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# Control of Brush Regrowth with Herbicides on Pine Plantations in Northern California

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# IN BRIEF...

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Comprehensive tests of herbicides for controlling regrowth of brush were made on land cleared for pine plantations in northern California. Treatments were applied during 1962-65 on burned-over forest and on two bulldozed brushfields. A tractor-drawn sprayer equipped with a boom and hoses was used to simulate practical operations on 324 large plots covering 64.8 acres. Broadcast sprays or hand applications on individual plants, or both, were made once, twice, or three times in consecutive years, beginning in 1962, in nine combinations of method and year. Three herbicides—2,4-D [(2,4-dichlorophenoxy) acetic acid], 2,4,5-T [(2,4,5-trichlorophenoxy) acetic acid], and a 1:1 mixture of the two—were tested at three dosage levels. The herbicides were applied during the summer when conditions were favorable for brush kill. Results from these tests were supported in subsequent years by observations of larger areas sprayed by helicopter during both summer and fall months.

Susceptibility of brush regrowth to herbicides depended more on size and density of plant crown and on development of root systems than on species of shrub. First-year seedlings and sprouting plants with small open crowns were commonly killed by a single application. Repeated sprays were required to kill vigorous plants that had developed large, dense crowns before the initial herbicide application. Two sprays in consecutive years greatly reduced vigor and competitive effect of most brush stands, but many living plants were still present. Three sprays produced excellent control of the most resistant plants on the plots and killed the numerous small seedlings which became established on bulldozed areas during 1963 and 1964.

Experience in applying results from test plots showed that spray treatments started during the first or second year after land clearing, and repeated as needed, produced consistent brush control with minimum use of herbicides. However, when the initial application was delayed a few years until the brush regrowth had become well established, results were more erratic and heavier dosages and more follow-up applications were required, with consequently less efficient use of herbicides and money. Repeated spraying in consecutive years or alternate years provided much more effective use of herbicides than did wider spacing of repeated applications. Land use objectives will determine the number of repeat applications needed in each situation.

Each herbicide—2,4-D, 2,4,5-T, or a 1:1 mixture of the two—produced satisfactory brush kill on the test plots. For site preparation spraying, 2,4-D alone or combined with 2,4,5-T usually is used to control brush reestablishment ahead of pine planting. For release spraying over planted pines, the usual practice is to apply 2,4,5-T alone because of the greater tolerance of ponderosa pine *(Pinus ponderosa* Laws.) to this herbicide. This herbicide controls most brush species, but is relatively ineffective on mariposa manzanita *(Arctostaphylos mariposa* Dudl.).

An herbicide dosage of 3 to 4 pounds, a.e., per acre was most effective and economical in most situations. A 2-pound dosage was effective on first-year brush seedlings, and it killed resistant plants on plots sprayed in 3 consecutive years; but this low dosage was ineffective where applied on well-established brush regrowth or where a single spray was applied. A 4-pound rate produced consistently good brush control in repeated applications; it was particularly needed if the initial spray was delayed past the first year of brush regrowth or when repeat spraying occurred in alternate years or at longer intervals. An 8-pound rate produced greatest kill from a single application but was in excess of needs for repeat applications. A total of 8 to 10 pounds, a.e., of herbicide per acre spread over two or three applications would be much more effective and efficient.

Hand spraying effectively controlled the more vigorous brush regrowth but many recently germinated small seedlings always were missed. Consequently, broadcast spraying produced better control of the total brush stand; it is a much faster and cheaper application for use on large areas. Hand spraying may be needed under special conditions when broadcast sprays are not possible or are inadvisable.

Forest managers in California have long been aware of the need for controlling brush regrowth on cleared land. Before 1962, however, the research on use of herbicides to control our mountain brush species was inadequate for the development of techniques practical on large areas. The earlier work had been limited mainly to tests of hand applications of chemicals on individual brush plants. Though effective, this method was too time consuming and costly for wide-scale use.

During the period 1962-65, comprehensive tests of repeated herbicide applications were conducted on large plots in northern California. The aim was to develop quickly some practical methods for using herbicides to control brush on thousands of acres being planted to pine. Results of this administrative study, conducted jointly by the California Region and the Pacific Southwest Forest and Range Experiment Station of the U.S. Forest Service, were applied, as they became apparent year by year, in the form of guidelines prepared for large-scale spraying projects. Also, an instructional manual was written at the end of the study (Bentley and Estes 1965), and a brief summary of the effectiveness of repeated herbicide applications was issued (Bentley 1967). The present report documents the comprehensive study and includes previously unpublished data.

The approach taken in these tests of herbicide application emphasized the development of practical methods for wide-scale use. We compared hand applications with broadcast boom methods, which showed greater promise. We tested the two application methods as single treatments and as repeated treatments, to determine the best combination for obtaining the desired degree of brush kill. We included those herbicides that had been most effective in hand spraying trials.

We conducted the herbicide tests on many large plots so as to obtain results that would simulate closely the effects of large-scale spray jobs, to provide considerable acreage for visual judgment of results each year, and to allow evaluation of various treatments under a wide assortment of local conditions.

The tests were made on areas cleared by machine during the year before we began our spray applications. We applied the sprays during summer months when shrub plant growth was considered at near optimum stage for killing small plants. This approach allowed direct extension of results to other mechanically cleared areas where herbicide applications were to be used as a part of site preparation ahead of pine planting. We also could estimate and compare effects of the different spray treatments for controlling brush on areas recently planted to pine, although in such uses the spraying was delayed until about September 1 to avoid undue damage to the young pines, as determined by concurrent studies (Bentley 1967).

## STUDY AREA AND PROCEDURES

The three study areas included a burned-over pine forest site and two manzanita brushfield sites. The pine forest, near Foresthill on the west slope of the Sierra Nevada, had burned in 1960. All merchantable timber had been removed and the debris windrowed or piled with bulldozers during 1961 and early 1962. The brushfields, located above Viola and near Mount Shasta in the Cascades, had been cleared by heavy bulldozing in 1961.

At each location two blocks of 54 large rectangular plots were laid out to allow use of tractor-drawn spray equipment. Each plot was 66 by 132 feet (20.1 by 40.2 m) with an area of 0.2 acre (0.08 ha), making 10.8 acres (4.37 ha) per block. The total of 324 plots in the study occupied 64.8 acres (25.93 ha)—an appreciable acreage for observational data.

## Herbicide Treatments

The sprayers were equipped with hoses for hand applications and with a collapsible boom which could be extended for broadcast applications. Nine sequences of hand sprays (H) and broadcast sprays (B) were tested as follows:

| *1962* | *1963* | *1964* | *Total* |
|---|---|---|---|
| B | — | — | 1 |
| B | B | — | 2 |
| B | B | B | 3 |
| B | B | H | 3 |
| B | H | — | 2 |
| B | H | H | 3 |
| H | — | — | 1 |
| H | H | — | 2 |
| H | H | H | 3 |

The three sprays were applied in consecutive years because of the need to complete the study within a 3-year period, even though alternate year spacing of certain spray treatments might be more effective.

Low-volatile esters (butoxy ethanol) of 2,4,5-T and 2,4-D were tested singly and as a 1:1 mixture of the two at different dosages as follows:

| *Herbicide* | *Rate* | *Dosage* |
|---|---|---|
| — | — | *lb a.e.*[1] |
| 2,4,5-T | Moderate | 4 |
| 2,4-D | Moderate | 4 |
| 1:1 mix | Moderate | 4 |
| 1:1 mix | Light | 2 |
| 1:1 mix | Heavy | 8B,16H |

[1]Pounds acid equivalent per acre for broadcast spraying and per 100 gallons for hand spraying (1 lb/acre = 1.12 kg/ha; 1 lb/gal = 1.2 kg/1000 l).

For the low-volume broadcast sprays applied with a boom, the herbicide was mixed with 0.5 gallon of diesel oil and sufficient water to make 20 gallons of emulsion per acre (187 l/ha). For the hand sprays, the herbicide was mixed with 1.0 gallon of diesel oil, and water was added to make 100 gallons of emulsion. In hand spraying, the herbicide was carefully applied to the leaves and stems of sprouting plants and the larger seedlings to the point of drip-off; additionally, the wand was passed over dense stands of very small seedlings to give a heavy broadcast coverage, but no attempt was made to locate and spray all small individual plants.

The five herbicide-dosage treatments were applied in each of the nine application method (hand or broadcast spray) sequences, so that a total of 45 spray treatments and 9 unsprayed plots were located at random in each 54-plot block. Thus each method sequence was applied on 10 plots at a location, but each specific method-herbicide-dosage treatment was applied on only 2 plots per location.

The herbicide applications were started each year in June at Foresthill, continued at Viola, and completed at Mount Shasta in late July or early August. Air temperatures were favorable for herbicide reactions at all times, although on some plots either the temperature or wind movement was above that allowable for aerial applications. Spraying was discontinued if spray might drift excessively onto adjacent plots.

## Brush Plant Records

Uneven disturbance of the soil during bulldozer operations resulted in variable stands of brush regrowth on the study areas, particularly at Foresthill, where logging and debris piling caused spotty removal of regrowth already established in 1961. Because of variations in brush plant numbers from plot to plot, at the start of herbicide treatment in 1962 we counted plants on each plot. This count was the base for determining changes caused by treatments.

In 1962 we recorded number of plants, by species and age, that were present at the time of initial spraying. In 1963 and in 1964 we tallied the new seedlings that had become established during the current year, even though they might die from current herbicide treatment or from natural causes. In 1965 we counted the older plants surviving the different treatments, and the new seedlings of the year. From these records, we summarized for each plot the number of plants present at the start of spraying in 1962, total number of plants established up to termination of spraying, and percent survival in 1965 of all plants established before 1965.

In determining average percent survival of plants under any one treatment, we based the average on total number of plants established in all plots receiving that treatment, and total number of surviving plants in those plots. The number of plants established was about the same for each treatment when the average was based on more than four plots per treatment. However, when the average was based on only two to four plots per treatment, the number of plants established per treatment was highly variable.

Counts of shrub plants were made on one half of each plot, in a 0.1-acre strip 33 feet wide along the centerline of the plot. This strip was divided into five 0.02-acre quadrats marked with short stakes. Generally, all plants of a particular species-age class within a quadrat could be readily located and tallied, but in extremely dense stands of more than approximately

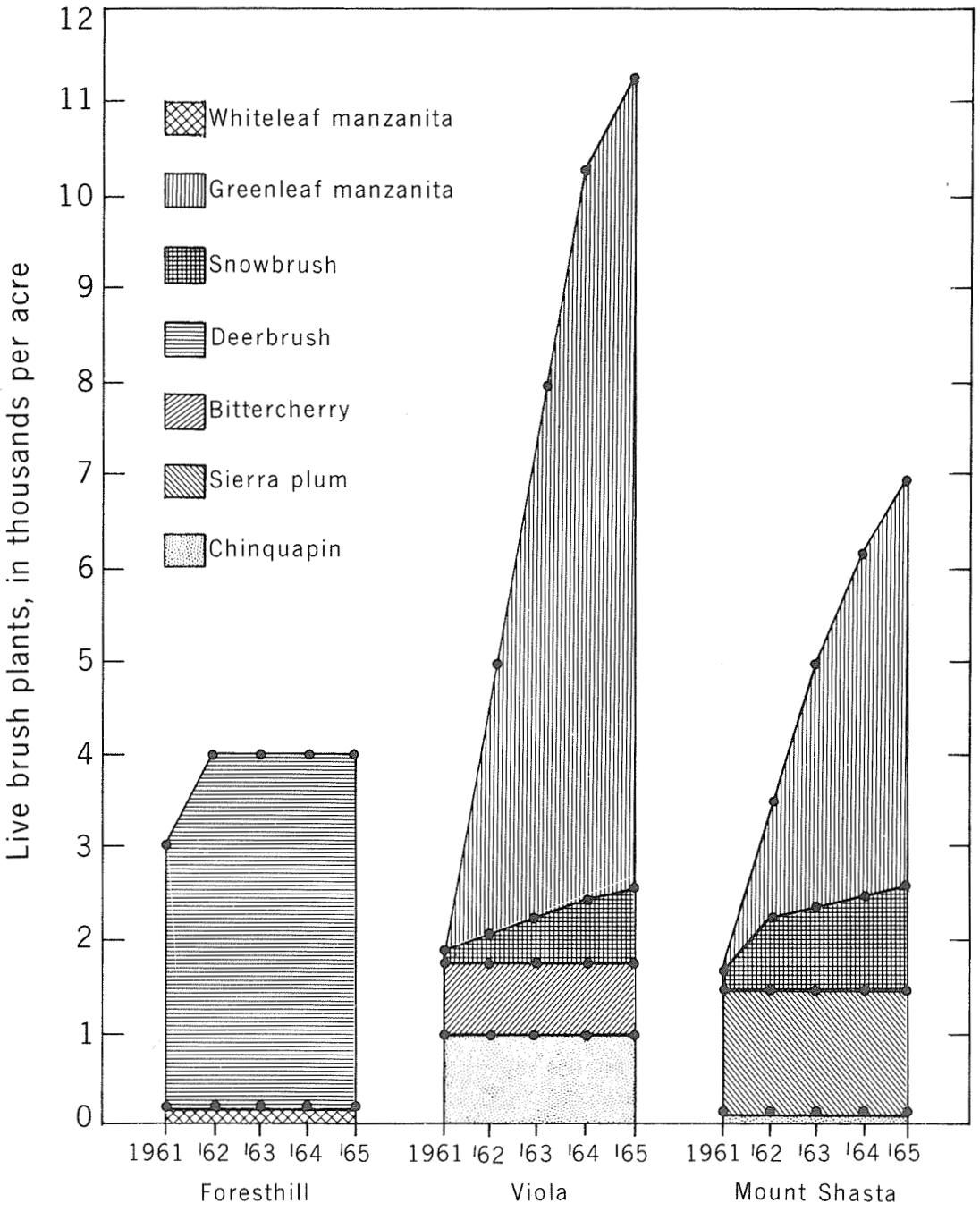


**Figure 1**—Typical patterns of brush plant establishment from 1961 through 1965—on pine forest burned over in 1960 at Foresthill, and on brushfields cleared by bulldozing in 1961 at Viola and Mount Shasta. (Data on bearclover at Foresthill are not included.)

200 plants per quadrat, estimates were made from counts on four representative milacres. Plants were easily found in all years on sprayed plots where brush had been kept to small size, but estimates were less precise for 1963 and 1964 in the dense stands on unsprayed plots; in some plots, the total number of plants estimated for all preceding years was less than the number actually counted in 1965.

# PATTERNS OF BRUSH REGROWTH

The typical pattern of brush plant establishment from 1961 through 1965 on each study area is shown in *figure 1*.

## Shrub Species, Foresthill

Deerbrush *(Ceanothus integerrimus* H. & A.) was the dominant shrubby species on most plots. The seedlings established in 1961 and 1962 were growing vigorously by summer 1962. On unsprayed plots, the plants continued growth to heights of 3 to 6 feet by 1965; the spreading branches covered much of the ground in typical stands, and many small plants had died under the dense canopies. For all plots, the average number of plants in 1962 was about 3800 per acre. On unsprayed plots, 63 percent of this number survived in 1965.

Whiteleaf manzanita *(Arctostaphylos viscida* Parry) also was present on most plots. The plants were vigorous but of lower stature than deerbrush. Though occasionally dense, stands averaged only about 180 plants per acre for all plots in 1962. A few additional plants became established by 1965, and average survival on unsprayed plots was 75 percent of the original plants.

Deerbrush and manzanita together produced rather full brush covers by 1965 on most unsprayed plots; they provided excessive competition to young pines.

Bearclover *(Chaemaebatia foliolosa* Benth.), a low-growing semishrub, occurred in patchy stands. Where present as almost solid mats, this species represented extremely heavy competition to pine seedlings. The individual plants could not be consistently identified and counted; the tremendous numbers of small shoots tallied on the plots were not comparable to plant counts of other species. Consequently, plant numbers for bearclover have been omitted from the data summaries in this report. Reactions of this important species to herbicide treatments, however, were similar to those shown in the data for whiteleaf manzanita.

Other than bearclover, the most common brushy plants reproducing as sprouts were scattered stumps of black oak *(Quercus kelloggii* Newb.). This species was fairly well controlled by the herbicide treatments most effective on whiteleaf manzanita.

In summary, at Foresthill most plants of the regenerating brush stand were established by 1962.

## Shrub Species, Viola and Mount Shasta

In these areas, large numbers of new brush seedlings continued to become established each year. Seed had remained irregularly mixed within the upper soil even though the objective of the heavy bulldozing had been to push all brush plants, duff, seed, and several inches of topsoil into the windrows.

Greenleaf manzanita *(A. patula* Greene) was the shrub present in greatest number on the Viola plots in 1962. Taking all Viola plots together, an average of about 100 plants per acre were sprouts from old root crowns; the remainder were new seedlings. Seedlings became established at more than 2500 per acre in 1962, 1963, and 1964, with about 1000 new plants in 1965, making an average total of 8900 per acre by 1965. Seedling mortality each year was inconsequential.

Snowbrush *(Ceanothus velutinus* Dougl. ex. Hook) also was widely distributed in 1962 as sprouts from old root crowns, averaging about 100 per acre. But it occurred mainly as new seedlings which continued to be established each year. Plant numbers were much lower than for manzanita; only about 800 snowbrush plants per acre had become established by 1965 as an average for all Viola plots. However, the fewer plants of this vigorous species produced as much, or more, total plant crown, and probably represented more competition to pines during the first few years, than did the manzanita.

The dominant sprouting species were bittercherry *(Prunus emarginata* Dougl.) and chinquapin *(Castanopsis sempervirens* [Kell.] Dudl.). These vigorous species were potentially strong competition to pine if left uncontrolled, even though there were fewer plants per acre than manzanita.

Bittercherry was present on about half of the Viola plots as numerous sprouts from roots severed during the bulldozing operation. The average of approximately 800 plants per acre on those plots where the species occurred was much higher than the average number of old plants present before bulldozing. The new bittercherry plants were small and poorly rooted when the tests were started in 1962.

Chinquapin was widely distributed as vigorously growing sprouts from old root crowns remaining intact after bulldozing. The average number of plants of this tough species, about 950 per acre, was sufficient to produce a rather dense cover if left uncontrolled.

On the Mount Shasta plots, brush regrowth was similar to that at Viola, except that plant numbers for manzanita averaged only about one-half as many. But the stands still were sufficient to produce a very dense brush cover on most of the area. The number of snowbrush plants, an average of about 1050 per acre, was greater than at Viola.

Sierra plum *(Prunus subcordata* Benth.) was widely distributed and was the only important sprouting

species. The plants, averaging 1400 per acre, had sprouted from severed old roots, but had not developed strong new root systems.

Chinquapin, present as scattered plants on less than half the plots, on an average of about 80 plants per acre, was not an important species on this area.

In summary, on the bulldozed brushfields at Mount Shasta and Viola, there was a need to (1) control the full stands of sprouts and numerous seedlings present at the initial spraying, and (2) space follow-up sprays to control the continuing establishment of new seedlings during the next 3 years.

# CONTROL OF BRUSH REGROWTH BY TREATMENT

Results of the treatments are reported for single and repeated applications, hand and broadcast applications, different herbicides, and different dosage rates.

## *Single Herbicide Application*

A single herbicide application in 1962 killed a high percentage of the brush plants that had become established before the spraying, with the exception that poor kill resulted from broadcast sprays at the lightest dosage rate. The control of initial brush regrowth, however, even on plots where herbicides were most effective, was considered adequate for only the most susceptible brush plants. These were small seedlings of deerbrush, greenleaf manzanita, and snowbrush; weak crown sprouts of manzanita and snowbrush; and weak root sprouts of bittercherry and Sierra plum. Plants generally not killed by a single application included the most resistant species: whiteleaf manzanita seedlings; bearclover sprouts; and the vigorous crown sprouts of manzanita, snowbrush, and chinquapin. A single application in 1962 at Viola and Mount Shasta gave poor overall control because many new seedlings became established in succeeding years *(fig. 2)*. Survival by species varied *(fig. 3)*.

Most plants of deerbrush, the dominant species, were killed by a single spray of adequate dosage, but more than half of the resistant whiteleaf manzanita seedlings survived. Most stands of bearclover fully recovered after a single spray application. For the 20 plots sprayed once at Foresthill, an average of more than 700 plants per acre (exclusive of bearclover) were still present in 1965.

A single spray in 1962 killed about one-half of the plants that became established on the plots at Viola and Mount Shasta. Survival was greatest for greenleaf manzanita and snowbrush because many new seedlings became established after 1962. Survival was lowest for bittercherry and Sierra plum, all of which were established as poorly rooted sprouts ahead of the 1962 spray treatment. At Viola, chinquapin, a tough sprouting species, showed 41 percent survival of the crown sprouts present in 1962.

Total number of plants surviving in 1965 on plots receiving a single application averaged 4671 per acre for 20 plots at Viola and 3716 for 20 plots at Mount Shasta. In large part these were seedlings established after the 1962 spray, but also included sprouts of chinquapin and other resistant plants. In addition, nearly 1000 new seedlings per acre were established in 1965 at each location.

At all three locations, we concluded that at least two or three repeated sprays were needed to provide adequate control of the more resistant brush species and to kill the numerous small seedlings established after the first spray treatment.

## *Repeated Herbicide Applications*

At Foresthill, the second and third sprays reduced the brush stands to low levels *(fig. 2)*. Deerbrush was

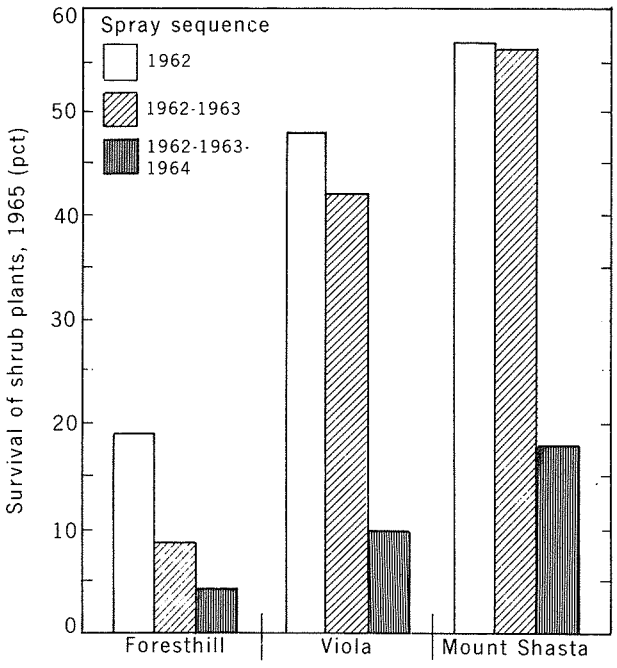


**Figure 2**—Survival in 1965 of shrub plants (all species except bearclover) on herbicide treatment plots was strongly influenced by number of repeated sprays. (Average survival is based on plants established up to termination of spraying in 1964, on plots hand or broadcast sprayed with three herbicides at three dosages, 20 to 40 plots per treatment average.)

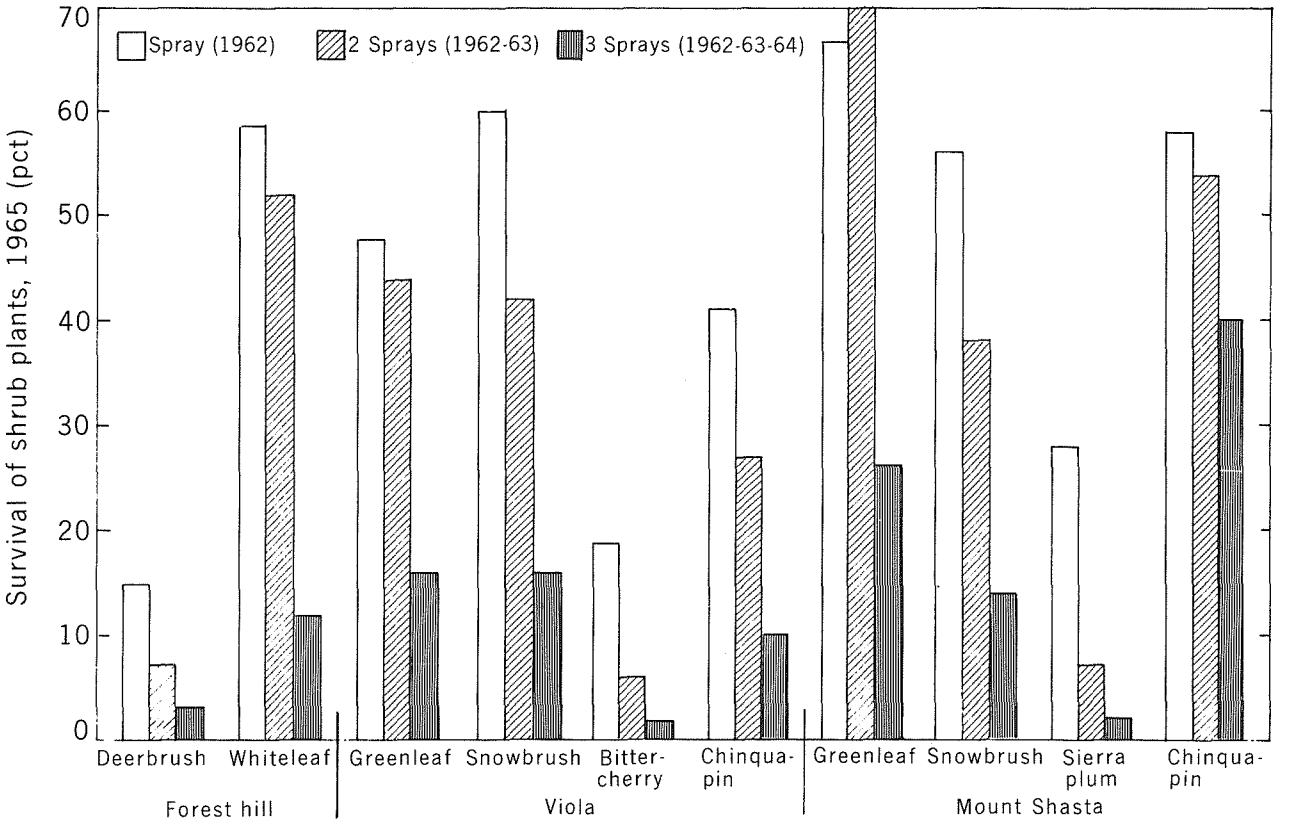


**Figure 3**—Survival in 1965 of individual shrub species on all herbicide treatment plots was influenced by resistance of species as well as by spray sequence. (Averages are based on same plots as in fig. 2.)

nearly eliminated from 29 plots sprayed twice and 40 plots sprayed three times *(fig. 3)*. Plants surviving after three sprays were mainly on plots broadcast sprayed at the low dosage of 2 pounds per acre. Three sprays were required for good control of whiteleaf manzanita seedlings; half of the plants survived on plots sprayed twice. Bearclover also required three sprays for full control, although two sprays were much more effective than a single application.

At Viola and Mount Shasta the two sprays, applied in 1962 and 1963 on 30 plots at each location, produced low kill of the total brush stand *(fig. 2)*. Most of the surviving plants were new manzanita and snowbrush seedlings established in 1964, plus small 1963 seedlings missed by hand spraying *(fig. 3)*. At Viola, the average number of plants surviving in 1965 was 4363 per acre, including 3779 plants of greenleaf manzanita. At Mount Shasta the 3667 surviving plants per acre included 3198 manzanita plants, mainly new seedlings. Two sprays nearly eliminated sprouts of bittercherry and Sierra plum. But 27 percent of the chinquapin sprouts still survived at Viola, and 56 percent of the few plants at Mount Shasta were still alive.

On 40 plots sprayed three times at Viola and 40 plots at Mount Shasta, the repeated applications greatly increased plant kill over the two applications *(fig. 2)*. The lower survival for plots receiving three sprays was caused mainly by control of manzanita and snowbrush seedlings established in 1963 and 1964. Better control also was obtained from three sprays on sprouting species, particularly for chinquapin which was reduced to only 10 percent survival at Viola *(fig. 3)*. Although a high degree of control was obtained from three sprays, a large number of small plants still remained in 1965. For example, at Viola an average of 1133 surviving plants per acre included 898 manzanita plants, and at Mount Shasta the average survival of 1030 plants per acre included 808 manzanita plants. In addition, an average of nearly 1000 new seedlings per acre became established in 1965 at each location.

## Hand Spray vs. Broadcast Sprays

Hand spraying effectively reduced the brush plants that were established by 1962 but missed many of the small plants established in 1963 and 1964. Thus, hand

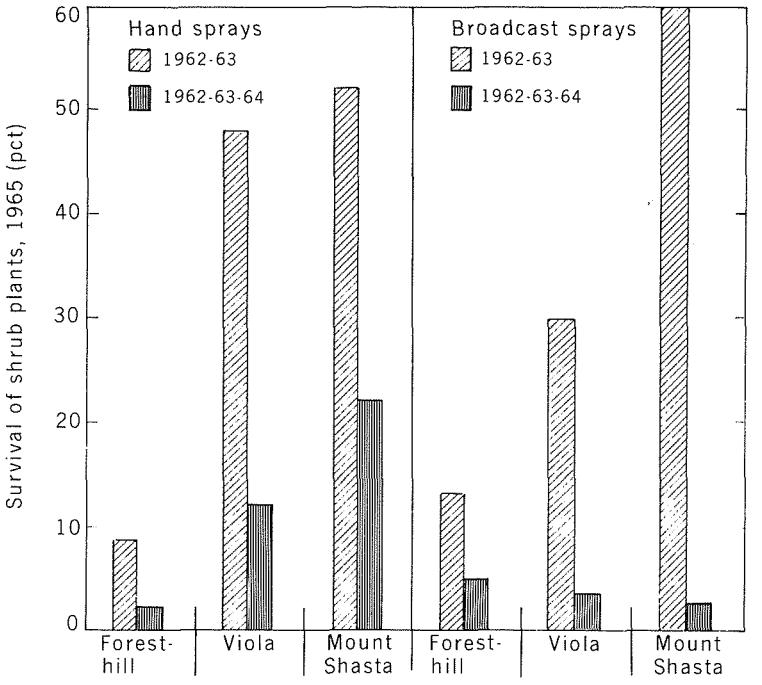


**Figure 4**—Survival in 1965 of shrub plants established by 1964 on hand-sprayed plots is contrasted here with that on broadcast-sprayed plots. (Averages are based on plots sprayed twice or three times, 9 or 10 plots per treatment average.)

sprays were very effective at Foresthill where most plants were established by 1962 *(fig. 4)*. In contrast, on plots hand sprayed twice at Viola and at Mount Shasta, about half of the plants survived. Three hand sprays were much more effective.

At Foresthill, hand spraying produced more complete kill than did broadcast spraying, although both application methods were effective *(fig. 4)*. At Viola and Mount Shasta, where many new seedlings became established in 1963 and 1964, broadcast spraying was clearly more effective than hand spraying, particularly when plots were sprayed three times—1962, 1963, and 1964. For ten plots at Viola, three broadcast sprays reduced the total brush stand to 4 percent average survival, and on nine plots at Mount Shasta, to only 3 percent.

Because adequate brush control can be obtained from broadcast spraying, this method has practical advantages over hand spraying for work on large areas—cost is much lower and it is possible to cover more acreage during the short season when the brush plants are most susceptible to herbicides.

Using hand spraying as a follow-up treatment after broadcast sprays on the test plots did not appear to have any practical advantage, particularly where broadcast spraying was much more effective in killing dense stands of newly established brush seedlings. Follow-up hand spraying might be needed in some situations: for example, in reducing brush cover over many years on fuelbreak strips within pine plantations. In other situations, hand spraying might replace broadcast spraying if danger of herbicide drift from aerial sprays was a critical problem, or where spraying during certain seasons required selective herbicide placement to avoid damage to pines.

## Different Herbicides

Each of the three herbicides produced essentially the same degree of shrub control. We did not observe any consistent differences in the field, and none were shown by the data summaries. For one comparison, we used all plots receiving the so-called "moderate dosage"—4 pounds a.e. per 100 gallons or 4 pounds a.e. per acre—which gave large samples of 17 to 54 plots for each herbicide. The data for these samples showed essentially the same percent survival of brush plants for each of the three herbicides on each study area *(fig. 5)*.

Data from those plots receiving either two or three broadcast applications at the 4-pound rate showed considerable variation because there were only two plots per sample of each herbicide, but no consistent differences between herbicides were apparent *(fig. 5)*. The three spray applications (1962-63-64) produced a uniformly high degree of brush control for each of the three herbicides at each location, except for greater plant survival on plots sprayed with 2,4-D at Foresthill. Significance of this variation was not determined.

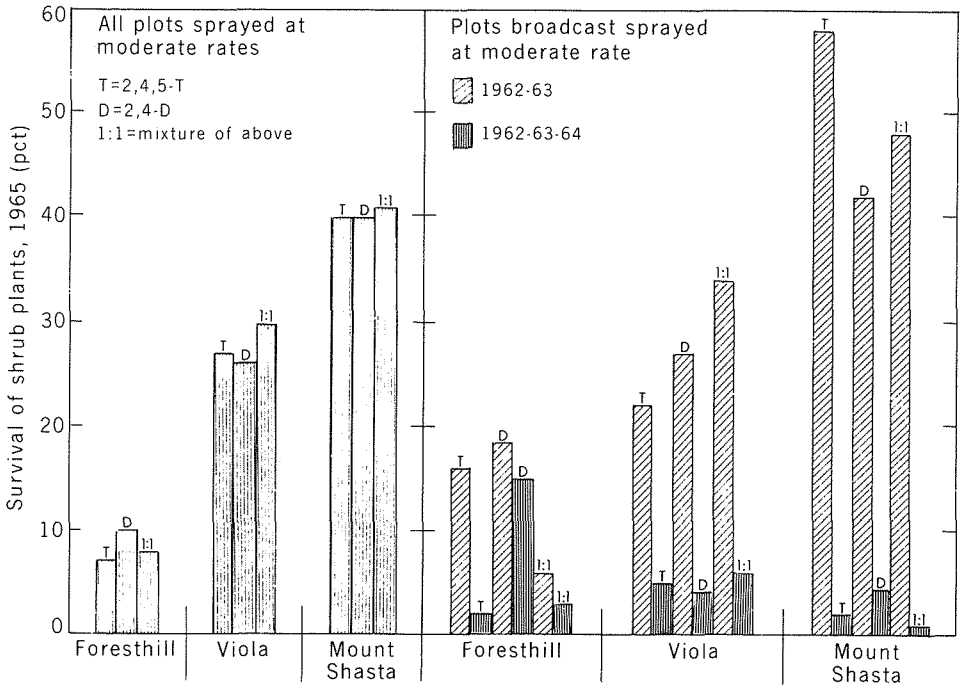


**Figure 5**—Survival in 1965 of shrub plants established by 1964 is contrasted here for plots sprayed with three different herbicides. (Averages for all plots, hand-sprayed plus broadcast-sprayed, are based on 17 to 54 plots per treatment sample; but averages for plots broadcast sprayed twice or three times are based on only two plots per sample.)

The variability in data from plots receiving two sprays (1962-63) appeared to be caused mainly by large differences between plots in numbers of brush seedlings established in 1964 after spraying had been terminated in 1963. All herbicides appeared to be effective on plants established prior to spraying.

Because there was little difference between herbicides in control of small brush regrowth on the plots, in subsequent site preparation spraying on pine plantations the cheaper 2,4-D has been used either alone or in combination with 2,4,5-T. A 1:3 mixture of 2,4,5-T and 2,4-D has been recommended for stands of small brush plants, and a 1:1 mixture for stands having larger plants of chinquapin and snowbrush, or other species assumed to be susceptible to 2,4,5-T.

The more expensive 2,4,5-T has been recommended for release sprays over ponderosa pine seedlings because the pines have much greater tolerance to this herbicide than to 2,4-D.

## Different Broadcast Dosage Rates

The effects of herbicide dosage rate were best observed in 1963 on those plots broadcast sprayed in 1962. At this time the brush kill was much more irregular on plots receiving the 2-pound rate than on plots sprayed at 4-pound or 8-pound rates. On some plots, the spray at 2 pounds a.e. per acre appeared to have little effect; on other plots the vegetation was affected the first year but had recovered by 1965 if the plots had not been resprayed.

On all plots that received repeated applications, the apparent differences caused by dosage rate were largely eliminated by 1965. At Foresthill, however, the 2-pound rate was still noticeably less effective than the heavier rates in killing well-established deerbrush seedlings, which have ordinarily been considered relatively susceptible to herbicides *(fig. 6)*. At Viola and Mount Shasta, where the brush regrowth was dominated by weak seedlings established during the course of spraying *(fig. 1)*, all herbicide dosage rates effectively controlled the regrowth on plots sprayed three times *(fig. 6)*.

On plots sprayed twice at Viola and Mount Shasta, plant survival was high regardless of herbicide dosage per acre. Greater survival at higher dosages probably reflected greater numbers of new plants established in 1964, rather than differences in effects of herbicide dosage rates. The two-plot samples were too small for true evaluation of individual dosage rate on plots where variable numbers of plants became established after spraying was terminated.

On plots broadcast sprayed three times at each location, the 8-pound rate produced more consistent plant

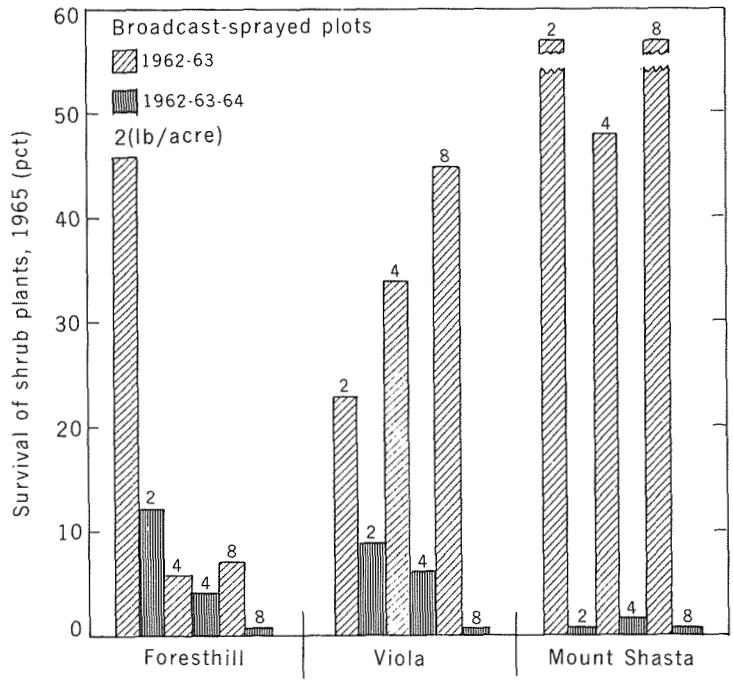


**Figure 6**—Survival in 1965 of shrub plants established by 1964 is contrasted here for plots broadcast sprayed twice or three times at different herbicide dosage rates. (Averages are based on plots sprayed with 1:1 mix of 2,4-D, and 2,4,5-T, two plots per treatment sample.)

kills plot by plot, but clearly was more than was needed for adequate plant control. The 8 pounds a.e. of herbicide could be spread over at least two yearly applications at lighter rates to produce greater effect from the same amount of herbicide.

A relation between initial dosage rate and the effectiveness of follow-up sprays on brush plants with dense foliage has been observed on many spray tests in California and was well illustrated by vigorous deerbrush seedlings sprayed at Foresthill. On a 2-year-old plant with densely foliaged crown in 1962, the initial broadcast spray at the 2-pound rate typically killed only about one-third of the total crown area, the 4-pound rate killed foliage deeper into the crown, and the 8-pound rate killed all, or most, of the total crown. An initial saturation hand spray also killed the total crown on almost all deerbrush plants. Follow-up sprays killed most of the plants in the 4-pound or 8-pound initial spray group, and the hand-sprayed plants. On plants in the 2-pounds-per-acre initial spray group, however, the repeat sprays at this low rate did not kill all parts of the crown, and many of these plants were still alive in 1965 after three spray applications. In contrast to the results on vigorous plants, the less vigorous deerbrush plants—those with open crowns in 1962—were eliminated by three sprays at any of the dosage rates; most of these plants were killed by the initial spray.

These results suggest that follow-up applications of 2 to 4 pounds per acre, after an initial application at the 4-pound rate, probably would produce effective control. A total of 8 to 10 pounds a.e. of herbicide spread over three applications would be more effective than a single heavy application on deerbrush, and very much more effective on the associated resistant species—whiteleaf manzanita and bearclover.

# DISCUSSION

Percent survival of established plants serves as a good comparison of effects from different herbicide treatments; as in our tests, it is the standard comparison in studies where numbers of plants differ from plot to plot. Number of surviving plants per acre would be a more meaningful basis for eavluating treatments because this measure represents the nucleus remaining for potential development of a future brush stand. Use of number of plants, however, is limited to fairly uniform brush stands, or to comparisons involving a sufficient number of plots per treatment sample. As illustrated by results on plots at Mount Shasta (*fig. 7*), the data for percent survival and for number of surviving plants, based on 9 to 40 plots per sample, produce similar curves. By either basis of comparison: one spray reduced brush stands by about one-half; two sprays added little to the apparent herbicide effectiveness, because many new seedlings became established after the last spraying; but a third spray killed many of these seedlings and reduced the brush stand to a low level.

Although either of the above treatment comparisons

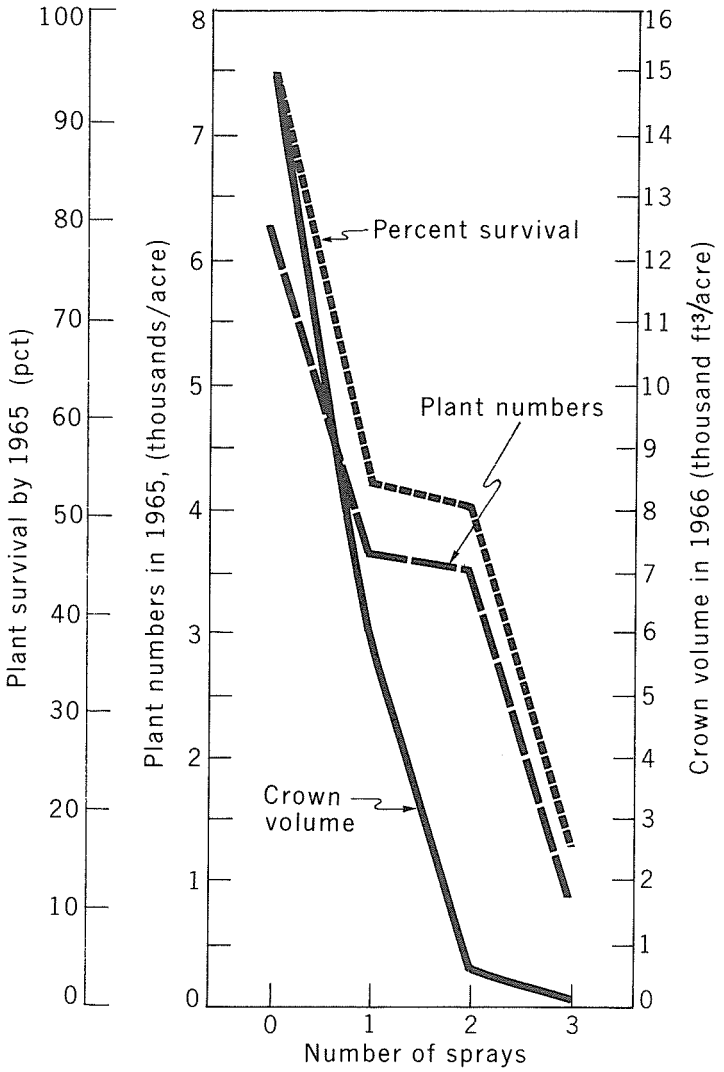


**Figure 7**—Relative effects of one, two or three spray applications are shown here by percent survival of plants and number of surviving plants per acre; these measures are contrasted with a measure which better expresses reduction in number, size, and vigor of shrub plants—crown volume of surviving plants. (Plant counts and percent survival are based on shrub plants established by 1964 on all plots at Mount Shasta; crown volume is measured on plants present in 1966.)

is useful in specific situations, neither fully evaluates the extent to which a brush cover has been reduced by herbicide treatment. Reductions in size and vigor of surviving plants also should be taken into account. Crown volume of the surviving plants—measured as cubic feet per acre ($ft^3$/acre)—is one expression of size and vigor of a brush stand. Measurements on the Mount Shasta plots, in *figure 7,* show that either two or three sprays effectively held down volume of brush cover and greatly reduced its competitive effects, even though many plants still remained.

One spray reduced brush crown volume by more than one-half. Two sprays lowered the volume all the way down to about 450 $ft^3$/acre in 1966—a ratio of 3 to 100 when compared to unsprayed plots—even though some 4500 plants per acre still survived. Three sprays gave more complete brush control with about 90 $ft.^3$/acre average crown volume in 1966, but nearly 2000 small plants per acre remained.

The crown volume curve gives a much better measure of the effectiveness of two sprays than does either the percentage survival curve or plant numbers curve *(fig. 7).* Measurements of total brush crown volumes, as described by Bentley and others (1970), expressed competitive effects of the brush stands. On plots having variable densities of brush, the total crown density was closely related to survival and growth of young ponderosa pine seedlings on the plots (Bentley and others 1971). Where the pines were planted on a bulldozed area, their growth was outstandingly better on those plots having total brush crown volume below 5000 to 10,000 $ft^3$/acre at the end of the first 5 years after bulldozing.

In summary, on almost all plots at the three locations, two or three spray treatments obviously held brush crown volumes to a very low level, regardless of the initial brush stand densities. Repeated spraying kept the brush well below the level where it would have competed materially with pine seedlings planted 1 or 2 years after land clearing.

# CONCLUSIONS

The conclusions made now, 10 years after completion of the administrative study of herbicide application, are based not only on the test plots but also on helicopter spraying of many pine plantations in northern California. With the test results, this practical experience helped to identify the significant factors in brush control on such areas.

In the tests, a high degree of brush control was obtained from the most effective plot treatments because spraying was started when regrowth was small, the spraying was done during the summer when air temperatures and soil moisture were favorable for herbicide reactions, and spraying was continued in consecutive years before the plants fully recovered from preceding sprays.

At some locations, helpcopter spraying produced less satisfactory control, which could be attributed to one or more unfavorable conditions: (1) initial spraying was not started until brush regrowth was large and well established, more than 2 years after land clearing; (2) sprays were applied late in the season, in September or later, when low temperatures or plant moisture stress reduced herbicide effectiveness; or (3) initial spraying was delayed a few years and sprays were applied late in the season—making control particularly difficult. Practical experience showed that these disadvantages could be largely overcome by applying maximum recommended dosages, particularly in the initial spray, and by applying as many follow-up sprays as required to produce the desired degree of control. Better brush control was obtained, with less total herbicide, on the areas where spraying was started when brush plants were small, and follow-up sprays were applied in consecutive years or in alternate years.

## Plant Susceptibility to Herbicides

Susceptibility generally depended on size of plant crown and development of root system rather than on plant species. The following description applies to brush regrowth commonly found on pine plantations in northern California.

*Highly susceptible plants*—those most readily killed by a single broadcast foliar spray—included

1. Small seedlings in first or second growing season, with open crowns and poorly developed root systems; usually under 12 inches in height. Species included greenleaf manzanita, snowbrush, and deerbrush.
2. Root sprouts with open crowns, not yet well established after bulldozing. Species included bittercherry and Sierra plum.
3. Small, weak crown sprouts with open crowns, established during first 2 years after burning or bulldozing. Species included greenleaf manzanita and snowbrush.

*Less susceptible plants*—those seldom killed by a single spray, but tending to recover rapidly and needing one or more follow-up sprays—included

1. Seedlings of resistant species, notably whiteleaf manzanita on the test plots.
2. Large, densely foliaged seedlings of most brush species, usually more than 2 years old and having well-developed root systems. On test plots they included greenleaf manzanita, snowbrush, and vigorous deerbrush seedlings.
3. Vigorous sprouts from root crowns having well-developed root systems. Resistant species included chinquapin of all ages, and older sprouts of greenleaf manzanita and snowbrush.
4. Sprouts of bearclover.

A mixture of brush plants always occurs on plantations, with more than one kind present in numbers sufficient to be highly competitive if not well controlled. Control of the most susceptible may release more resistant plants that eventually will provide strong competition with pines. Thus, herbicide spray treatments need to be planned to control the less susceptible species. Our tests indicated that repeated sprays aimed at control of chinquapin, bearclover, whiteleaf manzanita, or large vigorous snowbrush plants—depending on which is the key problem plant—will provide adequate control of the total brush cover.

## Spacing of Herbicide Applications

A single broadcast foliar spray has seldom, if ever, produced the desired degree of brush control on pine plantations. An exception could be a stand of the most susceptible plants, where few new plants became established after the first spray. One or more follow-up sprays will usually be needed. However, if follow-up sprays have been planned, they can be terminated once the brush stand has been reduced in crown volume or plant numbers to meet the aim of the plant control operation.

The number of sprays actually needed depends on the age and size of the brush plants at the time of the

initial application, the herbicide dosage rate in each application, and spacing of the follow-up sprays.

Spacing of follow-up sprays in consecutive years, as in our plot tests, was effective, but spraying in alternate years also produced good brush control on some larger areas. On the plots at Foresthill, where nearly all brush plants were established by 1962, the consecutive-year spraying probably was best. The initial application was needed by 1962 because the brush plants already were fairly large and densely foliaged; consecutive-year sprays gave good brush control before the plants had recovered. On the bulldozed brushfields at Viola and Mount Shasta, where many new seedlings were established each year through 1965, the three sprays obviously would have been more effective if spread over more than 3 years. Experience from spraying larger areas of manzanita brushfields indicated that spacing could well have been 1962-63-65, 1962-64-66, or 1963-64-66, for three sprays, or 1962-64 or 1963-65, for two sprays.

In practical operations, the restricted time and funds available in any one year often prohibit consecutive-year spraying of all areas where this spacing might be desirable. Alternate-year spraying often is the closest allowable spacing. Wider spacing should be avoided if possible—it does not make the most effective use of herbicides.

Results from large-scale spray operations definitely showed that the most effective control of brush regrowth was obtained by applying the initial spray during the first 2 years after removing the original brush cover. Delay of the initial spray until the brush plants were better established required more herbicide per application, and satisfactory brush control was less assured.

Bulldozed brushfields usually were ready for spraying the next year after brush removal. Brushfields burned during the spring could be effectively sprayed in early September, but delay of spraying until the next year produced more brush kill from the initial spray. However, if planting of pines is to be delayed until the second season, a site-preparation spray could well be applied during the first season, to reduce possible injury to planted pines.

## Selection of Herbicide

The plot tests did not show consistent differences in brush kill from applications of 2,4-D or 2,4,5-T or a 1:1 mix of the two—provided sufficient amounts were applied in repeated applications. Good brush control also has been obtained from each of these herbicides applied by helicopter on large areas. On some areas greenleaf manzanita has appeared to be particularly susceptible to 2,4-D, and less sensitive to 2,4,5-T. Well-established seedlings of mariposa manzanita are definitely resistant to 2,4,5-T and susceptible to 2,4-D, particularly during late summer and fall.

In practical operation, either 2,4-D alone or in mixture with 2,4,5-T (1:1, 2:1, or 3:1) has been used for site-preparation sprays ahead of pine planting. Because of the well-known greater resistance of ponderosa pine to 2,4,5-T, it has been used for "release sprays" over young pines. It is applied after pine buds are fully formed and have a protective resinous coating, typically about September 1 in northern California.

## Herbicide Dosage Rates

The effective minimum dosage rate, in plot tests and large-scale spraying, has depended on age and size of brush plants and on degree of recovery from a preceding herbicide treatment.

A dosage of 2 pounds a.e. per acre produced good control of resistant brush plants on plots sprayed three times in successive years, starting when the plants were still small. The first spray usually produced uneven effects, but repeated applications finally killed most of the plants. In other trials on more advanced regrowth, an application of 2 pounds per acre produced negligible effects. All observations indicate that a 2-pound dosage rate is effective only if applied as an initial spray during the first year of brush regrowth, and on brush stands kept at a very low vigor and small size by repeated spraying. Application of this low dosage on more advanced brush regrowth may well be wasted effort and expense.

Dosage of 4 or 8 pounds a.e. per acre produced good brush control from two or three applications on the test plots. The 8-pound rate obviously was greater than required; spreading this amount over 2 or 3 years would be advisable.

In practical operations, dosage rates of 3 or 4 pounds per acre have been commonly used and generally effective. The higher rate was needed on well-established brush regrowth. A satisfactory level of brush control was obtained where repeat sprays were applied as needed to reach the control objectives.

A primary aim on pine plantations ordinarily will be reduction of brush crown volume to a level that will allow full growth of planted pines. But this must be balanced against the level of brush control required in meeting other land use objectives. Thinning of the brush cover to allow easy access for future silvicultural activities may be one aim. Reduction of total woody

vegetation to improve fire control possibilities, at least on fuelbreak sites, can be another objective. Leaving some brush plants as readily accessible browse or cover for wildlife ordinarily should be an important aim during establishment of new plantations. The brush left for cover, usually in excess of that desired on all of a plantation, can be on areas within or adjacent to the plantations. Herbicide dosage rates and numbers of applications can be adjusted on all or any part of a plantation area to produce the desired results.

## Herbicide Application Method

Repeated broadcast spraying was more effective than repeated hand spraying on the test plots for controlling the many small brush seedlings often missed during hand spraying. A single hand spray, which saturated the foliage, was more effective than a low-volume broadcast application in killing resistant plants with dense crowns. However, after plant crowns had been reduced by an initial spray, either application method produced adequate brush control.

Broadcast spraying obviously is the most efficient application method on large areas, and it is the only feasible method for covering large areas during short periods when the brush plants are most susceptible to herbicides. Hand spraying may have a place, however, in situations where broadcast spraying by helicopter or ground-rig boom sprayers are not possible or not advisable. Hand sprays can be used for follow-up herbicide applications or fuelbreak areas of limited acreage within plantations, or on areas where spraying is required early in the season at a time when pines may be excessively damaged by broadcast sprays.

## LITERATURE CITED


Bentley, Jay R.

1967. **Brushfield reclamation in California.** *In* Herbicides and Vegetation Management in Forests, Ranges, and Non-cropland, Symposium Proceedings, [Corvallis, September 7-9, 1976], Div. Contin. Educ., Oregon State Univ., p. 186-195.

Bentley, Jay R., Stanley B. Carpenter, and David A. Blakeman.

1971. **Early brush control promotes growth of ponderosa pine on bulldozed site.** USDA Forest Serv. Res. Note PSW-238, 5 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.

Bentley, Jay R., and Kenneth M. Estes.

1965. **Use of herbicides on timber plantations.** California Region and Pacific Southwest Forest and Range Exp. Stn., Forest Serv., U.S. Dep. Agric., San Francisco, Calif. 47 p.

Bentley, Jay R., Donald W. Seegrist, and David A. Blakeman

1970. **A technique for sampling low shrub vegetation by crown volume classes.** USDA Forest Serv. Res. Note PSW-215, 11 p., illus. Pacific Southwest Forest and Range Exp. Stn., Berkeley, Calif.


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Bentley, Jay R., and Kenneth M. Estes.

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*Retrieval Terms:* Brush control; manzanita; herbicides; site preparation; plantations; ponderosa pine.

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