676	9,277
12 by 12	283	8.4	58	110.0	2,892	2,508	10,143
Natural	571	5.4	39	84.9	1,780	1,235	3,776

Source: Reukema (1959).

1/Merchantable stand includes cubic-foot volume of trees 5.6 inches d.b.h. and over to a 4-inch top, and board-foot volume of trees 7.6 inches d.b.h. and over to a 6-inch top.

PLANTATION CARE

Plantations require certain care and maintenance from the time the trees are planted until they are harvested. This care and maintenance includes recognition of injuries and their control, replacement planting, release from brush, fertilizing and cultivation, and thinning and pruning.

Plantation Injuries and Their Control

Mortality may be caused by physical factors such as fire, climate, and soil or by biotic factors such as insects, diseases, animals, or other vegetation. Some of these causes of mortality can be corrected by removal of the causal agent or host trees. Some losses can be corrected only by avoidance of situations conducive to mortality, or by certain protective measures to reduce losses during the life of the plantation. Prompt detection of injuries and corrective action are needed before losses become serious.

Fire–Uncontrolled fires are one of the major causes of mortality in established plantations. Although fire may be just as destructive in natural stands as in plantations, the extra cost of artificial regeneration makes it particularly important to provide fire protection.

A fire protection system should be a part of the planting plan (Wilson, 1967). Protective measures to lessen the chances for disastrous fires in plantations should be an integral part of the overall fire protection effort. Figures 77 and 78 are schematic diagrams of protective road systems that suggest ways to protect a plantation. Roads should be maintained throughout the life of the plantation. Special hazard reduction measures, such as chemical treatment of the grass and brush, pruning the lower dead branches, and light control burns, may be advisable for seed production areas or research plots, but may not be advisable or possible for large plantations.

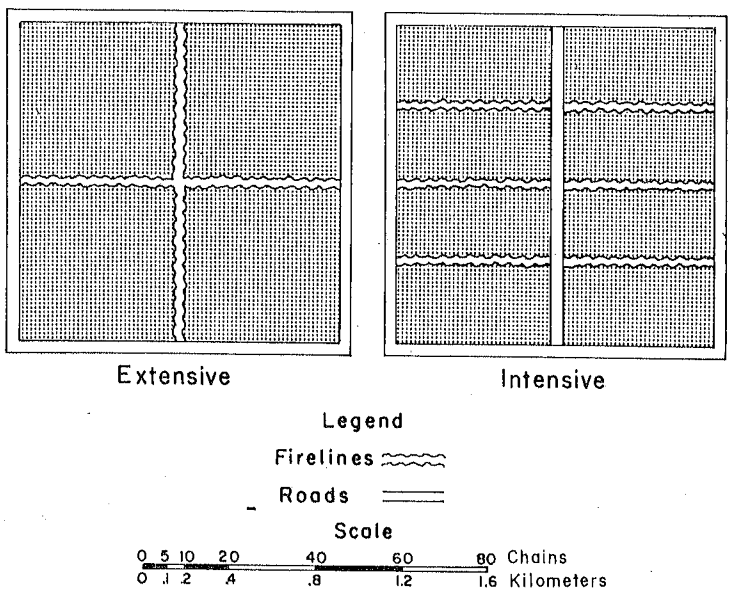

Figure 77. Firebreak system recommended by Robert W. Cooper, Forest Fire Laboratory, U. S. Forest Service, Macon, Ga: includes minimum standards for roads and permanent firelines in slash and loblolly pine plantations.

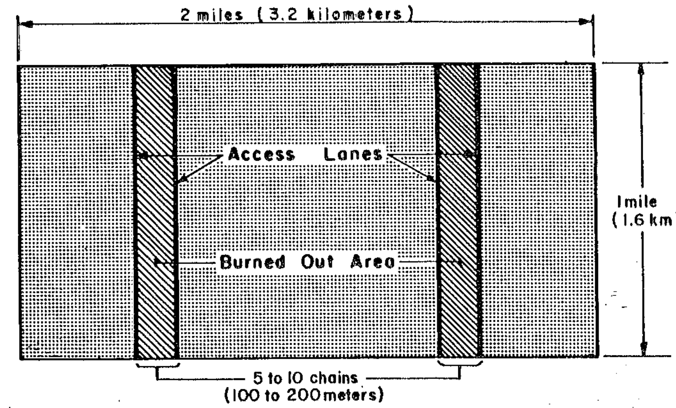

Figure 78. Proposed fire-safe design for large plantations in the southeastern United States, by Robert W. Cooper, Forest Fire Laboratory, U. S. Forest Service, Macon, Georgia.

The need for protection may vary by species. For example, Person (1937) found that pine and fir plantations sustained heavier losses from fire than redwood. In stands of young redwood, although the loss may be extremely high, resprouting can reforest the area. The Comptche Mendocino County Fire, in September 1931 destroyed 90 percent of the Douglas-firs and other nonsprouting species over several thousand acres of plantations established during the 1920's. Only 10 to 20 percent of the redwoods were completely killed, and an estimated 88 percent of the top-killed trees resprouted.

Climate–Forest trees may be injured or killed by freezing, frost heaving, heat, drought, wind, glaze, and snow. Some of these factors have caused very little known loss, whereas others have been indicated as causes of serious losses. Frost heaving is normally a factor only with newly planted trees. Damage by the others may occur at any time during the life of the tree. Generally, little can be done to prevent some of the losses due to climate, other than to avoid situations known to aggravate the danger.

Frost damage is most likely to occur on young seedlings than older trees, on planted seedlings than on natural seedlings, and on young fir seedlings than on pine seedlings. On Stanislaus

Experimental Forest, late spring freezes during 5 years of an 8-year observation period, damaged white fir seedlings more than sugar pines and ponderosa pines of the same age class on the same area (Schubert, 1956). Older native pines showed no freezing damage during this period, whereas, some twig kill was noted on young white fir saplings and poles.

Young sugar pines were found to be more susceptible to freezing than ponderosa pines and Jeffrey pines on Stanislaus Experimental Forest, with Jeffrey pines the least affected by sudden drops in temperature after growth had started (Schubert, 1955). Hallin (1957a) also reported that Jeffrey pines were more resistant to freezing temperatures than ponderosa pine on Blacks Mountain Experimental Forest. Wagener (1949) reported top kill of Coulter pines and bigcone Douglas-firs in southern California.

Introduced species and nonlocal planting stock of native species may be more susceptible to freezing injury than planting stock of a local seed source. Squillace and Silen (1962) reported greater frost damage on ponderosa pines from Eldorado County seed source, than on local ponderosa pines planted in the Oregon-Washington provenance studies. The knobcone-Monterey pine F_2 hybrids planted on Stanislaus Experimental Forest were all killed by freezing, whereas, native pine planting stock was undamaged (Stark, 1964).

The F_1 hybrids from knobcone pine mother trees in El Dorado County were more frost and snow resistant than F_2's from the Institute of Forest Genetic plantation, when seedlings from both sources were planted on American Forest Products Corporation land at 4,000 and 5,000 foot elevations.[33]

Several control measures may be used to reduce freezing losses. The best measure is to avoid planting in known or suspected frost pockets. If areas with poor air drainage must be planted, select species that have been proved frost hardy. Small openings surrounded by dense tall trees or depressions are likely to be locations that trap cold air. Artificial shade may protect young seedlings from freezing temperatures.

33/ Adams, Ronald S. Minutes of the State Forester's Reforestation Advisory Committee meeting, Martel, California, June, 1967.

Frost-heaving is most likely to be a source of mortality for fall planting at medium to high elevations on south-facing slopes in all parts of California, except along the coast. On these south slopes, alternate soil freezing and thawing may occur as long as the ground remains free of snow from early fall to late spring. Frost-heaving is more pronounced on heavy clay soils than on sandy ones and is restricted almost entirely to newly planted trees.

Just how much mortality is caused by frost-heaving is unknown, though the lower survival of fall-planted trees has been attributed to frost-heaving. In fact, frost-heaving has been reported to be one of the main disadvantages of fall planting at higher elevations in northeastern California (Show, 1930), in southern California (Sischo, 1958), and in Humboldt and Mendocino Counties (Person, 1937; Schofield, 1929). However, for the north coast area in general, Roy (1957) stated that frost damage to late fall-planted trees should be rare, but that it is likely to be a factor further inland.

The best solution to the frost-heaving problem seems to be to plant south-facing slopes late in fall or early spring. For special plantings where extra costs can be justified, artifical shade may be used to reduce the amount of frost-heaving.

Heat has been reported to be a cause of seedling mortality in California (Baker, 1929; Maguire, 1955), but there has been no positive evidence that heat has killed many trees in plantations. Baker (1929) found that young seedlings less than 3 months old could be killed when heat at 130°F. to 143°F. was applied directly to the tender stems before the protective bark had formed. Roeser (1932) reported that soil temperatures of 122-125°F. would kill newly germinated seedlings. Since generally only 1- or 2-year-old seedlings are planted, excessive heat may be a problem only in direct seeding or in nurseries.

The evidence to date seems to indicate that heat alone is not a serious factor in field planting. On Stanislaus Experimental Forest, heat killed less than 1 percent of the new seedlings. In his analysis of seedling mortality in a seeding experiment at Burgess Springs (Lassen National Forest), Lloyd (1937) indicated that heat caused only 0.4 percent of the mortality. Stein (1957) reported that none of the mortality of sugar pine seedlings was caused by heat in a direct seeding test in Oregon. Therefore, no particular control measures are needed to reduce seedling mortality caused by heat alone.

Drought has been reported to be the major cause of seedling mortality (Baker, 1955; Dunning and Kirk, 1939; Fowells, 1953a; Fowells and Dunning, 1948; Fowells and Kirk, 1945; Show, 1924, 1930). Death by drought occurs when the plant loses water faster through the needles than can be absorbed through the roots. Drought occurs not only when there has been too little rain to maintain the soil moisture level above the permanent wilting point, but also when roots cannot take in enough water from an adequate supply in the soil. If the plant dies when the soil moisture is in a liquid or vapor state, it is known as *physiological drought;* if it does so when the soil moisture is frozen, it is known as *winter kill.* Therefore, the plant may die from "drought" at any time during the year.

Newly planted trees are more likely to be killed by drought than trees which were planted one or more years ago. Plants with a low root-regenerating potential are killed by drought more easily than seedlings with a high root-regenerating potential. Also, trees are more likely to be killed on hot, dry, windy days than on cool, moist, calm days. Strong winds during the planting season in southern California (Sischo, 1958) and in the north coast area (Person, 1937) have made planting inadvisable at times.

Drought losses can be reduced in several ways: (1) defer planting in the fall until the soil is wet down to at least 12 inches, (2) plant only seedlings with a high root-regenerating potential, (3) stop planting in spring when the surface 2 inches of soil appears dry, (4) do not plant on hot, dry, windy days, and (5) fill the planting hole properly with moist soil.

Snow may cause some damage to young trees; however, the lack of snow may be more harmful than too much of it. Winter kill at medium to high elevations occurs generally only when there is no protective covering of snow. Heavy, wet snow has been reported to damage sapling and pole-size trees of many species (Hallin, 1957b; Maul, 1958; McCullock, 1943; Pearson, 1950). However, unless the stem is broken or too severely bent, most young trees will recover and show little or no damage by midsummer. A heavy, wet snow during spring 1959 severely bent many young sugar, ponderosa, and Jeffrey pines on Stanislaus Experimental Forest, but when the trees were reexamined in September, almost all had recovered completely (fig. 79).

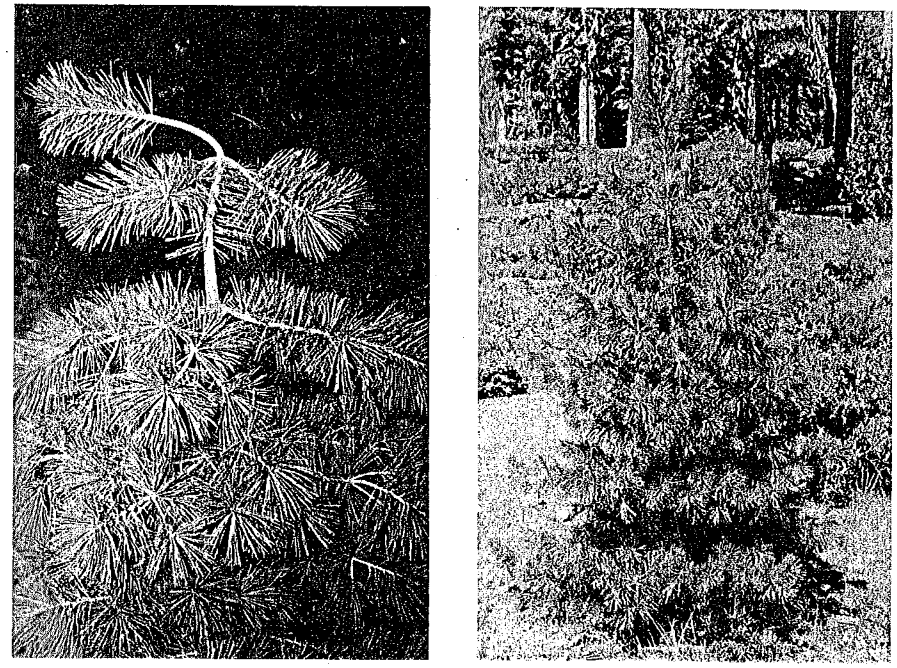

Figure 79. Conifers readily recovered from some snow damage on Stanislaus Experimental Forest. *Left,* snow bent terminal on young sugar pine, June 1959; *right,* same tree the following September.

Soil–In general, soil is not a cause of seedling mortality except under conditions of poor drainage, excessive erosion, silting, or certain parent material. Low soil fertility of forest soils has not been reported as a cause of seedling mortality, but it may be a cause of poor growth. If plantings are made on poor sites, it may be necessary to fertilize. Gessel and Walker (1956) demonstrated that application of nitrogen fertilizer would double the growth of young Douglas-fir on poor sites in Washington.

Excessive erosion may be a problem in areas with steep slopes, that may be controlled by contour trenching or by leaving logging slash in place. Silting is generally only a problem when trees are planted in small depressions or basins. The problem of silting is corrected by avoiding depressions and planting only in shallow basins, where basins are required to improve survival.

Areas with excess moisture such as wet meadows should not be planted. Similarly, areas with a high water table in lodgepole pine stands should not be planted with conifers other than lodgepole.

Show (1930) reported that almost all attempts to grow sugar pine in the lava-ash soils near McCloud resulted in complete failures. However, ponderosa and Jeffrey pines have been planted successfully in these soils. Serpentine soils generally should be avoided as planting sites.

Insects–Many different species of insects have been reported to attack and kill young trees in California (Callaham, 1960; Clements, 1953; Hall, 1957, 1959; Isaac and Dimock, 1958; Keen, 1952; McKenzie, 1941; Miller, 1950; Stevens, 1959; Struble, 1955, 1957). The pine reproduction weevil *(Cylindrocopturus eatoni* Buch.) has been the most destructive insect on low vigor trees in ponderosa and Jeffrey pine plantations. In the Big Springs plantations, 90 percent of the 5- and 6-year-old trees were killed (U. S. Forest Service, 1940). Recurrent weevil attacks have killed up to 75 percent of the trees in the Mt. Shasta and Burney Mountain reforestation projects (Fowells and Dunning, 1948). Vigorous ponderosa and Jeffrey pines are seldom severely damaged by the pine reproduction weevil.

Callaham (1960) reported that individual trees vary considerably in their susceptibility which they transmit to their progenies. The backcross hybrid of Jeffrey and Coulter pines *(Pinus jeffreyi* x *P. jeffreyi* x *P. coulteri)* has shown considerable resistance to the weevil (Hall, 1959; Miller, 1950). This hybrid planted on three different areas where weevil damage has been high showed only 4 to 7 percent mortality compared to 24 to 64 percent for Jeffrey pine (Hall, 1959).

Other insects which have caused considerable damage to young pines are: mountain pine beetle *(Dendroctonus monticolae* Hopk.) on sugar pine (Clements, 1953; Keen, 1952) and lodgepole pine (Keen, 1952); California five-spined engraver *(Ips confusus* Lee) on all pines (Keen, 1952; Struble, 1955); pine needle-sheath miner *(Zelleria haimbachi* Busck) on most pines and hybrids except lodgepole pine (Stevens, 1959, 1961); lodgepole needle miner *(Recurvaria milleri* Busck) on young lodgepole pines (Struble, 1958); white fir sawfly *(Neodiprion abietis* Ross) on white fir (Struble, 1957) and the pine sawfly *(Neodiprion* spp.) on ponderosa and Jeffrey pines (California Forest Pest Control Action Council, 1958); Douglas-fir beetle *(Dendroctonus pseudotsugae* Hopk.) on Douglas-fir in California (Keen, 1952) and in the Pacific Northwest (Isaac and Dimock, 1958); bird's eye pine midge *(Retinodiplosis inopsis* O.S.) on ponderosa and Jeffrey pines (California Forest Pest Control Action Council, 1958); Yosemite bark weevil *(Pissodes yosemite* Hopk.) and pine tip moth *(Rhyacionia zozana* Kearf.) on ponderosa pine reproduction (California Forest Pest Control Action Council, 1959).

Various control measures have been recommended, from removal of infested trees to aerial treatment with various chemicals. Insect damage on private lands should be reported to the California Division of Forestry, Sacramento, California, and on National Forests to the Division of Timber Management, California Region, San Francisco, for advice or assistance in proper control measures.

Diseases–Several diseases have caused severe mortality of young trees (Bega and Smith, 1960; Childs, 1955; Kimmey and Mielke, 1959; Lightle, 1954, 1955; Meinecke, 1928; Miller, et al., 1959; Offord, 1961; Vaux 1948; Wagener, 1958; Wagener and Cave, 1946). Losses in young stands were caused primarily by four classes of disease pests: mistletoes, stem rusts, root rots, and foliage diseases.

Mistletoe has been a serious pest on conifers throughout the State. True mistletoe *(Phoradendron pauciflorum)* occurs frequently on white fir in the southern Sierra Nevada and southern California (Offord, 1961). Dwarfmistletoe *(Arceuthobium campylopodum)* has a statewide distribution where it occurs on many conifers (Kimmey and Mielke, 1959; Offord, 1961). On the hard pines, it is a more serious pest on poor sites on the eastside Sierra Nevada and southern California than on the good sites in the westside Sierra Nevada. On red and white firs it may be found on all kinds of sites, whereas on sugar pine, dwarfmistletoe is spotty in occurrence and does the most damage on the best sites.

The best control measure is to remove all mistletoe infected trees within at least 66 feet of the plantation. Infected branches can be pruned off plantation trees, if the infection is at least 6 inches from the main stem. Trees with infections on or within 6 inches of the main stem should be cut.

Stem rusts are particularly damaging to young stands. The white pine blister rust *(Cronartium ribicola)* has been especially destructive to sugar pine (Meinecke, 1928; Miller, Kimmey, and Fowler, 1959;

Offord, 1961; Vaux, 1948). It also has damaged western white pine, whitebark pine, and limber pine. Commandra rust *(C. commandrae)* and western gall rust *(Peridermium harknessii)* have been responsible for understocking in seedling, sapling, and pole stands in California (Meinecke, 1928; Offord, 1961).

White pine blister rust has been controlled by eradication of the alternate host *(Ribes),* pruning if the canker occurs only on the branches (otherwise the entire tree must be destroyed) and by use of fire in site preparation (Miller, Kimmey, and Fowler, 1959). Hayes and Stein (1957) indicated that in Oregon, sugar pine crop trees could be increased to 81 percent of the probable future crop trees by removing cankered branches and by releasing promising sugar pines from other larger trees. Pruning was done at a cost of $0.50 per tree and consistently cleared 95 or more percent of the pruned trees of visible infection. The other stem rusts can be controlled by pruning infected branches or complete removal of trees for stem infections.

A number of antifungal antibiotics and conventional fungicides have been tested to control blister rust on sugar pine (Quick, 1964, 1967a,b; USFS, 1964). Several conventional fungicides were found to be as effective as acti-dione and phytoactin for direct control of blister rust, but specific treatments for control have not been determined for field application.

The most destructive root disease in California has been *Fomes annosus* (Offord, 1961; Wagener and Cave, 1946). Highest mortality has occurred in southern California and in the eastside Sierra Nevada and has been found in all parts of California. Heaviest losses have occurred in ponderosa and Jeffrey pines; however, sugar pine, Coulter pine, red fir, and white fir have been killed (Wagener and Cave, 1946). Another root rot [*Armillaria mellea* (Vahl) Fr.] has caused mortality in Jeffrey pine and sugar pine (Bega and Smith, 1960; Offord, 1961). In the Pacific Northwest a root disease *(Poria weirii)* is currently recognized as the most serious fungus disease of Douglas-fir (Childs, 1955). This root rot attacks trees of all age classes and causes progressive mortality in young-growth stands. *Phytophthora* root rot has been found on a number of species in nurseries (Bega and Smith, 1960) and reported to have severely damaged Port-Orford cedar plantations in California (James, 1958).

Best control of root rot consists of fumigating nursery soils to minimize the probability of spreading the diseases to plantations throughout the State. Areas of known or suspected infection in the field should not be planted.

Elytroderma needle blight (*Elytroderma deformans* Weir) has caused serious defoliation of ponderosa and Jeffrey pines (Lightle, 1954, 1955; Offord, 1961). It has been found most commonly in young reproduction under 20 feet high. Red band needle blight *(Scirrhia pini)* has recently flared up in north coast Monterey pine plantations, and threatens complete mortality in some (California Forest Pest Control Action Council, 1967). Trees with foliage disease must be eradicated and burned to control spread.

Small animals–Several species of small animals cause serious damage to young trees. Some have almost completely ruined or destroyed young plantations, whereas others have caused little or no serious damage. Rabbits, wood rats, pocket gophers, and porcupines have caused extensive damage to young trees in different parts of the State. Squirrels, though less destructive, may be a serious problem in some locations.

Rabbits were particularly destructive in the early brushfield plantations in northeastern California (Dunning and Kirk, 1939; Fowells and Dunning, 1948; Kirk, 1941, 1947; Show, 1930; Tillotson, 1917). In the plantations established on National Forests between 1930 and 1947, rabbits damaged up to 75 percent of the trees (Fowells and Dunning, 1948). In the Burney Spring brushfield rabbit damage was most severe on the narrow stripped plots and least on the burned-stripped ones (Kirk, 1947). Rabbits have also been reported to be major cause of injury to plantations in southern California (Sischo, 1958).

Rabbit damage can be reduced by complete site preparation and by repellents. Complete site preparation reduces their food supply and protective cover. Two repellents, TMTD and ZAC,[34] have been reported to be effective against rabbits (Besser, 1957; Walters and Soos, 1961).

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[34] TMTD–active ingredients, tetramethylthiuram-disulfide.
ZAC–active ingredient, zinc dimethyl dithio carbamate cyclohexylamine complex.

Squirrels and pocket gophers have damaged planted trees in the Blacks Mountain area. Squirrel damage has been mostly twig cutting, but they also girdle small seedlings. Gophers damage roots but may also do considerable damage to the tops. In 1960, gophers were credited with two plantation failures that had been previously attributed to other causes (California Forest Pest Control Action Council, 1962).

Gopher damage can be reduced by complete site preparation or poison bait. Normally poison bait is not required except in special areas where damage has been severe. A tractor-drawn mechanical poison bait applicator has been developed by University of California, Davis (Kepner, *et al.*, 1962; Kepner, Cummings and Howard, 1964; Marsh and Cummings, 1968). This has possibilities in plantations where the soil is not rocky nor slopes too steep for equipment operation.

Wood rats were reported to have been one of the most serious limiting factors in the establishment of plantations in Mendocino County during the decade 1923 to 1932 (Person, 1937). Up to 50 percent of the redwoods were destroyed by rodents, principally wood rats. The greatest amount of damage occurred to seedlings planted in the older burned or cutover areas. The least occurred in plantations on areas planted within 2 to 3 years after removal of the timber. In 1958, wood rats were reported stripping bark and girdling the tops of young redwoods in Mendocino County (California Forest Pest Control Action Council, 1961).

Damage by wood rats can be reduced by complete site preparation and by destruction of their nesting areas.

Porcupines have damaged pines throughout the Sierra and Coast Range Pine subregions (Averell, 1959). On Stanislaus Experimental Forest, porcupines girdled or partially girdled three-fourths of the ponderosa and Jeffrey pines in one plantation. No Jeffrey pines were seriously damaged, whereas up to 37 percent of the ponderosa pines were killed. At Blacks Mountain Experimental Forest, porcupines have done extensive damage in sapling and pole stands of Jeffrey pine (Hallin, 1957a).

Porcupines have been killed by shooting and poisoning. However, more effective control methods are needed.

Mountain beaver, commonly called "boomer," is reported to cause considerable damage in localized areas (California Forest Pest Control Action Council, 1967). It damages terminal shoots, clips lateral branches, and strips bark of 1- to 20-year old conifers. Most serious damage has occurred in Del Norte County. A toxic foam offers possibilities for control.

Large game animals--Almost all the damage to reproduction by big game animals is caused by deer. However, some browsing by elk has been reported (California Forest Pest Control Action Council, 1962). Merrill (1953) reported that black bears destroyed about 313,000 pole-sized trees during 1953 on 1,838 acres of land owned by Georgia Pacific Corporation (formerly Hammond Lumber Company) in Humboldt County. Most seriously damaged are young redwoods and Douglas-firs. Trapping has been the main control measure used to date.

Deer damage on young reproduction has been reported in every forested part of the State (California Forest Pest Control Action Council, 1961; Fowells and Dunning, 1948; Person, 1937; Roy, 1957, 1960; Schubert, 1956; Sischo, 1958). In northwestern California, Roy (1960) found that the amount of damage varied from place to place and with amount of available preferred food. He stated that Douglas-firs were browsed more severely than either Jeffrey or ponderosa pine, but that damage was not serious unless other choice food was absent. About 130,000 acres of young regeneration in Humboldt and Mendocino Counties have been severely browsed by deer (California Forest Pest Control Action Council, 1961).

In northeastern California, deer damaged by browsing and trampling from 70-100 percent of the ponderosa and Jeffrey pines planted on the Sugar Hill burn during the period 1941 to 1946 (Fowells and Dunning, 1948). Absence of other browse was given as a contributing factor to the heavy damage. On Stanislaus Experimental Forest, deer severely browsed white fir seedlings, but did very little damage to the planted sugar and Jeffrey pines (Schubert, 1956). At the end of 6 years, the average height of browsed white firs was only 7 inches, while unbrowsed trees were over 24 inches (Schubert, 1956). Deer have also been a problem in southern California plantations (Sischo, 1958).

In the central Sierra Nevada, 1-0 ponderosa pine is damaged more severely than 2-0. One-year seedlings in California Division of Forestry, Forest Service and American Forest Products experimental plots were severely browsed before a terminal bud was formed after the second growing season.

Repeated browsing by deer reduced height growth significantly on the Six Rivers National Forest (Roy, 1960). The average height of unbrowsed 6-year-old Douglas-firs averaged 41 inches compared to 17 inches for browsed ones. In Oregon, Douglas-firs browsed three times during a 5-year period averaged only 8.3 inches compared to 55.9 inches for unbrowsed trees (Ruth, 1956).

Buck deer have caused considerable damage in the Coast Range and Sierra Nevada-Cascade Mountains by rubbing their antlers on young trees to remove antler velvet.

Plantations in heavy deer-threat areas may require control measures until the terminal buds are out of deer reach. Heidmann (1963a) found that shoot damage was reduced effectively by treating trees with a 10-percent solution of TMTD or ZAC. The repellents, applied in spring before growth started, protected the growing terminals for one season. The treatment should be repeated until the tops are out of reach. These repellents can be applied in the nursery before the seedlings are lifted to protect the trees during the first year after planting. Person (1937) reported that seedlings covered with large branches had less deer damage than seedlings in the open. Brush has been used in Oregon to protect young seedlings from deer. Another method to protect seedlings may be to plant preferred browse in plantations (Baron, et al., 1966).

Some landowners have obtained depredation hunting permits from the State Department of Fish and Game to reduce over-populations of deer causing heavy damage to reproduction.

Livestock--Cattle, sheep, goats, and horses may damage young regeneration by trampling, browsing, or accidentally pulling out recently planted trees. The amount of injury varies by intensity of grazing and kind of animals. Sheep and goats usually cause the most damage and horses the least.

Reported injury to plantations by livestock in California has been light. Sampson and Dayton (1913) reported very little damage by cattle, sheep, and goats on a series of plots located on Shasta National Forest. At Burgess Spring, cattle killed 2.4 percent of the trees, whereas sheep killed 15 percent (U. S. Forest Service, 1940).

At Teaford Forest in Madera County, Pieper and Biswell (1961) reported cattle killed 12 of the 677 trees present on the plot. Most of the seedlings killed by cattle resulted from trampling.

As a general rule, all livestock should be kept out of plantations. Horses and cattle should not be permitted to graze in plantations for at least the first 3 years after planting. Sheep and goats should be excluded until the terminal buds are out of reach.

Plantation Release

Plantations may require some release treatments to maintain an acceptable rate of growth. Release treatments covered here will be limited to those involving release from brush or grass during the first 10 or so years; release from competing trees through scheduled thinnings and intermediate harvest cuts are not considered.

Grass and brush are main competitors of trees for the limited supply of soil moisture and nutrients. Weeds, bracken fern, and other minor vegetation compete with trees in some areas, but they can be handled by the same methods as for grass or brush.

The need for release is greatest during the first few years, especially for plantations on areas without adequate advance site preparation. The need also will be greatest for plantations with dense fast growing brush species, such as chokecherry, deerbrush, and willow, or strong competitors as chinkapin, manzanita, and mountain misery. The need will be least for plantations on well-prepared sites, especially those that had a low initial density of brush or grass, or those with weak competitors as mountain whitethorn or littleleaf *Ceanothus.*

All brush competition may not be bad. Quick (1944) reported nitrogen fixation on snowbrush and the same was reported on deerbrush by Vlamis, Schultz, and Biswell (1958). Good growth has been noted on ponderosa pines growing in mountain whitethorn which may be due in part to nitrogen producing nodules on this species of *Ceanothus.*

The release treatment may be chemical or mechanical. Chemical release usually is the easiest and cheapest. Mechanical release through cultivation or mowing may be used in Christmas tree plantations, seed orchards, or seed production plantations, and for additional purposes such as reducing water runoff or working fertilizer into the soil.

Methods for reducing competition are described in some detail in Chapter IV.

PLANTING COSTS

The cost of establishing new forests by planting has increased significantly since 1930 (fig. 80), the trend being generally upward. These increased costs reflect more site preparation and higher labor rates (table 55).

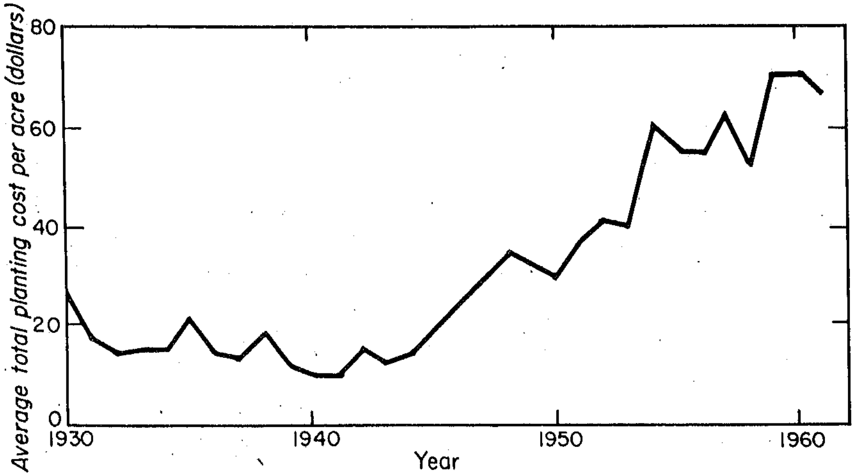

Figure 80. Trend of planting costs on national forests in California from 1930 through 1961.

Cost figures in table 55 should be used only as a guide to future planting. Costs for site preparation, trees, and planting have varied considerably from place to place depending on local conditions and numbers of trees planted per acre.

The trend on National Forests and forest industry lands has been to prepare a higher proportion of the area for planting, to do a better job of preparation, and a shift to more difficult areas as the easier ones have been regenerated. Machine planting on areas not too steep or rocky was found to be cheaper than hand planting (Buck, 1959).

Table 55. Range in costs of per acre site preparation, nursery stock, and planting.

Items	Cost
	Dollars
Site preparation 1/	20 to 70
Nursery stock 2/	5 to 73
Planting costs 3/	15 to 121
Total	45 to 264

1/ Least cost - light bulldozing of slash on a burn; greatest cost - windrowing dense brush.
2/ Least cost - \$17 per 1,000 stock at 303 (12' x 12') per acre; greatest cost - \$60 per 1,000 stock at 1210 (6' x 6') per acre.
3/ Least cost - machine planting at 5 cents per tree 300 trees/acre; greatest cost - hand planting at 10 cents per tree, 1210 per acre.

Planting costs may be reduced in the future through mechanization of nursery and planting operations. However, cost cutting at the expense of adequate stocking is not recommended. It is cheaper over the long run to do the job right the first time. Replanting is expensive. Inadequate stocking reduces expected returns.

The job on each area must be decided on the basis of local conditions. An experienced man will know how much site preparation is needed, the number of trees to be planted, and what follow-up care is required. If his choices are correct, the plantation costs will be reasonable.

Other ways to lower plantation costs are to. . . .

1. Improve stock quality so that fewer trees are required per acre for full stocking.

2. Improve methods of site preparation so that costs will be lower.

3. Improve efficiency of machines so that an adequate job is done for less money.

4. Produce Christmas trees where possible, so that planting costs may be written off at an early date.

5. Make greater use of machine planting on suitable areas so that over-all planting costs can be lowered.

6. Do more contract planting with experienced crews so that the number of plantation failures are reduced.

7. Care properly for plantations so losses by pests are minimized and crop trees will maintain a favorable growth rate.

8. Improve direct seeding so that a cheaper method can be used to regenerate difficult planting areas such as those on steep slopes or rocky sites.

9. Improve seed protection and chemical kill of brush to make it possible to seed rather than plant in chemically killed brush areas.

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VI SEEDING

Seeding as an economical alternative for forest regeneration in California has attracted forest managers since the early days of forestry. Two methods are discussed here: natural seed dissemination and artificial or direct seeding.

Natural seed dissemination, provided by residual trees after logging and after many fires over the years, has been responsible for most of the young growth in the State. Natural seed fall seldom fails to provide adequate regeneration if seed sources are available and **if time is of no concern.**

Natural regeneration currently is of primary importance in providing continuing productivity of the State's forest lands. The Forest Practice Act provides for rules prescribing regeneration methods. The rules require that seed sources be provided on all logged lands or alternative measures be taken under approved plans to assure regeneration.

Although the Forest Practice Rules are designed to provide continuing forest crops, they provide for only minimum performance. Many forest managers are looking for more than minimums to shorten their rotations and to improve the qualities of their products. In young-growth management, more rapid and economical regeneration methods than just leaving seed trees must be provided. Managers also are looking for more efficient logging practices that preclude leaving seed trees. Manipulating sites to promote quick natural regeneration or the application of direct seeding methods offer possibilities for reaching these objectives.

Effective practices to improve establishment of natural regeneration can assist in reducing cutting rotations and in improving seedling growth. The natural regeneration method is particularly attractive because it is the most economical initially. However, it is somewhat inflexible since it depends on sporadic cone crops, and on action during a very limited season in the year. And there are no

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Effective practices to improve establishment of natural regeneration can assist in reducing cutting rotations and in improving seedling growth. The natural regeneration method is particularly attractive because it is the most economical initially. However, it is somewhat inflexible since it depends on sporadic cone crops, and on action during a very limited season in the year. And there are no means of controlling initial stocking. Two important steps are required to improve results from use of this method–site preparation and rodent control.

Direct seeding methods, although less economical initially, offer other desirable features. They are more flexible than either providing for natural regeneration or planting, are considerably more economical than planting, and give better control of stocking than natural regeneration. Direct seeding also can be used in nonstocked areas where no natural seed sources are available.

NATURAL SEED DISSEMINATION

Natural regeneration is considered here as a method to restock small clean-logged areas with a perimeter seed source and areas understocked but having scattered residual trees for seed source.

Inflexibility in timing has been mentioned as a disadvantage to this method. Several factors contribute to this inflexibility:

1. Medium to heavy cone crops are required. Since these occur infrequently it is not always possible to take advantage of sites prepared during logging. And contrary to early beliefs, conifer seed shed from crops before logging generally will not lie dormant in the soil to provide post logging germination (Isaac, 1935). If logging is done in off cone years, there are three alternatives to obtain regeneration.

   a. Leave seed trees and trust that regeneration will fill in eventually.

   b. Leave seed trees and return later at the time of a good cone crop to prepare a seed bed.

   c. Clean-log or leave seed trees and provide for artificial regeneration.

2. The site must be prepared just before seed fall so that a loose mineral soil seed bed is provided. The dry season is best for this operation.

3. Rodent control also must be done just before seed fall--not more than 3 weeks or less than a few days in advance of maximum seed dispersal.

In addition to inflexibility of operations, another disadvantage is lack of stocking control. Optimum seedling density is difficult to attain.

The economic advantages in establishing natural regeneration where site preparation and rodent control are used are expressed in costs of from 1/4 to 1/2 those of direct seeding using the same preparation.

Operations for clean-logging followed by some slash disposal generally provide adequate site preparation for natural regeneration. Generally, Douglas-fir logging areas should be planned so that the amount of mid-day insolation is minimum. Intermittent sun is better than the same amount at one time (Franklin, 1963). Ponderosa pine reproduced best in small openings also (Curtis and Lynch, 1957). Openings should be large enough to provide overhead light with some side light, but small enough to provide some shade from margins. In understocked areas, the same site preparation methods recommended for direct seeding and planting should be used to remove competing vegetation and to provide a good seed bed (see Chapter III). And similar rodent control procedures should be followed.

Seed Dissemination

Little can be done to control the amount of seed falling on prepared sites. Because of uncontrolled variations in seed production and the many variables affecting seedling establishment, the odds for an optimum stocking are rather low.

Fowells and Schubert (1951a) estimated that about 60,000 good ponderosa pine seeds are needed to obtain 500 established seedlings to the acre on prepared sites with rodent control. The seed-to-seedling ratio is about 120 to 1 at the end of the tenth year. This ratio compares favorably with a seed-to-seedling ratio of about 80 to 1 for sugar pine at the end of the third year on Stanislaus Experimental Forest (tables 56, 57). The seed-to-seedling ratios for white fir and incense cedar were 55 to 1 and 25 to 1, respectively. The ratios indicate that all four species are suitable for direct seeding as well as for natural seeding.

Table 56. Natural regeneration after clearcutting of small even-aged groups[1] during a good seed-year (1948) and a poor seed-year (1949), Stanislaus Experimental Forest, California.

Year examined	Sugar Pine 1948	Sugar Pine 1949	All pine [2] 1948	All pine [2] 1949	White fir [3] 1948	White fir [3] 1949	Incense-cedar 1948	Incense-cedar 1949	All conifers 1948	All conifers 1949
	Number of seedlings per acre									
1949	527	–	552	–	7,682	–	0	–	8,324	–
1950	405	14	460	35	3,842	0	120	74	4,422	109
1951	373	9	427	32	2,988	0	49	39	3,465	72
1954	498	123	557	157	2,570	236	1,260	1,188	4,387	1,581
1957	470	97	524	118	1,995	532	1,114	1,028	3,633	1,678

1/ Size of groups varied from ½- to 3-acre stands of a mixed conifer forest.
2/ Includes sugar pine, ponderosa pine, and Jeffrey pine.
3/ Also includes a few red fir seedlings.

Table 57. Seedfall, by species, on clearcut areas[1] of half to 3 acres, 1948-1956, Stanislaus Experimental Forest, California.

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

1/ For same areas indicated in table 56.
2/ Also includes a few red fir seed.
3/ Based on a seed-trap count from traps spaced on a grid 1 chain apart throughout the clearcut openings.

The efficiency of natural seed fall was also tested in the central Sierra Nevada. The better sites of a large 1959 burn had been prepared for planting by the landowner. A 10-acre portion of this burn prepared in 1963 contained a few large residual ponderosa and sugar pines and a dense stand of young growth white fir in part of the perimeter. It was selected by the State for a natural seed fall study (Adams, 1966). A 1964 light-to-medium cone crop of white fir and ponderosa pine scattered 24,600 and 49,700 seeds per acre, respectively, on the 10 acres. In fall 1965, these seeds produced 1,700 and 400 seedlings per acre respectively. The seeds-to-seedling ratio was 14 to 1 for fir and 124 to 1 for pine. There was no attempt to control rodents.

Site Preparation and Rodent Control

The importance of site preparation and rodent control is also quite evident in the Stanislaus Experimental Forest study referred to earlier. Small even-aged groups of mature timber were clean-logged in 1948 and 1949 on plots ranging from 1 to 3 acres (group selection cutting). A heavy 1948 seed crop of sugar pine and white fir fell on the 1948 logged area, but very little in 1949 for that year's logging (table 57). Seedling establishment was good for the 1948 cut where the seed fell on a prepared site (table 56). The regeneration areas plus a quarter-mile buffer strip around the entire unit were baited to control seed-eating rodents (Cosens and Tackle, 1950). The bumper seed crop in 1952 (185,000 sound pine seed per acre), which fell on the areas, added only about 100 seedlings--a seed-to-seedling ratio of about 1,850 to 1. No site preparation or rodent control was done before the 1952 seed crop. Most of the areas were still bare; however, the soil had compacted as is normal after 4 years.

Condition of the seedbed was also shown to be important on Blacks Mountain Experimental Forest (table 58) (Tackle and Roy, 1953). Of the 33,329 ponderosa and Jeffrey pine seedlings that started on bare ground after the heavy seed year in 1948, 11,017 were still alive at the end of 4 years; of the 2,914 that started under a heavy ground cover, only 127 lived 4 years.

In the central Sierra Nevada, American Forest Products Corporation prepared 72 acres on poorly stocked slopes covered by mountain misery. The stock consisted of young or thrifty mature ponderosa pine. Preparation was done just before the 1960 bumper ponderosa pine seed fall. It consisted of terracing and ripping slopes with a D-9 Caterpiller tractor and road ripper followed by application of 1080 treated grain. Regeneration was more than adequate (Adams, 1969) [34](fig. 81).

Table 58. *Germination and survival of ponderosa and Jeffrey pine, on Blacks Mountain Experimental Forest, California, by density of ground cover.*

Ground-cover density	Germination spring 1949	Survival in fall of . . . 1949	1950	1951	1952
	Number of seedlings per acre				
Bare	33,329	14,043	13,122	12,035	11,017
Light	11,420	3,025	2,178	1,535	1,277
Medium	3,816	710	389	222	139
Heavy	2,914	457	254	143	127

Source: Tackle and Roy, 1953.

Timing

Site preparation should be done in July and August so that a loose mineral soil seed bed will be ready for the September-to-October seed fall. Rodent control should be done about mid-August for Douglas-fir in the coastal areas and from late August to mid-September for pine in the Sierra Nevada–depending on elevation. If only true firs are to be the seed catch, then rodent baiting should be done about two weeks later than for the pines.

34/ Maben, Robert. Natural regeneration on mountain misery prepared slopes. American Forest Products Corp. 1967. (Unpublished report to the State Forester's Reforestation Advisory Committee.)

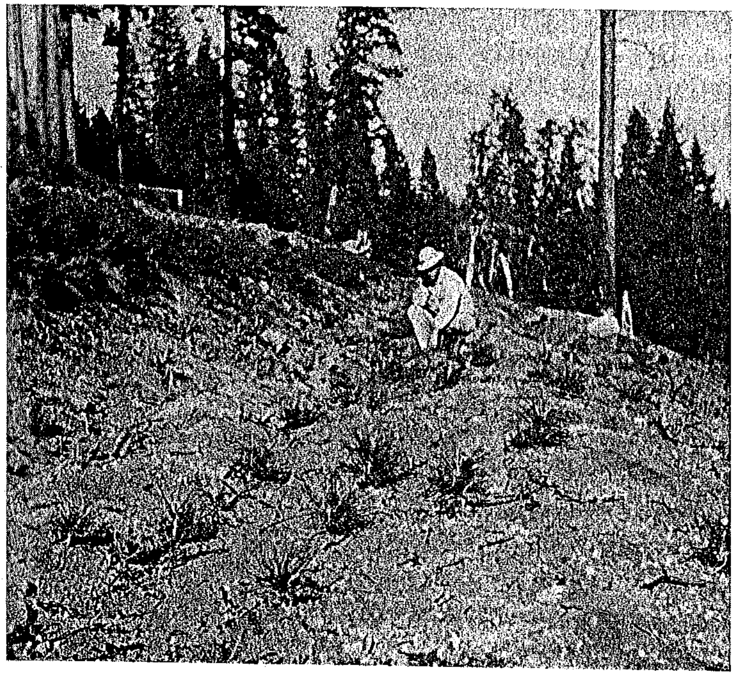

Figure 81. Ponderosa pine is regenerating naturally on a bulldozer prepared terrace.

Covering Seed

An additional step in improving conditions for natural regeneration is to cover the seed after the majority have been shed from their cones. This can be done by dragging a chain, channel iron drags (Hall, 1967) or harrow over the area. The use of such equipment, however, is limited by terrain.

The Stanislaus study mentioned earlier points out the importance of covering the seed with soil. In fall 1948 after seedfall, 20 plots (each 4 milacres) were raked by hand to cover the fallen seed. Each plot was paired with an unraked plot. The average number of sugar pine seedlings per raked plot was 1.1 compared to 5.2 for the unraked–a highly significant difference.

DIRECT SEEDING

One of the primary advantages of direct seeding is that with an adequate seed supply, areas can be seeded promptly after catastrophes or recent clean-logging–on the other hand, planting may require 1 to 3 years for nurseries to build up necessary planting stock for more than normal demands.

Direct seeding can be started earlier in the fall when it is still too dry to plant and before planting stock is available. Therefore, many of the difficulties associated with planting are eliminated. Areas can be seeded that are too steep, rocky, or impenetrable for planting. Problems associated with growing, storing, shipping, and planting trees are avoided. Immediate good cone crops required for natural seeding are not needed if stored seed is available.

Total direct seeding costs generally averaged one-fourth to one-half planting costs. Direct seeding requires more seed than is needed to produce planting stock, but nursery and high transportation costs are sharply reduced. Burned areas can be seeded immediately, before costly site preparation is required. Furthermore, slash disposal need not be as complete as for machine planting. Since more acres can be seeded than planted per man-day, labor costs are considerably lower than for planting.

These favorable attributes have made direct seeding a highly attractive method for foresters confronted with large reforestation projects. However, direct seeding cannot be recommended as a replacement for planting in all areas, until the causes of frequent failures have been substantially eliminated.

Some of the common obstacles to direct seeding are:

1. Seed- and seedling-eating rodents, birds, and insects that cause severe losses during the first growing season.

2. Rapid drying of exposed stratified seeds that retard or prevent seed germination.

3. Rapid drying of the soil that retard or prevent germination of covered seeds and inhibit seedling growth or cause mortality.

4. Numerous fungi that destroy seeds and young seedlings.

5. High surface temperatures that inhibit seed germination.

6. Early fall and late spring frosts that freeze small seedlings or heave them out of the ground.

7. Grass, herbs, and brush that deprive seedlings of moisture, light and nutrients.

8. Animals that browse or trample seedlings.

Direct seeding in California has been quite sporadic (fig. 82). Most seedings have failed, but there have been intermittent successes to rekindle hope in direct seeding. Seedings have been made in all the major forested areas in California.

Three methods have been used: (1) broadcast, (2) spot, and (3) drill. In broadcast seeding, the seeds are scattered by hand, hand-operated seeders, fixed-wing aircraft, and helicopters. In spot seeding, the seeds are placed in the soil by hand, corn planters, and specially designed walking-stick type seeders. In drill seeding, the seeds are planted by a rangeland drill and several types of smaller drills specially designed for conifer seeds.

The first direct seeding in California was in 1901 on the San Bernardino Forest Reserve (Cox, 1911). Jeffrey pine seed was sown broadcast and placed in small holes made with a stick (spot seeding). The seeding, done on the dry foothill slopes, was a failure. After a short lull, seeding was resumed in 1905 on Angeles National Forest. About 528 acres were unsuccessfully seeded with Jeffrey pine. Seeding was abandoned in southern California in 1912.

The first seeding in the northeastern part of California was done in 1908 (Show, 1930). From 1908 to 1913, about 120 acres were seeded with ponderosa, Jeffrey, and sugar pines. The seedings were on many small areas in brushfields without site preparation. Since these trials were all failures, a switch was made to tree planting in 1913.

Seeding studies were started by research personnel from Feather River Experiment Station in 1912 (Dunning, 1940). From 1912 to 1916, 21 small studies were begun at Feather River Station and near Bear Creek Ranger Station Plumas National Forest. These trials were

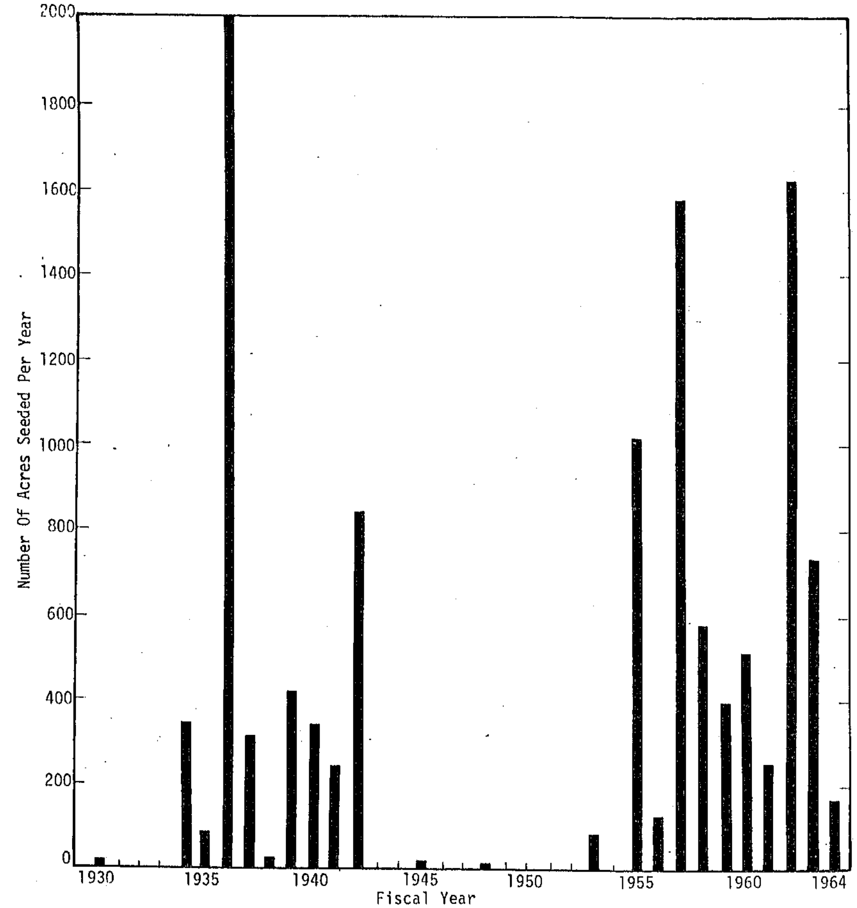

Figure 82. Annual seeding of conifers on National Forests in California 1930-1964.

to test different methods, but all were failures. However, severa small seedings on National Forests in the northeast part of the Stat between 1921 and 1930 were successful (Dunning, 1940). These successful projects renewed interest in seeding on National Forests During the period 1934-1942, more than 4,600 acres were seeded ir the Sierra Nevada-Cascade province. Of this acreage, 2,000 acres were seeded in 1936, the most ever seeded in a single year on Nationa

Forests. Only 29 percent of the acreage seeded during this 9-year period had 100 or more seedlings per acre (Dunning, 1940). Nearly all the successful seedings were on three large fresh burns: (1) the Anderson Valley burn on Stanislaus, (2) the Middle Creek burn on Eldorado, and (3) the Forest Hill burn on Tahoe.

The poor results of these seedings, and shortage of manpower during World War II led to a sharp reduction in seeding after 1942. Less than 50 acres were seeded between 1943-1950, mostly small experimental studies.

Seeding since 1951 has increased appreciably (table 59). During the past 10 years, seeding on National Forests has averaged about 700 acres per year. Most was done on Angeles, Klamath, Lassen, and Six Rivers National Forests.

In 1958, seedings were started on Indian, State, and private forest lands. Seeding on State lands has been only a few acres, mostly experimental, whereas seedings on Indian and private forest lands have been large-scale operations. In 1964, private forest industry surpassed the Forest Service in cumulative acres seeded (16,270 vs. 11,856).

The trend in seeding for the decade starting in 1965 appears to be upward. However, much depends on the success of the 22,000 acres seeded between 1960 and 1964 that have not been fully evaluated.

Broadcast Seeding

Over 95 percent of seedings in California have been by the broadcast method. The first seedings were with "Cyclone" seeders. The first aerial seeding was in 1941. Most acres seeded since 1955 have been from aircraft.

About 650 acres were broadcast seeded before 1930. One of the earliest was 500 acres on Angeles National Forest. Only 18 acres of this acreage was considered satisfactory. All broadcast seedings in the northeastern part of the State before 1930 were failures--chiefly because brushfield sites were not prepared (Show, 1930).

About one-third of the areas broadcast seeded between 1934 and 1942 had a stocking ranging from 120 to 980 seedlings per acre. However, three-fourths of the stocking was from natural seedlings (Fowells and Dunning, 1948). The "successes" were all on fresh burns which occurred between 1934 and 1936. All seedings on burns 2 years and older failed.

Table 59. Annual forest seeding in California exclusive of windbarrier seeding, by ownership, 1951-67. 1/

	Public forest lands						Private forest land			All ownership
	Federal			Nonfederal						
scal ear	National forest	Other 2/	Total	State forest	Other state	Total	Forest industry	Other private 3/	Total	Total
	Acres									
51	0	0	0	0	0	0	0	0	0	0
52	0	0	0	0	0	0	0	0	0	0
53	83	0	83	0	0	0	0	0	0	83
54	5	0	5	0	0	0	0	0	0	5
55	1,023	0	1,023	0	0	0	0	0	0	1,023
56	125	0	125	0	0	0	0	0	0	125
57	1,583	0	1,583	0	0	0	0	0	0	1,583
58	579	16	595	19	0	19	262	0	262	876
59	394	21	415	9	65	74	0	14	14	503
60	513	0	513	1	0	1	3,420	37	3,457	3,971
61	249	288	537	2	0	2	2,140	7	2,147	2,686
62	1,633	95	1,728	1	0	1	2,976	20	2,996	4,725
63	726	662	1,388	3	0	3	2,513	3	2,516	3,907
64	162	1,399	1,561	2	0	2	4,959	0	4,959	6,522
65	836	281	1,117	45	0	45	4,280	2,560	6,840	8,002
66	1,602	839	2,441	43	0	43	6,830	1,293	8,123	10,607
67	540	0	540	1	0	1	6,535	1,251	7,786	8,327
otal			13,654			191			39,100	52,945

ata based on acreages reported in Tree Planters' Notes Nos. 9, 13, 15, 19, 23, 27, 30, 34, 9, 44, 49, 56, 62, 68, 74, and 80.

In 1941 and 1942, more than 1,000 acres of snow-covered land were aerially seeded with about 2 pounds of ponderosa and Jeffrey pine per acre. The area had been trated with strychnine bait before seeding. The ground was not prepared before seeding. Seed germination was excellent, but most of the seedlings died during the summer drought (Fowells and Dunning, 1948). All early trials of seeding on snow similarly failed. Because of these failures seeding on snow is not recommended for California.

Seedings on snow in other regions also have been failures. Stein (1951) reported germination of noble and silver fir seed on snow in the Pacific Northwest, but none of the seedlings had a reasonable chance to survive. Jack pine seeds were broadcast with Cyclone seeders on snow and on bare ground on a fresh burn in the Lake States (Roe, 1963). The snow seeding was a failure, whereas areas seeded on bare ground had 9,000 to 13,000 seedlings per acre.

Many of the broadcast seedings during recent years have been successful, especially those on the Hoopa Indian Reservation and several National and industrial forests in northwestern California.

Of all the areas seeded on National Forests since 1930, 43 percent were stocked with at least 100 seedlings per acre; however, no information is available on seedling distribution. Almost all the adequately stocked areas were seeded within 1 year after a hot burn or following special site preparation. The failures were on old burns and unprepared sites.

Broadcast seeding seems to be practical in many areas in northwestern California, but has shown less promise on the Sierra Nevada-Cascade ranges.

Seed-spot Seeding

Direct seeding by the spot method has succeeded at times, but failed at others. The success, as with the other methods, depends on good seed, rodent control, and good site preparation. It is less attractive than other seeding methods, as it is slower and more laborious. However, it is considerably faster and easier than planting seedlings.

The first spot seeding in California was on San Bernardino Forest Reserve in 1901 (Cox, 1911). Rodents consumed all seed in this trial and subsequent ones made between 1905 and 1912 on Angeles National Forest.

The spot seeding trials made in northeastern California from 1908 to 1913 (Show, 1930) on unprepared areas, were likewise all destroyed by rodents, except those protected by wire screens.

The first successful seeding by the spot method was in 1925 on the 1924 Antelope Burn on Lassen National Forest (Dunning, 1940). About 9 acres were seeded in the ashes with local ponderosa and Jeffrey pine seed. This successful seeding was followed by two more in fall 1929 and in spring 1930. One was a 6-acre plot seeded with sugar pine and the other an 8-acre plot with ponderosa pine. These were both on fresh burns, later rated as fully stocked (Dunning, 1940).

Most of the spot seeding since 1930 has been on small experimental plots. Between 1934 and 1961, almost 131,000 seed spots were sown in over 50 studies. Most of trials were with ponderosa and Jeffrey pine seed. Average seed germination was 30 percent, with a second-year seedling survival of only 15 percent. These trials were primarily to test different ways to protect the seeds against rodents. The specific results are covered in appropriate sections in this Chapter under "Rodent Control Measures." With adequate rodent protection, hand-operated seeders can be used successfully in spot-seeding.

Spot-seeding with redwood seed in the north coast area has been successful where care was exercised in preparing the spot and planting the seed (Fritz, 1950).

Corn planters (fig. 83) and several other types of seed planters have been tried in California. The corn planter was first tried in northeastern California in several successful seedings during 1908 to 1910 (Show, 1930). It has been used more recently on Kimberly-Clark Corporation lands in Shasta County.[35] One of the more successful seeders is a "seeding gun" or "walking-stick" seeder used on Soper-Wheeler Company lands near Strawberry Valley, Yuba County (fig. 84).

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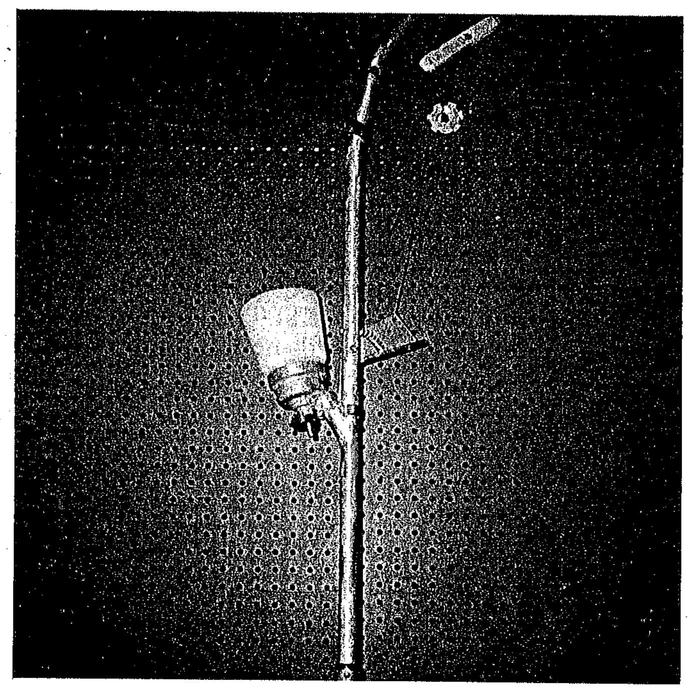
[35] Bowman, Hal. Spot-seeding with corn planters by Kimberly-Clark Corporation. 1967. (Personal communication).

Figure 83. Corn planters have been tried as a means of direct seeding.



Drill Seeding

Drill seeding in California has been limited to a few experimental trials. The first drill seeding was with a rangeland drill near McCloud (Schubert, Buck, and Evanko, 1960). The drill (fig. 85) was specifically designed by the Forest Service to seed grass on rough rangeland. Results of three trials on well-prepared plots have been encouraging (fig. 86). The drill is rugged and can withstand the hard usage that cannot be avoided on wildland seeding operations. Its chief disadvantages are excessive weight and poor maneuverability. Other types of drills are under study that would overcome these disadvantages significantly. One is being developed by the California Division of Forestry from a single row corn planter (fig. 87). Another is the HC Furrow-seeder developed commercially in the southern states (Croker, 1960). A more recent machine designed by the University of Idaho and modified by the U. S. Forest Service, San Dimas Equipment Development Center, has been tested successfully in the southern states (Stevenson, 1966; U. S. Forest Service, 1967). Plans and specifications are available from the Forest Service.

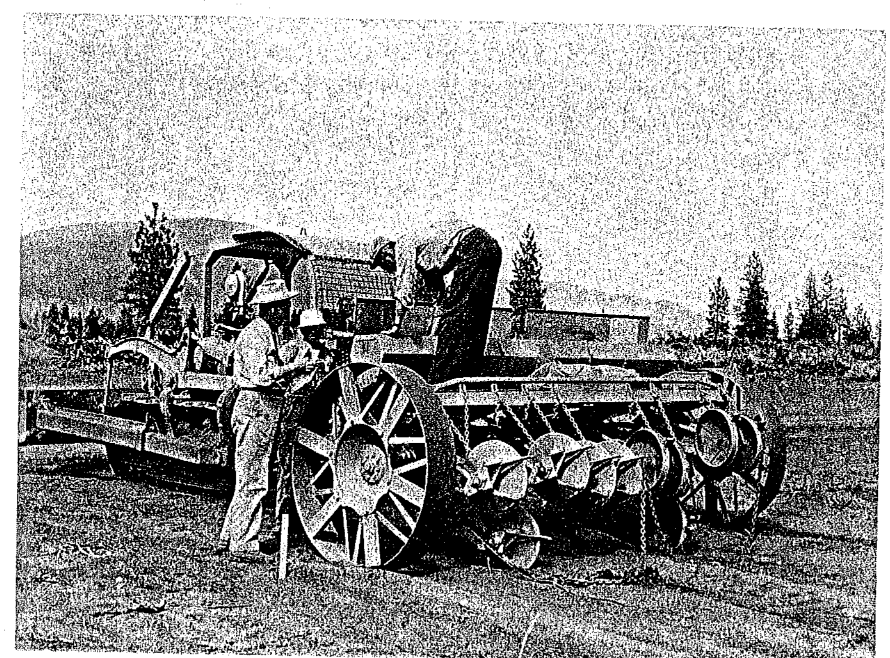


Figure 85. The rangeland drill has two drills in place to sow ponderosa pine

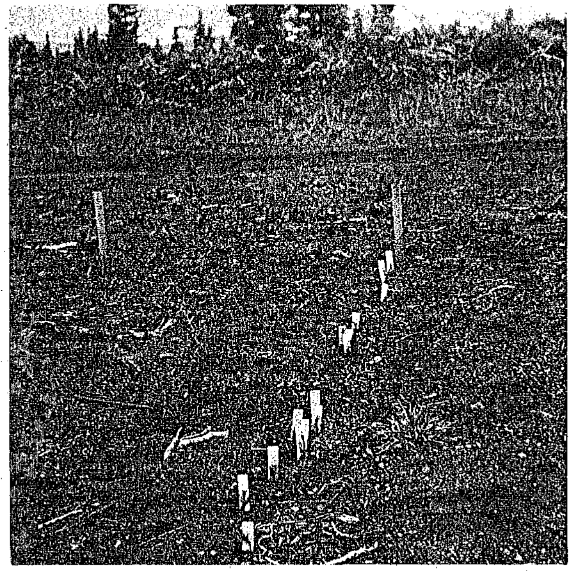


Figure 86. Part of a row sown with the rangeland drill shows distribution of ponderosa pine seedlings.

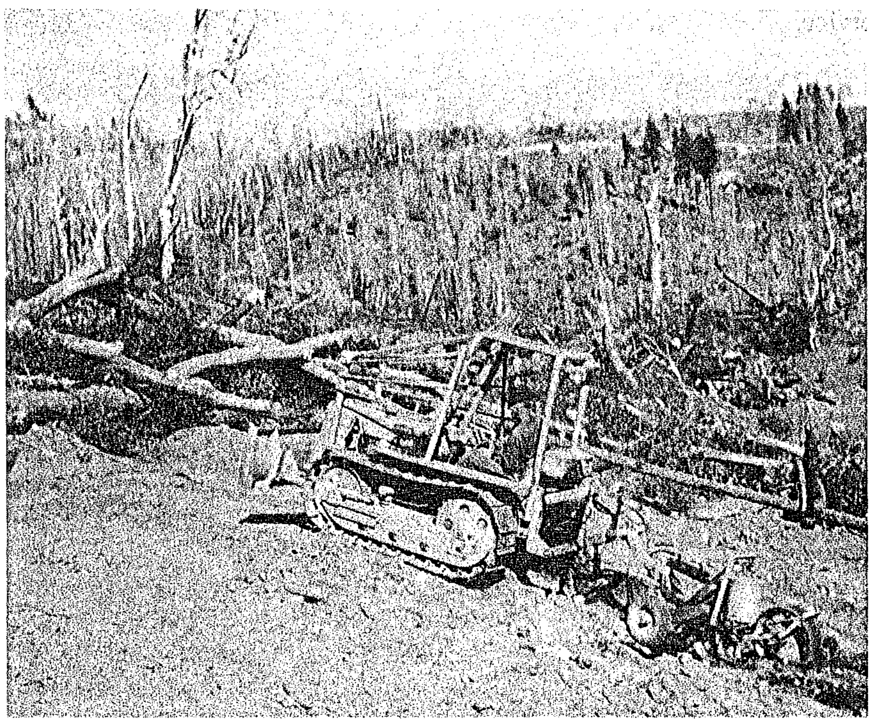


Figure 87. Drill seeding with a single row furrow seeder.

Drill seeding has several advantages over other seeding methods. Its main advantages over broadcast seeding are seed coverage, lower seed requirements, and better stocking control. However, it is considerably slower and requires better site preparation. Its chief advantages over spot-seeding are lower costs and a high probability that seed will escape pilferage by rodents, but it requires more seed and cannot be used on steep and rocky areas.

CAUSES OF SEED AND SEEDLING LOSSES

Many factors can hinder seedling establishment. They include seed-eating rodents, herbivorous insects, drought, freezing, and competition from other plants for moisture, light, and nutrients. Other factors are birds, browsing animals, heat, fungi, and frost heaving. Losses caused by any one or more factors will vary by locations and years.

Animals

Seed-eating rodents have been the main cause of failures in direct seeding (Dunning, 1940; Fowells and Schubert, 1951b; Keyes and Smith, 1943; Show, 1930; Sischo, 1958; Smith and Aldous, 1947). Show (1930) reported that rodents were the primary cause of failure of direct seeding trials by the Forest Service before 1912. He concluded that, without adequate protection against rodents, direct seeding was predestined to failure.

Rodents continue to plague foresters who attempt to direct seed. Keyes and Smith (1943) reported that rodents ate all the seed in 94 percent of the 24,333 seed spots in their studies during 1939-1941. Smith and Aldous (1947) listed 44 mammals that were found to eat coniferous seeds. The tree squirrels, chipmunks, and white-footed deer mice were reported as responsible for the greater part of all seed depradation. Keyes and Smith (1943) also listed ground squirrels, wood rats, and kangaroo rats as heavy seed eaters. Of these rodents, deer mice are the most destructive.

At times rodents were believed to serve a useful function through their habit of caching seeds for food at a later date. Numerous conifer seedlings were found to have originated from rodent caches on Stanislaus Experimental Forest. However, shortly after the seeds started to germinate, rodents dug up and ate the seeds and destroyed the seedlings. Even when left undisturbed, rodent caches seldom contributed much toward stocking the area (Fowells and Schubert, 1951a).

In spring of 1953, sugar pine seedlings in rodent caches along the edge of a logging road on Stanislaus Experimental Forest averaged 284,000 seedlings per acre in early June. But by September rodents had destroyed all these seedlings.

Rabbits have been destructive in some areas. In the Burney Springs experiment, rabbits damaged or destroyed 57 percent of the ponderosa and Jeffrey pine seedlings after the protective screens were removed (Kirk, 1947). Rabbits also contributed to the failure of spot seeding in southern California (Sischo, 1958). However, rabbits rarely have been a serious problem in areas where the protective brush cover was eliminated through adequate site preparation.

Browsing animals, such as deer, elk, and livestock, have caused serious damage in some areas. The damage to seeded or planted trees are similar. The extent of damage was covered in the chapter on planting.

Sowing browse, grass, and conifer seed together so that the browse and grass provide a buffer crop may be a method for reducing conifer seedling damage from large animals. In a test in the central Sierra Nevada, eight species of grasses and legumes were drill seeded on Stanislaus National Forest with endrin-arasan treated ponderosa pine seed. A modified rangeland drill was used to sow the seeds. At the end of the second growing season the conifers were undamaged but deer had used almost the entire buffer crop (Baron, *et al.*, 1966).

Insects

Several species of insects have been reported to cause heavy seedling mortality (Fowells, 1940; Keen, 1952; Kirk, 1947; Roy, 1957b; Sischo, 1958). Even so, the exact amount of damage may not be known until rodent control is more effective. In areas where rodents were excluded from the seed-spot by protective devices, or were killed before direct seeding, insects have become one of the major causes of seed and seedling destruction.

Keen (1952) has indicated that seedlings may be destroyed by white grubs, cutworms, wireworms, grasshoppers, leafhoppers, aphids, centipedes, millipedes, and various bark-chewing beetles. Actual losses in the field have been observed from white grubs, cutworms, wireworms, millipedes, and grasshoppers. Destruction of seedlings by the other insects indicated by Keen probably have occurred, but have not been reported or recognized during survival examinations.

Fowells (1940) reported seedling losses caused by cutworms ranging from 8 percent on sugar pine to 53 percent on incense-cedar during a 5-year period on Stanislaus Experimental Forest (table 60). Losses were significantly higher in cut-over stands than in virgin timber. Fowells also reported ponderosa pine seedling losses caused by cutworms amounting to 46 percent in the Burney Spring and 21 percent in the Burgess Spring experimental direct seeding studies.

Table 60. Seedling losses caused by cutworms during a 5-year period at Stanislaus Experimental Forest.

Item	Incense cedar	Sugar pine	Ponderosa pine	White fir	Total
Germinated No.	2,314	1,536	3,054	511	7,415
Killed Pct.	52.9	7.9	28.6	34.4	32.3

Source: Fowells (1940).

The quantity of root-feeding insects vary with density and type of vegetation. The populations are lowest on bare areas, light to intermediate in heavily forested areas, and heaviest in areas covered with dense grass. As grass and weeds revegetate cleared areas, the populations of white grubs, cutworms, wireworms, and other species of root-feeding insects increased (Keen, 1952). Root-feeding insects can reinvade an area. On several plots near Fish Camp in Mariposa County, cutworms and wireworms destroyed 70 percent of the Jeffrey, ponderosa, and sugar pine seedlings from tetramine-treated seeds, and 50 percent of the endrin treated seeds.

These losses were on seedlings in plots installed the second year after the brush had been removed. No losses occurred on these same plots where seedings were made the first spring after brush removal.

Similar results were reported for seedings in northeastern California. For example, no cutworm damage occurred on the Burney Spring experimental seeding made the first spring after site preparation, whereas heavy cutworm damage occurred in the fall plantation following a year's growth of grass and other herbaceous plants (Kirk, 1947).

Dieldrin proved effective to control cutworms and wireworms on the plots near Fish Camp: 5 percent dieldrin granules dusted over a 2-foot radius around seed spots at a rate of 10 pounds to the acre the third year after site preparation gave adequate protection. None of the seedlings in the treated spots were destroyed, whereas more than 90 percent of those in adjacent untreated spots were eaten by cutworms and wireworms. Rates up to 50 pounds of dieldrin to the acre had no adverse effect on seeds or seedlings.

Grasshoppers have been a serious problem in several areas. Grasshopper damage in northern California has been noted particularly in the McCloud flat area on Shasta-Trinity National Forest, where several attempts at starting a new stand have failed. In 1954, 60 acres on the Ash Creek burn of 1952 were sprayed from the air with dieldrin in diesel oil (Averell, 1954). No grasshopper damage was noted on seedlings in the treated area. In southern California grasshoppers have been one of the most damaging of the insect pests (Sischo, 1958).

Plantations from seedings also are subject to some of the same damage by other insects as reported for planted seedlings in the previous chapter.

Drought

Seedling mortality has been caused by droughty conditions in many seeding experiments (Dunning, 1940; Fowells, 1953; Fowells and Schubert, 1956; Kirk, 1947; Lloyd, 1937; Sischo, 1958). In a direct-seeding trial at Feather River Experimental Forest, mortality of seedlings from late germinated seed was attributed to drought (Dunning, 1940). At Bear Creek brushfield seeding, drought caused the death of almost all seedlings (Dunning, 1940). Lloyd (1937) reported drought killed 39 percent of the ponderosa and Jeffrey pine seedlings in the Burgess Spring experiment. During an 8-year observation period, about half of the mortality of sugar pine, ponderosa pine, and white fir seedlings on Stanislaus Experimental Forest was attributed to drought (Fowells and Schubert, 1956). Sischo (1958) reported that drought has been one of the main causes of seedling mortality in southern California.

There is a strong possibility that some mortality attributed to drought may have been caused by other factors. For example, in the Feather River study referred to above, Dunning (1940) reported little seedling mortality for fall sown seeds. Thus, delayed germination of the spring sown seed may have been the major contributing factor. In the Burney Spring brushfield experiment, none of the seedlings from early spring sown seed were killed by drought.

According to Fowells,[36] new seedlings were killed by drought in June when the moisture in the top 6 inches of soil was 10 percent above the permanent wilting point. Losses increased in July and August when the soil moisture below 6 inches dropped to within 2 percent of the wilting point. Seedlings with long, fast-growing tap roots were able to withstand drought conditions better than those with short, slow-growing tap roots.

A California Division of Forestry seeding study supports these data.[37] Broadcast-seeding of Douglas-fir, white fir and ponderosa pine resulted in respective survival of 13, 7 and 48 percent in a prepared site reinvaded by grass. Douglas-fir and white fir roots were unable to penetrate deeply enough to maintain adequate moisture uptake as soil moisture receded.

Seedlings from seeds sown in late spring generally do not have adequate root systems to survive the June drought.

36/ Fowells, H. A. File report on seedling mortality in 1935 at five site factor stations located on Stanislaus Experimental Forest.

37/ Adams, Ronald S. File report on stocking results of Blue Canyon seeding study, October, 1967.

Freezing

Young seedlings are more susceptible than older plants to sudden drops in temperature below the freezing point. Fowells (1948) reported that the highest and lowest temperatures occur at or near the ground line. Seedlings were most frequently frozen when the freeze happened in spring after growth started and in fall before the seedlings had hardened off.

Sugar pine, red fir, and white fir seedlings were found to be damaged more severely by freezing temperatures than ponderosa and Jeffrey pines (Schubert, 1955, 1956). An early fall freeze damaged all 1-0 sugar pine seedlings in nursery beds at Stanislaus Branch Station whereas none of the ponderosa or Jeffrey pines in adjacent beds were damaged (Schubert, 1955). At Fish Camp, 74 percent of the sugar pine seedlings were damaged compared to only 9 percent of the ponderosa pines and 8 percent of the Jeffrey pines (Schubert, 1955). However, at the Burgess Springs experiment 18 percent of the ponderosa and Jeffrey pines were killed by frost (Lloyd, 1937).

On Stanislaus Experimental Forest, freezing injury was found to affect height growth of white fir and incense cedars more than sugar pines (Schubert, 1956).

Heat

The amount of seedling mortality caused by heat injury seems to be negligible. On Stanislaus Experimental Forest, loss of seedlings from insolation or stem killing at the soil surface occurred occasionally when the surface temperature reached about 130 ° F. during late May and early June. [38] Only one seedling was killed during the period June 21-30 when the average maximum soil temperature was 142 °F. No loss was reported due to heat injury after the first of July even though a temperature of 151 ° was recorded at the ¼-inch depth.

In a laboratory study, Baker (1929), found that young seedlings could be injured quickly by temperatures about 130° F. He found that the injury-causing temperature varied by species. These temperatures, for species commonly encountered in forest regeneration, were: Coulter pine, 131° F.; ponderosa pine, 133° F.; lodgepole pine 131 ° F.; Douglas-fir, 137 ° to 142° F.; bigcone Douglas-fir, 134 ° F.; grand fir, 130 ° F.; and redwood, 125° F. Hoffman (1924) found that a temperature of 144° F. at the soil surface killed the cambium of Dougals-fir in the Pacific Northwest. Fowells [39] found that the temperatures inside the stem of seedlings were 119 ° to 133 ° F. when the temperatures at the soil surface varied from 121° F. to 141 ° F.

38/ See footnote 36, p. 317.

The critical temperatures indicated by Baker (1929) may not be reached until the seedlings have hardened off sufficiently to withstand higher temperatures. Controlled artificial heat applied to the stems of young Douglas-fir seedlings allows comparison of susceptibility of several ages to heat kill. When 140 ° F. and 130° F. were applied for 5 and 60 minutes, respectively, seedlings less than 8 weeks old succumbed (de Keijzer and Hermann, 1966).

Evidence that heat may not be an important cause of mortality is further strengthened by a report of only 0.4 percent heat kill in northeastern California (Lloyd, 1937) and no mortality recognized as heat kill in southwestern Oregon (Stein, 1957).

White fir is more susceptible to heat kill than other species, particularly pines. In a direct-seeding study by the State in the central Sierra Nevada, 1 seedling each of 25 pairs each of newly germinated white fir, Douglas-fir and ponderosa pine were shaded with box shook on the south-southwest side of each seedling. [40] The following survivals were recorded:

	Shaded	Unshaded
	(percent)	
White fir	82	37
Douglas-fir	85	70
Ponderosa pine	100	100

39/ See footnote 36, p. 317.

40/ Adams, Ronald S. Blue Canyon direct seeding study. 1967. (Unpublished report to the State Forester's Reforestation Advisory Committee.)

Fungi

Very little seedling mortality has been reported for fungi in direct seeding trials, where detailed records of mortality were kept, except in the north coast area. On Stanislaus plots, only about 2 percent of the total mortality was caused by fungi.[41/] The heaviest losses were sustained by incense-cedar seedlings and the least by sugar pines (table 61). The kill on white fir and ponderosa pine seedlings was intermediate between sugar pine and incense-cedar. At Burgess Springs, fungi killed less than 0.1 percent of the ponderosa and Jeffrey pine seedlings (Lloyd, 1937).

In a study on soil reaction and seed germination, Tarrant (1954b) found no seedling mortality due to damping-off fungi except in soils with a high pH. Soils in conifer stands generally have a pH below 6 which is not favorable for fungal growth. However, the soil pH, after a timber burn or slash burning, is considerably higher and may result in seedling mortality caused by damping-off fungi (Tarrant, 1954a, 1956).

Root rot can be a limiting factor in establishing coast-redwood seedlings.[42/] Throughout the range of redwood, no natural seedlings were found where the soil had not been disturbed. Only occasionally was seedling survival noted on undisturbed direct seeded plots. Seedling roots were destroyed by fungi in the duff and litter. Redwood seeding to be successful requires some kind of mechanical disturbance of the soil or burning of the duff and litter. Douglas-fir is subject to similar infections, but not to the same degree as redwood.

Frost Heaving

Frost heaving has not been a serious cause of mortality in seeding experiments (Dunning, 1940; Fowells and Schubert, 1951b; Kirk, 1947; Lloyd, 1937). Shallow-rooted seedlings, that are most readily frost heaved, generally have been killed by drought before frost heaving becomes a problem.

41/ See footnote 36, p. 317.
42/ Muelder, D. W. Effectiveness of seed trees for natural regeneration. 1962-63. (Annual University of California research project report to the State Forester. 1963.)

Table 61. Comparison of seedling mortality by causal agent in the Stanislaus site factor study and Burgess Spring direct seeding trial.

Study area and year	Tree species[1/]	Seedling basis	Frost	Rodents	Insects	Fungi	Heat	Drought	Animals[2/]	Misc.[3/]	Total
			(Mortality caused by –)								
		Number	Percent								
Stanislaus Expt. Forest 1935	PP	678	0.0	12.2	38.5	1.2	1.8	20.3	0.0	6.2	80.2
	SP	248	.0	23.0	21.4	.8	1.2	11.7	.0	6.8	64.9
	WF	327	.3	19.9	36.1	1.8	.3	26.3	.0	8.6	93.3
	IC	205	.0	20.0	54.1	6.3	.0	11.2	.0	5.4	97.1
Subtotal/Average		1,458	.1	16.9	37.2	2.0	1.1	18.9	.0	6.7	82.9
Stanislaus Expt. Forest 1936	PP	584	.5	.7	31.7	.7	.8	9.1	.0	10.4	53.9
	SP	233	17.2	.0	1.3	.0	.0	13.3	.0	5.1	38.2
	WF	69	.0	.0	17.4	2.9	.0	36.2	.0	31.9	88.4
	IC	516	.0	.6	60.7	3.5	.0	14.7	.0	11.0	90.5
Subtotal/Average		1,402	3.1	.5	36.6	1.9	.4	13.2	.0	10.8	66.5
Burgess Spring 1936	PP	2,744	18.7	1.9	18.6	.0	.4	38.0	1.2	14.8	93.6
	JP	2,883	15.2	1.8	20.4	.1	.3	40.1	1.5	11.6	91.0
Subtotal/Average		5,627	16.9	1.9	19.5	.0	.4	39.1	1.3	13.2	92.3

Source: Summary of seedling mortality at five site factor stations located on Stanislaus Experimental Forest by H. A. Fowells, and Progress report prepared by L. D. Lloyd. "Field study of germination and mortality to Jeffrey and ponderosa pine seedlings–Seeding experiment on the Burgess Spring Experimental Range." 1937.

1/ PP = ponderosa pine; SP = sugar pine; WF = white fir; IC = incense-cedar; JP = Jeffrey pine.
2/ Includes trampling damage by man, livestock, and dee[illegible]

An injury related to frost heaving is girdling or severing small seedling stems by action of surrounding ice. The damage is caused by wind chafing the seedlings against the ice or possibly by expansion and contraction of the ice against the seedling (Whitesell, 1959).

Competition

Young coniferous seedlings must compete with all other vegetation for the limited amount of soil moisture, sunlight, and available nutrients in the soil. Unless the areas are cleared of competing vegetation, young seedlings are at a great disadvantage. The need for site preparation (O'Keefe, 1960) has been stressed in Chapter III.

The importance of getting regeneration started promptly after a burn may even be greater for direct seeding than for planting. On the Bogus burn, stocking of transplants and seedlings were about equal when the trees were started the first year after the burn (Baron, 1962). However, only 2 percent of the seedlings from the second-year seedings survived, compared to 25 percent for transplants.

Large burns are frequently sown with grass to minimize establishment of undesirable vegetation and to reduce soil erosion. The study on the Bogus burn indicated some species of grass could be started at the same time as the trees, but that others were detrimental (Baron, 1962). Big bluegrass had the least and orchardgrass the most adverse effect on trees (table 62). Direct seedings 2 and 3 years after the grass was started were failures.

RODENT CONTROL MEASURES

Effective rodent control is an essential prerequisite for direct seeding. Without some form of control, rodents (mainly mice, chipmunks, and squirrels) may consume all the seed (Hooven, 1966). Three methods have been used to reduce seed losses: (1) screen barriers to keep rodents from seeds, (2) lethal baits to destroy rodents, and (3) chemical repellents or lethal systemics to repel rodents from seeds.

Table 62. Tree survival and seed-spot stocking by grass species and year of pine planting.

Grass species (seeded first year after burn)	Survival of trees by year planted			Stocking of seedspots by year planted		
	First	Second	Third	First	Second	Third
	Percent					
Big bluegrass	63	36	10	61	0	0
Hard fescue	67	28	7	48	1	0
Pubescent wheatgrass	68	18	1	47	1	0
Redtop	66	22	4	49	0	0
Tall oatgrass	47	12	6	35	0	0
Timothy	39	16	1	52	0	1
Perennial ryegrass	50	18	16	44	0	2
Orchardgrass	39	14	5	29	0	1
No grass	57	68	26	69	14	8
Average all plots	60	25	8	55	2	1

Source: Baron (1962).

Screen Barriers

Seeds can be protected from rodents by placing small hardware cloth screens over the seed spots. The screens also reduce high surface soil temperatures (Fowells and Arnold, 1939) and provide beneficial shade (Krauch, 1938). Fowells and Arnold (1939) reported maximum air temperatures were more than 12° F. lower inside screens than outside.

Screen barriers, although effective to protect seeds, have some disadvantages which limit them to small scale operations. The screens (1) cost 75 to 90 cents each, (2) must be transported to the area, (3) distributed to the seeding spots, (4) worked into the soil about 1 inch, (5) removed at the start of the second growing season, (6) retrieved, and (7) transported back to the warehouse for reuse on the next project.

Show (1930) was the first to use wire screens to cover seed spots. He found that they were the only way to protect seeds long enough to permit germination. He concluded, however, that the cost of this protection prohibited its use for anything but experimental studies.

During the past 30 years, many tests have been made with cone-shaped (fig. 88) and dome-shaped (fig. 89) screens (Dunning, 1940; Fowells and Arnold, 1939; Fowells and Schubert, 1951b; Keyes and Smith, 1943; Schubert, 1955; Sischo, 1958; Stein, 1955a, b, 1957). Keyes and Smith (1943) were the first to conduct comprehensive tests with cone screens. The screens were found to protect seeds from rodents; however, other agents reduced their effectiveness. Rodents were responsible for only 2 percent of the seed losses in protected spots, compared to 94 percent in unprotected spots. In one of their tests, sheep knocked over almost all the screens; and in another, snow movement and frost heaving lifted the cones to permit rodents access to the seeds. When screens are used repeatedly in the same area, rodents learn to enter the screens by tunneling under the screens (Adams, 1962; Dunning, 1940; Kirk, 1947).

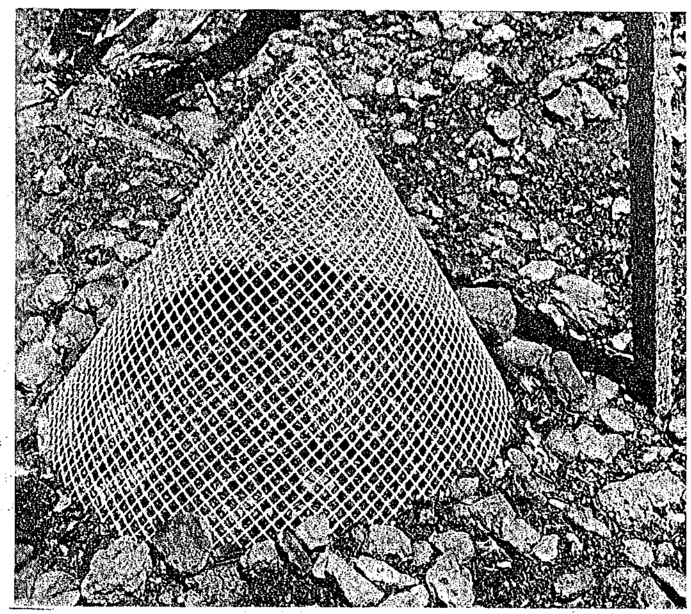


Figure 88. Cone-shaped screen used in direct seeding to protect seeds from rodents (U. S. For. Serv. photo).

Figure 89. Dome-shaped screen to protect seeds from rodents (U. S. For. Serv. photo).

Since 1934, members of Pacific Southwest Station have set out nearly 131,000 seed spots, with and without screen protection (table 63). Germination and survival have been consistently higher in the protected spots; however, there have been a few complete failures too. Seed germination in screen spots averaged 81 percent, ranging from 2 to 100 percent; whereas, average seed germination in unscreened spots was only 12 percent.

Screens also reduce low soil surface temperatures and mortality from freezing. On Fish Camp plots, screens reduced freezing losses by more than 50 percent (Schubert, 1955).

Cone and dome screens have been equally effective in protecting seeds from rodents. The chief advantage of the dome screen has been cost--about half that of cone screens. Dome screens require less hardware cloth and are faster to make than cone screens. Furthermore, they are easier to install and carry. One man can carry 2 to 3 times as many dome screens as cone screens. However, costs of material and labor still are prohibitive on large scale seeding projects.

Table 63. Germination and stocking in screened and unscreened seed spots in direct seeding trials, 1934-1961.

Seed spot treatment and species	Seed spot basis	Germination	Stocking	
			First year	Second year
	Number	Percent	Percent	Percent
Screened:				
Ponderosa pine	14,365	82(39–100) 1/	62(10–97) 1/	49(7-97) 1/
Jeffrey pine	13,155	82(40–99)	60(20–99)	46(9–88)
Sugar pine	5,461	76(2–100)	51(0–100)	45(0–100)
White fir	407	65(10–98)	35(8–88)	27(4–65)
Douglas-fir	480	85(28–100)	79(21–96)	64(20–79)
Red fir	250	61 2/	5 2/	1 2/
Incense-cedar	240	81(52–100)	42(10–85)	33(10–80)
Subtotal/Mean	34,358	81(2–10)	59(0–100)	47(0–100)
Not screened:				
Ponderosa pine	59,629	12(0–100)	5(0–90)	3(0–82)
Jeffrey pine	31,991	10(0–82)	2(0–75)	1(0–74)
Sugar pine	2,747	24(0–100)	16(0–84)	11(0–52)
White fir	1,347	14(5–81)	9(2–59)	6(1–47)
Douglas-fir	290	58(10–83)	48(4–71)	39(0–60)
Red fir 2/	250	10	2	1
Incense-cedar	0	--	--	--
Subtotal/Mean	96,254	12(0–100)	4(0–90)	3(0–82)

Source: Data on file at Pacific Southwest Station and numerous published reports.
1/ Percentages enclosed in parenthesis indicate ranges.
2/Only one trial with red fir.

To cut costs, small cylinder-shaped screens (fig. 90) were tested in several areas in California and Oregon. The first ones tested were made by rolling a 4-inch square of either fly screen or hardware cloth into a cylinder 4 inches long and 1 inch in diameter. These screens, called "K-screens" [43] are inexpensive and do not require removal after the seed germinates. Although good results have been reported for trials conducted in Oregon (Stein, 1955a, 1957), tests in California have not been satisfactory (Roy and Schubert, 1953; Sischo, 1958). The poor results in California have been due to excessive frost heaving, poor seed germination, too rapid drying of the soil inside the screen, destruction of the screens by deer and livestock, and removal by ground squirrels and other animals.

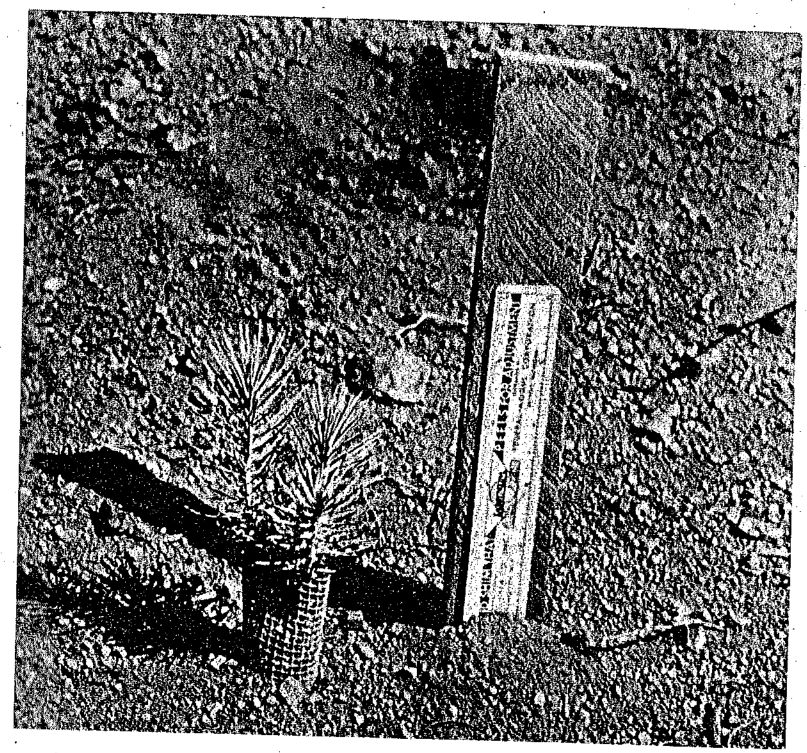


Figure 90. A 4-inch cylindrical screen was tested to protect seed from rodents.

43/Suggested by Joseph Keyes, formerly with the U. S. Fish and Wildlife Service.

Solid metal cylinders have been tried in a few areas. In southern California, Juhren (1950) reported first-year establishment of 55 to 61 percent for spots protected with beer cans that had their tops and bottoms removed. His unprotected spots were all robbed by rodents. Sischo (1958) held trials with beer cans and metal cylinders; they all failed. Two small tests on Stanislaus Experimental Forest were also failures; seed germination was low and seedling mortality high, probably due to excessive drying and overheating.

Hattersley (1953) reported very high survival with seed spots covered with paper in southern California. The same method was tried in northwestern California without success (Tevis, 1953). And later trials with paper covered spots in southern California were also reported as failures (Sischo, 1958).

Lethal Bait

Extreme precautions must always be taken when lethal chemicals are used in direct seeding, and proper clearance must be obtained from the local County Agricultural Commissioners. Application of "1080" is permitted only under the direct supervision of a governmental agency representative experienced in handling this poison, such as a County Agricultural Commissioner.

Lethal baits to destroy rodents have four undesirable features: (1) they may kill birds and other animals if necessary precautions are not followed; (2) they kill rodents, which are important in the biological control of seedling-feeding, cutworms, white grubs, and other harmful insects (Jameson, 1952); (3) they leave a population vacuum which is soon filled by rodents from adjacent untreated areas (Hooven, 1966), and (4) they are impractical to use except on large areas.

Many experiments have been conducted in California during the past 50 years to find an effective chemical to reduce seed destruction by rodents. Most of the chemicals tested have been extremely lethal to animals. But the amounts and the methods used have been directed specifically toward control of small mammals without endangering the lives of larger animals, particularly deer and livestock. Poisoned oats and wheat have been used most often as lethal bait.

The poison bait has been distributed in two ways: (1) broadcast or (2) placed in selected spots. In the broadcast method, the bait was scattered lightly over the area to be regenerated, plus a 1/4 mile buffer zone around the area either by aircraft or Cyclone seeder. In the spot method, about 1/2 tablespoon (10 to 20 kernels) of bait was placed close to the underside of logs, stumps, rocks, and other spots where rodents visit; but where the bait could not be reached readily by livestock or game animals. The amount of chemical used was too small to endanger larger animals, but large enough to kill rodents if they consumed at least 10 to 20 grains of bait. About 1 quart of poisoned bait was distributed per acre–in about 80 spots or broadcast uniformly over the area.

The three lethal chemicals tested most extensively were: (1) strychnine, (2) thallium sulphate, and (3) sodium fluoroacetate (compound "1080"). Results of the tests, with these and other chemicals, have been extremely variable. Some chemicals have been completely ineffective under the test conditions, while others seemed to give promise of success. Compound 1080 has given least variable results.

Strychnine was the least effective of the chemicals tested. Show (1930) first used it in the brushfields of northeastern California during the period 1908-1912. He used both the broadcast and spot method to distribute strychnine-treated wheat. Control was considered ineffective, as rodents consumed most of the pine seed.

Other trials with strychnine on National Forests were held between 1914 and 1935. Some were with poison treated grain bait and others with poison coated pine seeds. All were failures, since rodents consumed the tree seeds despite the treatments (Dunning, 1940; Fowells and Schubert, 1951b).

Thallium sulphate was reported to be more effective than strychnine to control rodents; however, even this chemical did not give complete control (Dunning, 1940). Krauch (1945) reported that thallium sulphate-treated sunflower seeds were effective in providing protection to natural seedfall of Doulgas-fir on Lincoln National Forest in New Mexico. In Idaho and Washington, the same treatment produced satisfactory results in a direct seeding with western white pine (Schopmeyer, 1940). Smith and Aldous (1947) reported rodents were practically eliminated by thallium sulphate bait on small areas in California, but the areas were reinvaded within 3 to 10 days after treatment.

Sodium fluoroacetate, commonly referred to as Compound 1080 or just 1080, has been used most widely in forest rodent control. It was used in a natural regeneration experiment on Stanislaus Experimental Forest in 1948 (Fowells and Schubert, 1951b). Poisoned oat groats, treated at the rate of 3 ounces of 1080 per 100 pounds of groats, were distributed in July over an area of 600 acres, at a rate of 1/2 to 2/3 pound per acre. In late September, just before seedfall, only one chipmunk was caught in 120 trap nights. In fall 1948, 400 screened and 400 unscreened seed spots were sown with five sugar pine seeds per spot. By September 1949, only 38 percent of the screened and 16 percent of the unscreened spots were stocked with one or more seedlings. Many of the unscreened and some of the screened spots showed definite evidence of rodent activity. Natural seedfall yielded 29,000 sugar pine and 167,000 white fir seeds per acre in the treated area.

Although the 1080 poisoning was not considered satisfactory in terms of the direct seeding, it was satisfactory in terms of natural regeneration. In June 1949, 707 sugar pine and over 12,000 white fir seedlings per acre were counted in staked milacre quadrats. The cost of the rodent poisoning was only 46 cents per acre for bait and labor (Cosens and Tackle, 1950).

The reduction of the rodent population following the July 1080 treatment, and the following buildup during winter and early spring, indicated the need for a second treatment. However, because of an exceptionally heavy snow, the second treatment was not done until early June 1949. Only 35 acres were re-treated with 5 pounds of 1080 poisoned sugar pine seed. Each carried about 12 milligrams of 1080, an extremely toxic dosage. However, on the basis of rodent census 2 weeks after treatment, this second poisoning was not effective: eight mice and one chipmunk were caught in 200 trap nights.

There are four important possibilities why the seeding failed:

1. The poison bait was not eaten because of "poison shyness."
2. The 1080 did not penetrate beyond the seed coat.
3. If eaten, the poisoned seed coat was discarded before ingestion without harm to the rodents (Spencer and Kverno, 1953).
4. Constant reinvasion of rodents from adjoining untreated areas.

These possibilities must be considered in all control work to make it effective.

Three-Stage Lethal Bait Treatment [44]

Failure to obtain adequate rodent control with single applications of thallium sulphate or 1080 for fall seedings led to a proposal of a 3-stage poisoning program.[45] The first treatment with 1080 was made on wheat 1 to 2 weeks before seeding in fall, the second treatment with thallium sulphate on oats in early winter before snowfall and the third treatment with 1080 on wheat before seed germination in spring. About 1 pound of bait per acre was recommended, placed in approximately 80 selected spots. The treated area included a buffer strip about 1/4-mile wide around the area to be regenerated.

Thallium sulphate was suggested for the second treatment in the event rodents had developed an aversion to 1080 during the first poisoning. Oats can be substituted for wheat without much sacrifice in effectiveness. The grain should be treated with aniline dye, preferably green, to insure identity of poisoned bait and to minimize bird mortality.

The 3-stage rodent treatment has been successful and recommended for standard practice in Oregon (Stein, 1955b, 1957). Their recommendation specified wheat for all three treatments.

44/ Members of the U. S. Fish and Wildlife Service have been most helpful in treating seed for use on National Forests. They may be consulted for latest seed treating and application instructions.

45/ Based on recommendations made in 1948 by Joseph Keyes, U. S. Fish and Wildlife Service, and Dr. E. W. Jameson, Jr., University of California.

The 3-stage rodent treatment may be used to protect natural seedfall and fall artificial seedings. For spring-sown seed, the treatments may be cut down to two poisonings; one should be with 1080 and the other with thallium sulphate.

Wheat was suggested as being better than other grain or conifer seed. However, McKeever (1963) reported that rodents consumed more 1080 treated Jeffrey pine seed than treated wheat, indicating pine seed as a preferred bait. Howard and Cole (1967) also have shown that deer mice prefer pine seeds to grains. More recent research by Howard [46/] indicates that among grain baits, crimped and whole oat groats are preferred and best absorb toxicants.

Howard [47/] suggested a mixed bait -- 20 percent bait treated with 10 ounce 1080 and 80 percent "clean" bait. This reduces the possibility of rodents becoming "poison shy."

A poison provided by the U. S. Fish and Wildlife Service's Denver Research Center for testing of forest rodents, labeled DRC 714, an organo thiophosphate, has been tried in the Mt. Shasta area of the Cascades, Challenge Experimental Forest in the northern Sierra Nevada and near Korbel in the Coast Range.[48/] It was effective in the Korbel area, but not in the others. Varieties of deer mice evidently vary in their susceptibility to the poison. However, it is entirely effective as a gophacide.

Small rodents, particularly deer mice are very prolific (Jameson, 1953). Antifertility agents applied to baits show promise in controlling mouse populations. [48/] Examination of deer mice offered baits treated with such agents indicated about 65 percent were abnormal. Based on this test, it is possible that populations once reduced by poisons can be maintained at a low level for some time with antifertility agents.

Diphacinone (trade name Diphacin) an anticoagulant poison on wheat at 2 pounds per acre showed considerable promise in 1967 testing.[48/] In the central Sierra Nevada and northwest California it afforded complete control of the deer mouse populations. A 2 percent formulation of diphacinone is registered for deer mouse control in California.[49/] The advantage of this toxicant over 1080 is that there is no danger of secondary poisoning of non-target species. More recently an even more effective anticoagulant chlorophacinone has been registered for forest rodent control in California.[50/] Rate of application is the same as for diphacinone.

46/Howard, Walter E. Rodent control in relation to forest regeneration. Progress report 1969-70. (Univ. of Calif. contract research project report to the State Forester, 1970.)

47/Howard, Walter E. Rodent control in relation to forest regeneration. Progress report 1965-66. (Univ. of Calif. contract research project report to the State Forester, 1966.)

48/Howard, Walter E. Rodent control in relation to forest regeneration. Progress report 1966-67. (Univ. of Calif. contract research project report to the State Forester, 1967).

Seed Treatment

The ideal method to control rodents would be to pretreat conifer seed with an effective repellent or sublethal dose of a systemic poison (Kverno and Hartwell, 1957). However, of several thousand chemicals tested by the U. S. Fish and Wildlife Service, U. S. Forest Service, State agencies, and others, only a few have shown some promise, and none of those available is effective as a repellent. In general, only the most promising chemicals have been included in field tests.

Numerous tests have been made in recent years with chemicals added directly to the seeds to protect them from rodents. All chemicals tested were lethal; however, the objective was to repel rather than kill rodents. Some chemicals have been systemic poisons. The dosages, in most cases, were sublethal unless large quantities of seeds were eaten.

Strychnine.—Before 1942 most of the tests were with strychnine though some tests included thallium sulphate, red lead, and numerous other chemicals. Strychnine was tried on ponderosa pine, Jeffrey pine, sugar pine, and white fir. All tests with strychnine have been failures (table 64). Seed germination and second-year stocking were generally higher for untreated seed than for strychnine treated seed (tables 64 and 65), indicating that the strychnine treatment probably inhibited germination. Following the tests by Keyes and Smith (1943) in 1941, strychnine has been abandoned as a rodent "repellent."

49/See footnote 46.

50/Marsh, Rex E. Use of chlorophacinone in forest rodent control, 1971. (Personal communication.)

Table 64. Direct seeding trials with unscreened seedspots, by tree species and rodent repellent, 1934-1961.

Item and Species 1/	Rodent repellent treatment					
	None	Strychnine	Tetramine	"1080"	Endrin	All
Seedspot basis:			Number			
PP	27,254	31,193	667	80	435	59,629
JP	2,015	29,896	80	--	--	31,991
SP	565	1,120	347	640	75	2,747
WF	160	1,187	--	--	--	1,347
DF	--	--	100	--	190	290
Total	29,994	63,396	1,194	720	700	96,004
Germination:			Percent			
PP	13	9	92	90	75	12
JP	16	10	38	--	--	10
SP	37	10	67	13	45	24
WF	81	5	--	--	--	14
DF	--	--	10	--	83	58
Average	14	9	74	21	74	12
1st. yr. stocking:			Percent			
PP	7	1	53	11	58	5
JP	13	1	38	--	--	2
SP	23	6	47	11	7	16
WF	59	2	--	--	--	9
DF	--	--	4	--	71	48
Average	8	1	46	11	56	4
2nd yr. stocking:			Percent			
PP	5	0	44	0	46	3
JP	11	0	34	--	--	1
SP	19	3	29	10	1	11
WF	47	1	--	--	--	6
DF	--	--	0	--	60	39
Average	6	0	35	9	45	3

1/PP = ponderosa pine, JP = Jeffrey pine, SP = sugar pine, WF = white fir, DF = Douglas-fir.

Table 65. Direct seeding trials with screened seedspots, by tree species and rodent repellent, 1934-1961.

Item and Species 1/	Rodent repellent treatment					
	None	Strychnine	Tetramine	"1080"	Endrin	All
Seedspot basis:			Number			
PP	12,728	583	539	80	435	14,365
JP	8,225	4,850	80	--	--	13,155
SP	4,375	392	219	500	75	5,561
WF	280	127	--	--	--	407
DF	190	--	100	--	190	480
IC	240	--	--	--	--	240
Total	26,038	5,952	938	580	700	34,208
Germination:			Percent			
PP	82	42	95	100	91	82
JP	85	79	45	--	--	82
SP	81	70	54	41	91	76
WF	90	10	--	--	--	65
DF	100	--	28	--	100	85
IC	81	--	--	--	--	81
Average	83	73	74	51	93	81
1st. yr. stocking:			Percent			
PP	63	16	71	65	84	62
JP	66	50	40	--	--	60
SP	53	58	33	38	29	51
WF	47	8	--	--	--	35
DF	93	--	21	--	96	79
IC	42	--	--	--	--	42
Average	62	46	55	43	81	59
2nd. yr. stocking:			Percent			
PP	49	12	67	60	74	49
JP	51	36	38	--	--	46
SP	48	46	26	36	19	45
WF	38	4	--	--	--	27
DF	79	--	20	--	72	64
IC	33	--	--	--	--	33
Average	49	34	50	40	67	47

1/PP = ponderosa pine, JP = Jeffrey pine, SP = sugar pine, WF = white fir, DF = Douglas-fir
IC = incense-cedar

Compound 1080.—Although this chemical is used for broadcast poisoning to kill rodents (Fowells and Schubert, 1951b), it has not been effective as a repellent (tables 64 and 65). In one study with ponderosa pine seeds, 90 percent of the unscreened spots with 1080 coated seeds had one or more germinated seeds (table 64). However, within 1 week, rodents had destroyed most of the seedlings while digging in the spots for ungerminated seeds.

Surface-coating sugar pine seeds with 1080, zinc phosphide, or red lead was ineffective in a study on Stanislaus Experimental Forest (Schubert, 1953). Rodents consumed most of the treated seeds in unscreened spots. No dead rodents were found in the study area. This is another instance that indicates rodents can remove treated seed coats without ingesting the poison. None of the three poisons or carriers inhibited germination.

Tetramine.-The systemic poison tetramine (Tetramethylene disulpho tetramine), applied in sublethal quantities, was the first chemical that satisfactorily repelled rodents in California. Seeds, soaked in a tetramine-acetone solution, absorbed tetramine into seed tissues (Dimock, 1957; Roy, 1957b; Shaw, 1953; Spencer and Kverno, 1953; Spencer, 1954). Both seeds and resultant seedlings contained the repellent. Although tests indicated satisfactory repellent properties, tetramine is extremely toxic to humans and large game animals. It is no longer generally available.

Endrin.—This highly toxic insecticide, is now the most commonly used seed treatment chemical, but it leaves much to be desired. It has been very effective against mice, but not the larger rodents. The specific formulation and the concentration of endrin probably should be varied for areas with different rodent composition and climate (Kverno, 1964).

Results with endrin-treated seeds have been variable. At Yosemite Mountain Ranch, seed germination was about the same for endrin-treated ponderosa pine seeds as for those treated with tetramine; however, first-year stocking was higher for the endrin treatment (table 66). Part of the difference in stocking was caused by a dense stand of bracken fern on one of the tetramine plots. None of the seed spots was disturbed by rodents. All spots were treated with dieldrin to prevent a repetition of the preceding year's heavy seedling mortality by cutworms and wireworms.

Table 66. Germination and first-year stocking of ponderosa pine seed treated with endrin and tetramine - Yosemite Mountain Ranch, 1956-7.

Seed treatment	Seed spot protection	
	Screened	Unscreened
	------- Percent ---------	
Germination:		
Tetramine	98	94
Endrin	97	97
Untreated	93	--
Stocking:		
Tetramine	84	65
Endrin	91	88
Untreated	77	–

At Stanislaus, endrin was ineffective in preventing rodent damage to sugar pine seeds. Rodents excavated, but did not consume, over half of the endrin-treated seeds in unscreened seed spots. Adams (1961) reported a successful seeding with endrin-treated Douglas-fir on a plot poisoned with 1080 treated grain. However, the seeding he made on another plot without the 1080 poisoning was a complete failure.

Endrin has not inhibited germination of Douglas-fir (Roy, 1961), ponderosa pine, or sugar pine seeds.

Arasan, a chemical registered for seed treatment in California, may be added to the endrin to offer protection against birds. This addition also may reduce some seed destruction by chipmunks and squirrels. The active ingredient in arasan is thiram. Derr (1964) found that arasan 42-S was more effective than arasan-75 as a bird repellent. He also stated that arasan 42-S was safer to use and more durable. However, it is somewhat phytotoxic to Douglas-fir and may reduce germination by from 10 to 15 percent in seed testing. Although thiram may depress laboratory germination, Jorgensen (1968) found that field germination of longleaf pine seed was improved. Derr's method to coat seeds with endrin-arasan 42-S, modified to meet California regulations, is as follows:

1. Add 2½ pounds of endrin 50-W to 2½ gallons of arasan 42-S and mix thoroughly.
2. Add 25 fluid ounces of Dow Latex 512-R to another 2½ gallons of arasan 42-S and stir briefly.
3. Blend the mixtures from (1) and (2) above.
4. Pour about 2.4 gallons of the endrin-arasan-latex mixture on 100 pounds of seed and mix in a tumbler or cement mixer.
5. Add about a 1/2 pint of alkaline fast green coloring, mix, and then surface dry.

Smaller quantities of the endrin-arasan can be prepared by taking the proper proportion of each material. The amount of chemicals needed will vary for different species depending on the seed surface. Use only the quantity needed to coat the seeds. California Agriculture Regulations require that the endrin concentration for conifer seed treatment shall follow concentrations and procedures given on the label of the Stauffer Chemical Co. 50-W endrin container. Concentration, by weight of seed, shown on the label is 0.5 percent active ingredient. The California Department of Fish and Game recommends using a green coloring such as "monasteral green" to make seed less attractive to birds. [51] The Agriculture Regulations further specify that only employees of governmental agencies or licensed pest control operators can endrin treat seed.

Aversion or Bait-Shyness

Kverno (1964) stated: "There are two and only two approaches to reducing wildlife damage; they are: (1) to reduce the number of animals or (2) to render the item less attractive." To date, none of the chemicals, except tetramine, has produced seed aversion or bait-shyness in rodents under field conditions (Kverno and Hartwell, 1957).

[51] Hunt, Eldridge. Report to the Animal Committee of the California Forest Pest Control Action Council, Nov. 27, 1969.

Pelletized Seed

Three small trials have been made with ponderosa pine seeds enclosed in a commercial pellet material, all without success (Fowells and Schubert, 1951b; Kraebel, 1955). In two tests, none of the seeds in pellets germinated out of several hundred planted. On the Kennett area at Shasta Lake, germination occurred in only 42 percent of the seed spots containing pelletized seed compared to 88 percent for unpellitized seeds.

It is possible that the pellet material was toxic to the seed or mechanically inhibited germination. Pelleting offers the advantage of making seed uniform in size and shape, which would be an advantage in machine seeding.

Effect of Fire on Rodents

In two studies, one on a timber burn and one on a slash burn, Tevis (1956a,b) found that fire does not effectively control seed-eating rodents. On an 87,000–acre timber burn, he found that the rodents survived by going underground (Tevis, 1956a). After the fire, insects provided an adequate food supply for the mice, while kangaroo rats fed on seeds from hidden stores. The hot slash burn either killed or drove out most of the mice on the area; however, after the first rain, mice reinvaded the area (Tevis, 1956b).

PROCEDURES FOR DIRECT SEEDING

The success of direct seeding depends on many different factors. Corrective action is needed to reduce or prevent losses caused by competition, rodents, insects, and drought. Seed quality, time of sowing, and depth of sowing will also affect seed germination and seedling establishment.

Procedures basic to any regeneration method involving seed require adequate site preparation, and rodent and insect control. These cannot be overemphasized. Site preparation was discussed in detail in Chapter IV. Rodent and insect control were described earlier in this chapter.

Seed Quality

Only high quality seed of local origin should be used in direct seeding. The seed viability must be determined by a germination test before seeding. The germinative capacity will vary by seed lot and species. To be suitable for direct seeding, minimum acceptable viability for pine should be 75 percent, for Douglas-fir 70 percent, and for true firs about 35 percent (Western Tree Seed Council, 1966).

Seeds also must have a high germinative energy, and should be capable of attaining 50 percent of maximum germination within 1 week. Seeds with a slow germination rate often fail to germinate under field conditions.

Seed Stratification

The need for stratification before sowing depends on season of seeding. Fall-sown seeds do not require stratification. Spring-sown seeds should be conditioned through moist-cold stratification for rapid and complete germination. Methods and duration of stratification were covered in Chapter II.

Time to Sow

Seeds may be sown during fall, winter, or early spring – depending on accessibility of the area. One of the chief advantages expressed for seeding over planting has been the longer seeding period in fall. But this advantage holds true only if rodents are adequately controlled. If rodents are not adequately controlled, fall seeding is not advisable as it exposes seeds to rodents for several extra months.

Fall seeding has these distinct advantages over spring seeding:

1. A longer seeding period.
2. No need for seed stratification.
3. Seeding is generally easier and faster while soil is dry.
4. Seeds usually germinate earlier in the spring.
5. Seedlings are better suited to withstand summer drought.

Late fall seeding is more desirable than early fall, since some seed eating rodents, such as squirrels and chipmunks, may be hibernating by then, thereby reducing the exposure period.

The only advantage of spring seeding over fall seeding is again the shorter period seeds are exposed to rodents. However, as rodents are readily attracted to fresh soil disturbance, this advantage may not be significant. All seeds can be destroyed in a few days when rodents are active.

Most of the advantages for fall seeding automatically become disadvantages for spring seeding, though they may not be significantly worse. The necessity for seed stratification is one of the more important disadvantages. To obtain prompt and complete germination when growing conditions become favorable, the seeds must be kept moist and sown in moist soil. If the seeds are permitted to lose too much moisture, germination is retarded or may cease entirely.

The spring seeding season is short, at best. Late snowmelt or late spring snows may delay seeding. To be successful, all spring seeding should be completed by mid-May; earlier in some areas, depending on the occurrence of spring rains. Seedlings from the earliest germination have the best chance for establishment. At Burgess Spring, 75 percent of the seedlings from seed which germinated before May 28 survived, but only 19 percent for seed which germinated between May 28 and June 18 (Lloyd, 1937). And only 4 percent of the seedlings that started between June 19 and July 9 survived the first summer.

Depth to Sow

Some conifer seeds have been shown to germinate better when exposed to light under laboratory conditions (Hellmers and Sundahl, 1959; Richardson, 1959). However, under field conditions seeds must be covered with soil or some other medium: (1) to reduce chances for detection by birds and rodents; (2) to ensure adequate moisture for germination; and (3) to aid in initial establishment. One of the main reasons for the poor establishment of broadcast sown seed has been the lack of proper seed coverage. In Oregon, Stein (1955b) reported heavy mortality when seeds were sown on top of the soil. Some seed covering is possible, however, by dragging the seeded area with chain, channel iron, or harrow. Broadcast ponderosa pine seed was effectively covered in a seeding test on Challenge Experimental Forest by using a tractor drawn drag (Hall, 1967). The drag consisted of a 20-foot railroad rail on top of the drum of a D-7 Caterpillar to which 5, 4-foot drags of 8-inch channel iron were fastened. First-year stocking was 72 percent for dragged plots and 48 percent for untreated ones. Even though there is improved seedling establishment when broadcast seeded areas are dragged, covered depths are difficult to control by this method. Some seeds may be buried too deeply, others not deeply enough.

Another advantage to spot and drill seeding is the control over depths of sowing. Spot seeding depths are easily controlled when the planter prepares his hole to deposit the seed. Whether furrow openers or discs are used on drill equipment, provision is usually provided for controlling depths of the seeding furrows.

How deep seeds should be sown will depend on the type of soil on the area and the species of seed. Small seed such as redwood should be sown with a light cover, whereas large seeded pines can be sown deeper. Under no condition should seed be sown more than 1/2 inch in heavy soil, even for the pines. Where the soil is light and dries out rapidly, pine seed should be sown deeper, usually 1/2 inch to 1 inch.

SOWING RATES

The amount of seeds required to obtain adequate stocking depends on many factors. The effect that some factors will have can be determined with reasonable certainty, whereas the effect of others cannot. Such things as seed viability and number of seeds per pound can be measured. However, the effect of weather and biotic agents can be based only on estimates from past performance. At best, these estimates can be used only as guides, since the environmental conditions will vary from place to place and year to year.

Some of the uncertainties affecting the success of direct seeding can be minimized by: (1) site preparation to reduce competition for soil moisture and to reduce insect populations; (2) poison baiting to reduce rodent populations; (3) seed treatment to improve germination percent and rate; (4) late seeding in fall to reduce exposure to hibernating rodents; (5) early seeding in spring to

provide a longer growing period before the advent of summer drought; and (6) seed and soil treatments to reduce losses by rodents and insects. Each of these treatments will help reduce the amount of seed required and increase the chances for success.

The amount of seed required also will depend upon the sowing method. Spot seeding will require the least amount of seed. Drill seeding will require about 2 to 3 times more seed than spot seeding, while broadcast seeding will require 4 to 10 times as much seed as drill seeding.

The sowing rates, indicated under the three sowing methods below, are based in part on past experience in direct seeding and in natural seeding and in part on theoretical probabilities. These sowing rates are intended to serve as guides and should be adjusted for local conditions whenever a change is warranted.

Spot Seeding

Various sowing rates have been used in the past. In the earlier studies in California, 10 to 20 seeds were sown per spot (Dunning, 1940) or enough seed to insure that at least one seed germinated per spot (Keyes and Smith, 1943). In more recent studies, this rate was reduced to 5 to 10 seeds per spot (Fowells and Schubert, 1951b; Roy, 1957a, 1961). Corson and Fowells (1952) recommended that five seeds be sown per spot, based on the assumption that ordinarily the chances were about 1 in 4 that a seed will germinate and the seedling live. Roy (1957a) suggested that five seeds should be sown per spot if the viability was 50 percent or more and up to 9 seeds for 30 percent viability. Seed of lower quality should not be used.

Sowing rates have varied even more in other regions of the United States. In one of the first published reports on direct seeding, Cox (1911) indicated that about 12 viable seeds should be sown per spot. In the Southwest, Pearson (1950) recommended sowing 10 to 15 seeds per spot, and Krauch (1938) sowed from 30 to 40. But in Oregon, Stein (1957) recommended sowing only two good seeds per spot and doubling the number of spots. Foresters for Soper Wheeler Company in Strawberry Valley, Yuba County, also have recommended from one to two seeds per spot, spacing spots 3 feet apart in the row with 8 feet between rows. [52]

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[52] Atkinson, Wm. Soper Wheeler Co. direct seeding methods. 1966. (Personal communication.)

Numerous problems are encountered in any attempt to determine precisely the number of seeds to sow per spot to obtain adequate stocking. The most serious problem is that the factors affecting seed germination and seedling survival may not occur at random. For example, rodents or insects may destroy one or all seeds or seedlings in a spot. Furthermore, if one seed or seedling is destroyed, the chances of the other seeds or seedlings escaping destruction are reduced. Factors of climate and soil also affect seed germination and seedling survival. The nonrandom effects of these factors, however, can be minimized–but not eliminated entirely--by effective rodent control and insecticides, by adequate site preparation, and by careful location of the seedspot to avoid unfavorable microclimatic and microedaphic conditions.

The number of seeds sown in each spot should be just sufficient to insure that most spots have at least one seedling and that few have many seedlings. There is no advantage to sowing more seed than indicated by the viability of the seed and the expected seedling mortality. Sowing at a higher rate than needed is a waste of seed and may lead to over dense stocking that will require thinning.

Sowing Guide

Schubert and Fowells (1964) developed a guide to determine the number of seeds to sow per spot for different stocking levels (fig. 91). Their guide is based on the probability or chance that a seed will germinate and the seedling will survive. Therefore, to use the guide, the germination and survival ratios must be known. The germination ratio is the number of germinated seeds divided by the number sown. The survival ratio is the number of seedlings alive after two growing seasons divided by the number initially emerged. To be most effective, the survival ratio should be based on data collected over a period of years. If no data are available, assume a survival ratio of 0.40 for the first seeding and then adjust for future seedings.

The following procedure is used to determine the number of seeds to sow per spot from figure 91.

1. Determine seed germination and seedling survival ratios.
2. Multiply germination ratio by the survival ratio by 100 to find the probability-of-success in percent.

3. Locate the probability-of-success (fig. 91).
4. Extend a vertical line from the point in (3) above to th acceptable stocking level curve.
5. Run a line horizontally from the intersection on the stockin curve to the number of seeds axis.
6. Sow the number of seeds per spot indicated.

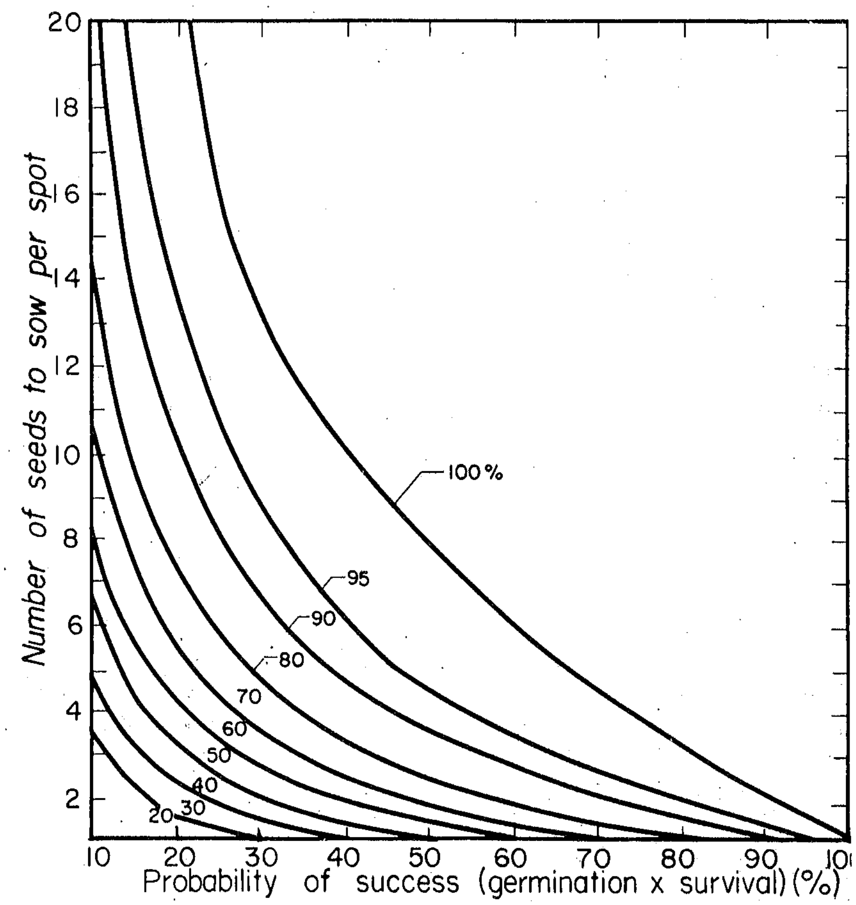

Figure 91. Expected stocking curves (percent of seedspots with one or mo seedlings) for various probabilities of success and sowing rate (From Schubert and Fowells, 1964).

For example, if the germination ratio is 0.80 and the survival ratio is 0.50, the probability-of-success is 40 percent. If you want 95 percent of the spots to have at least one seedling, you should sow six seeds per spot. If satisfied with 75 percent of the spots stocked, you would sow only two seeds per spot.

Three things must be considered in the application of the seeding guide. First, seed germination in the field may be 10 to 30 percent lower than in the laboratory. If the difference is known, the germination ratio should be adjusted. If the difference is unknown, assume about a 20 percent reduction in germination. Second, complete stocking requires two or more times as much seed per spot as a 10 to 20 percent lower stocking percent. Third, a high sowing rate results in excessive seedlings in many spots.

The survival ratio in California is likely to be low. This will lead to a large number of seeds per spot to get a high percent of stocking. Furthermore, many spots would have far too many seedlings. To avoid these undesirable features, it would be advisable to settle for a 50 percent stocking and sow more spots per acre. The maximum number of seeds to sow per spot may be further limited to five seeds. If more than five seeds are required, a lower stocking percent should be accepted.

Number of Seed Spots per Acre

The initial stocking for direct seeding should be about 800 spots per acre. This is slightly higher than the initial stocking for planting to compensate for a higher seedling mortality. If seed spots are sown to get 100 percent stocking of the spots sown, the spots should be set at a 7- to 8-foot spacing.

Since a lower stocking percent should be used, additional spots will be required to produce the 800 stocked spots. To add the extra spots, it is recommended that the distance between spots in the row be reduced and the 8-feet between rows be maintained. For example, for the 50 percent stocking, the spots should be set 3.4 feet (6.8 x .50 = 3.4) apart in the rows. A similar change in distance must be made for other stocking percents. The number of spots per acre and the distance between spots within rows spaced 8 and 10 feet apart are shown in table 67 for three desired stocking levels and expected stocking of 10 to 100 percent.

Table 67. Distance between seedspots within rows spaced 8 and 10 feet apart for several stocking levels and expected stocking rates.

Expected stocking (percent)	Desired stocking levels per acre - - 600: Spots needed	600: Distance between spots in rows spaced at - - 8 ft.	600: 10 ft.	800: Spots needed	800: Distance between spots in rows spaced at - - 8 ft.	800: 10 ft.	1,000: Spots needed	1,000: Distance between spots in rows spaced at - - 8 ft.	1,000: 10 ft.
	Number	- - Feet - -		Number	- - Feet - -		Number	- - Feet - -	
10	6,000	0.9	0.7	8,000	0.7	0.5	10,000	0.5	0.4
20	3,000	1.8	1.5	4,000	1.4	1.1	5,000	1.1	.9
30	2,000	2.7	2.2	2,670	2.0	1.6	3,330	1.6	1.2
40	1,500	3.6	2.9	2,000	2.7	2.2	2,500	2.2	1.7
50	1,200	4.5	3.6	1,600	3.4	2.7	2,000	2.7	2.2
60	1,000	5.4	4.4	1,330	4.1	3.2	1,670	3.2	2.6
70	860	6.4	5.1	1,140	4.8	3.8	1,430	3.8	3.0
80	750	7.3	5.8	1,000	5.4	4.4	1,250	4.4	3.5
90	670	8.2	6.5	890	6.1	4.9	1,110	4.9	3.9
100	600	9.1	7.3	800	6.8	5.4	1,000	5.4	4.4

The normal range in seed requirements for seed spotting is 1,600 to 3,200 per acre for California. This range is based on an assumption of 30 to 50 percent probability-of-success with 50 percent of the seeded spots stocked. A higher acceptable stocking percent for the same range of probability-of-success would require more seeds. For example, at 90 percent stocking, 3,560 to 6,230 seeds are needed per acre.

Drill Seeding

For drill seeding, 4 to 6 thousand **viable** seeds per acre are recommended until actual experience indicates a higher or lower rate. Drill seeding requires more seeds than seed spotting because some of them (1) will be dropped on unfavorable spots, (2) will be buried too deep or too shallow, and (3) may be damaged by the metering mechanism or the packing wheel.

The distance between rows should be about 8 or 10 feet. With rows spaced 8 feet apart, one seed should be dropped every 1 to 1-1/2 feet within the row. For rows 10 feet apart, the distance between seeds should be reduced to 3/4 to 1 foot within rows.

Seeding at these rates should give 800 to 1,000 seedlings per acre provided: (1) the area was adequately prepared and baited to control rodents; (2) seeds were treated with a rodent repellent; and (3) were covered with a 1/2 to 1 inch of soil; and (4) the rows were sprinkled with an insecticide.

Broadcast Seeding

Broadcast seeding will require 4 to 10 times as much seed as the other two methods. The higher seed requirements are because: (1) seed losses to rodents and birds may be extremely high; (2) many seeds will fall on unfavorable spots; (3) germination of exposed seeds is extremely low; and (4) seedling mortality may be extremely high.

Two steps can be taken to reduce seed requirements in addition to the six steps listed earlier: (1) site preparation to loosen the soil; and (2) follow-up dragging or harrowing to cover the seeds.

Species with small seeds or a low preference by rodents are the most suitable for broadcast sowing, but may not be the most suitable for timber production. Seeds of the spruces, hemlock, redwoods and

some of the small seeded pines are more likely to fall into sm depressions and be covered with soil than the large seeded pines su as sugar, Jeffrey, ponderosa, and Coulter. Also, the small ones a less attractive to rodents.

Data based on results of broadcast seeding are quite limited. T aerial seeding of Douglas-fir on the Hoopa Indian Reservati produced a good seedling catch from 14,000 sound seeds.[53] Abo 1 pound of seed was sown per acre on an area logged the previo year. At the end of the first growing season, 1,413 seedlings per ac were found on 201 milacre plots. Other seedings in the northweste part of the State by private industry and the Forest Service produc similar results.

Aerial seeding on Arcata Redwood Co. clean-logged operatio in Humboldt County has been particularly successful (fig. 92).[54] Under provisions of California's Forest Practice Rules an alterna plan was approved permitting the company to clean-log 845 acres old-growth redwood and artificially regenerate the area by seeding lieu of leaving seed trees. Site preparation consisted of planne burning. Seeding was done in the winter of 1960-61 and 1961-62. mixture of 1/4 pound Sitka spruce and 3/4 pound Douglas-fir c each acre was applied by helicopter. A stocking survey in Octob 1966 indicated a low of 33 percent stocked milacre quadrats wi seedlings over 12 inches high in one area to 93 percent in anoth (table 68). Overall stocking amounted to 69 percent, well over the 4 percent required by the Forest Practice Rules. Redwood seedlin from natural seed fall were found in 40 percent of the quadrats. In year or two, stocking will be even more complete as small established seedlings grow into the 12-inch plus class. Sprouts fro stumps added considerably to the stocking, also.

Seeding requirements for broadcast seeding are the same as fo natural regeneration on prepared sites with adequate rodent contro The number of established seedlings per acre is directly related to th seed supply minus the losses from rodents, insects, drought, an other factors. Therefore, to keep seed supply at a reasonable amoun efforts must be made to reduce losses.

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[53] Annual report. Pacific Southwest Forest & Range Experiment Station. 1961.

[54] Maclean, R. M. Arcata Redwood Co. alternate plan No. 1, report and reconnaissanc stocking survey of 10/19-10/20/66, California Division of Forestry. (Unpublished repor to the State Forester, 1966).

Figure 92. Measuring 6-year-old Douglas-fir seedlings from 1960 broadcast seeding on Arcata Redwood Company land.

Table 68. Percent stocked milacre quadrats from 1960-62 helicopter seeding of Arcata Redwood Company clean-logged areas.

Area	Redwood over 12 inches	Total redwood	Total all species over 12 inches	Total all species
May Creek	80.0	100.0	93.5	100.0
Streelow Creek	40.0	75.0	65.0	100.0
E. Highway 101 No. 1	11.1	50.0	33.3	55.5
E. Highway 101 No. 2	28.0	56.0	84.0	92.0
Average all areas	39.8	70.2	68.9	86.9

Source: Maclean (1966).

An increase in the amount of seed sown to compensate for losses is an impractical procedure. For example, over 14 million viable pine seeds fell on 47 acres during a 16-year period on Stanislaus Experimental Forest (Schubert, 1957). These seeds, falling on unprepared and untreated areas, produced only 3,000 seedlings--about 65 per acre. Here the seed to seedling ratio was approximately 5,000 to 1–about 1/2 pound of ponderosa or 2-1/2 pounds of sugar pine seed per seedling. The cost of the seed alone would have been about $125 per acre for ponderosa or $375 for sugar pine. However, with measures to reduce seed and seedling losses, the seed to seedling ratio was reduced to 80 to 1 at a seed cost of about $12 for ponderosa and $36 for sugar pine.

Seeding rates of 20,000 to 80,000 viable seeds per acre are recommended for broadcast seeding in California. The rates, by species, for sowing on freshly prepared sites with rodent control are:

	Seed to seedling ratio	Viable seed per acre (No.)	Approx. weight (lbs.) 1/
Species:			
Coast and Sierra redwood	100 to 1	80,000	3/4 to 1
Ponderosa, Jeffrey, and sugar pine	80 to 1	64,000	3 to 30
Knobcone, Monterey, and lodgepole pine	50 to 1	40,000	1/2 to 3
Douglas-fir	20 to 1	20,000	1/2 to 3/4
Red, white, and grand fir	20 to 1	20,000	1 to 4
Incense-cedar	20 to 1	20,000	1½

1/The larger of each pair of figures is for the largest seeds.

These rates should produce about 800 seedlings per acre. The rates should be adjusted for local conditions whenever a change is warranted.

SEEDING COSTS

The cost of establishing new forests by direct seeding has been quite variable, depending on: (1) the amount of site preparation needed, (2) the method used to prepare the area, (3) the amount of seed needed, (4) the price paid for the seed, (5) the cost of rodent and insect treatments, (6) the method used to sow the seed, and (7) the size of the area seeded.

The costs will vary for each of these items. Some areas, such as fresh burns, may require no site preparation; whereas, areas with dense brush may require considerable preparation at a high unit cost. Where fire or chemicals can do the job, it can be cheaper than with a bulldozer. Spot seeding will require less seed than aerial seeding, but may cost $25 to $70 per acre to seed compared to about $4 to $12 for aerial seeding. Costs for broadcast seeding with a cyclone seeder or drill seeding will be intermediate between that for spot seeding and aerial seeding. The amount of seed needed and the cost per pound will vary by species. Furthermore, costs per unit area will be greater for small areas than for large ones.

Therefore, seeding costs will show a rather wide range depending on many factors. The lowest cost per acre will be for large, fresh burns that require no site preparation or control of rodents and insects, and that could be aerially seeded with small quantities of low priced seeds. The highest cost per acre will be for small, dense brush-covered areas that require extensive site preparation and control of rodents and insects, and that are spot seeded with large quantities of expensive seed.

Seeding costs on National Forests in California have varied from about $8.00 to $117.00 per acre for seedings on 3,390 acres during 1956-1961.[55/] The 6-year weighted average seeding cost was $38.15 per acre (table 69). This average cost includes seedings on small and large areas, by different methods, with different kinds and quantities of seeds, and with different amounts of site preparation and other needed treatments. As such, it would apply to other similar combinations of seedings, but it would not necessarily be representative of a cost for any particular seeding in a specific location.

Spot seeding in the Northern Sierra Nevada on two industrial forest properties has ranged from about $3.00[56/] to $12.00[57/] an acre. The former was seeding selected spots in poorly stocked recently logged areas; the latter in completely unstocked areas formerly covered in brush, where seeding consisted of 900 spots to the acre, one man covering 3 acres per day. These costs did not include site preparation.

In a 1967 drill seeding study, the State of California established a cost of $14.40 per acre, which included only equipment and operator time plus ponderosa pine seed. The study was on an area formerly brush covered which had been cleared by the land owner. The equipment was a single row seeder drawn by an Oliver OC-3 tractor and the area was small so that operating costs were higher than could be expected from a production operation using a two row machine.

55/ Based on seed costs in annual planting reports by California Region, U. S. Forest Service.

56/ Bowman, Hal. Spot seeding with corn planters by Kimberly-Clark Corp. 1967. (Personal communication.)

57/ Cosens, Richard D. Spot seeding on Soper Wheeler properties, 1967. (Personal communication.)

Table 69. Average seeding costs on National Forests in California during the period 1956-1961

Item	Cost per acre 1/	Range in costs 2/
	------- Dollars -------	
Seed	5.54	2.81- 27.54
Site preparation	12.37	0- 70.00
Seeding	20.24	3.63- 68.53
Total	38.15	8.43-116.97

Source: Annual planting reports, California Region, U. S. Forest Service.

1/Includes cost for rodent control and other necessary project charges.

2/The lowest cost was for an aerial seeding and the highest for a seed spotting with protective wire screens.

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