

Efficacy of Herbicide Application Methods Used to Control Tanoak (*Lithocarpus densiflorus*) in an Uneven-Aged Coast Redwood Management Context¹

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Abstract: Three methods of tanoak (*Lithocarpus densiflorus* [Hook. & Arn.] Rehd.) control involving the application of the amine or ester form of triclopyr were evaluated in this coast redwood uneven-aged forest management study of herbicides. A cut-stump application with the amine form of triclopyr (Garlon 3A), frill cut with the amine form of triclopyr, basal-bark (outer surface) with the ester form of triclopyr (Garlon 4), and an untreated control were replicated three times. The tanoak control results in Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) and/or coast redwood (*Sequoia sempervirens* [D. Don] Endl.) predominated stands obtained in earlier studies in northern California and Oregon appear to be similar to the results of this study obtained in Santa Cruz County coast redwood stands. The need for tanoak control in an uneven-aged forest management context is discussed.

Tanoak (*Lithocarpus densiflorus* [Hook. & Arn.] Rehd.)⁶ is a prolific sprouter and aggressive competitor with coast redwood (*Sequoia sempervirens* [D. Don] Endl.) and Douglas-fir (*Pseudotsuga menziesii* [Mirb.] Franco) in mixed coniferous forests (Barrett 1995, Burns 1983, Burns and Honkala 1990a, 1990b, Little 1979, Tappeiner and others 1990). The coniferous species are commercially more valuable than tanoak (although tanoak is presently useful for fuelwood in the Santa Cruz area). Finding an effective means to control the competing populations of tanoak is often desirable. Whereas significant research information is available on controlling tanoak competition under management of even-aged forests, little information is available about controlling tanoak under management of uneven-aged coast redwood.

Although tanoak has many ecosystem values, as a source of food and cover for various species of wildlife, in cut areas following timber harvest operations, tanoak sprouting can often interfere with the natural regeneration and growth of coast redwood and Douglas-fir. In such instances, the selective use of herbicides accompanied with planting of coast redwood and Douglas-fir could help maintain the site for commercial purposes and ensure that tanoak will not be an undesirable competitor.

The goal of this research was to find an effective means to reduce a wide range of tanoak diameter classes (fig. 1). The specific objectives of this research project were to:

- Evaluate the efficacy of herbicide application techniques for control of tanoak, and
- Identify tanoak research priorities in the context of uneven-aged management of coast redwood and Douglas fir stands.

Literature Review

Early work to control tanoak using picloram, 2,4-D, and 2,4,5-T in a cut-frill treatment was conducted in Mendocino County, California, by Radosevich and others (1976). Ten years after treatment, tanoak mortality with 2,4-D, 2,4,5-T, and

¹An abbreviated version of this paper was presented at the Symposium on Oak Woodlands: Ecology, Management, and Urban Interface Issues, March 19-22, 1996, San Luis Obispo, Calif.

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⁶Scientific names are from Little (1979).

Figure 1—Dense population of varied tanoak trees sizes within the study site at Swanton Pacific Ranch.



picloram was 87, 79, and 94 percent, respectively. Only 2,4-D is still available for use in California.

A basal application of the ester form of triclopyr (Garlon 4)⁷ yielded satisfactory results (Warren 1980a). Warren sprayed small-diameter stems of tanoak and madrone during March, June, and September, 1975. After 2 years, “good” control of tanoak was obtained when a mix of 3 gallons of Garlon 4 to 100 gallons of diesel was used. In addition, “good” control was achieved from treatments made in June and September when a mix of 1 to 2 gallons of Garlon 4 to 100 gallons of diesel was used. The best results were obtained with stems less than 3 inches in diameter.

Tappeiner and others (1987) conducted a study on tanoak control in southwestern Oregon using cut-stump, cut-frill, and basal-spray treatments at different times of the year. The herbicides tested in that study were triclopyr, 2,4-D, and picloram + 2,4-D. With the cut-stump treatments, 2,4-D, triclopyr, and picloram + 2,4-D applied during November and February caused the greater mortality and reduced total sprout length and clump area more than applications in May and August. Results of the cut-frill treatments indicated that herbicides applied during November caused the greatest dieback. Triclopyr generally produced better control with less variability. Basal treatments exhibited less control compared to the cut-frill application. Basal treatments using triclopyr gave better control in August. Although good control has been shown with picloram + 2,4-D, this herbicide is not certified for use in California.

Helgerson (1990) studied the response of underplanted Douglas-fir seedlings to herbicide control of a sclerophyll hardwood overstory. Frills around the base of the trees were each injected with 2 ml of triclopyr mixed with water (1:1, v/v). The primary species treated were tanoak, Pacific madrone (*Arbutus menziesii* Pursh.), and chinkapin (*Castanopsis chrysophylla* [Dougl.] A. DC.). Two years after treatment, 50 one-year-old (i.e. 1-0) container-grown Douglas-fir plugs and 50 two-year-old (i.e., 2-0) Douglas-fir bareroot seedlings were planted in the treated area. Helgerson concluded that stem injection of hardwoods was a viable

⁷Garlon 3A and Garlon 4 are Trademark names of products of the DowElanco Company.

approach of converting hardwood stands back to Douglas-fir; both plugs and bareroots were acceptable planting stock.

Cafferata and Yee (1991) used both the amine and ester forms of triclopyr (Garlon 3A and 4) for control of tanoak at Jackson Demonstration State Forest, Fort Bragg, California. Cut-stump, frill, and basal applications were compared. Trees evaluated 1.5 years after cut-stump treatment with Garlon 3A gave 80-84 percent control of resprouts. Garlon 3A gave 41 percent control of all frill-treated trees; 99 percent of trees treated were tanoak. Basal treatments of undiluted Garlon 4 gave 55 percent mortality of stems less than 1 inch in diameter and 12 percent mortality of stems from 1 to 3 inches in diameter, 87 percent of the treated trees being tanoak.

Additional and more detailed information on herbicide control of tanoak can be found in Cafferata and Yee (1991), Helgerson (1990), Tappeiner, and others (1987), Warren (1980a,b), and Wurm (1976). Information on the ecology and silvical characteristics of tanoak and coast redwood can be found in Barrett (1995), Burns (1983), Burns and Honkala (1990a,b), Olson and others (1990), Tappeiner and McDonald (1984), and Tappeiner and others (1990). Research work on the economic potential of tanoak has been and is currently under way at several locations in northern California (Area Independent Development Corporation 1987, California Department of Forestry 1994).

Materials and Methods

Herbicide Characteristics

After reviewing the chemicals available to control tanoak, it was decided that the best candidates were triclopyr in the form of an amine (Garlon 3A) and a triclopyr formulation containing 4 pounds of triclopyr ester per gallon (Garlon 4).

Triclopyr was chosen for two reasons. It has been shown to be an effective control agent of tanoak in other experiments (Cafferata and Yee 1991, Tappeiner and others 1987, Warren, 1980a, b) and triclopyr is considered environmentally safe because of its degradation characteristics. Based on field studies, triclopyr is reported to degrade fairly rapidly when used according to label directions. Thus the potential for triclopyr reaching groundwater is greatly reduced (DowElanco 1990). Triclopyr is readily converted to its parent molecule and easily degraded by the sun, resulting in minimal to no adverse effects to aquatic organisms when applied around streams and other bodies of water (DowElanco 1990).

The amine form of triclopyr used in the frill and cut-stump treatments in this experiment is a water-soluble triethylamine salt formulation which contains 3 pounds of the triclopyr acid per gallon. The ester form was used in basal applications and is an oil-soluble, water emulsifiable butoxyethyl ester formulation which contains 4 pounds of triclopyr acid per gallon.

The triclopyr contained in both formulations acts much like the normal growth hormones in a plant. However, as the chemical is absorbed and moves to the growth centers of the plant's internal structure, it disturbs the natural balance of plant growth hormones. This imbalance inhibits normal cell division and related chemical processes, thus producing twisted and thicker tissues which result in the shutdown of plant processes and eventual death.

Site Characteristics

Uneven-aged forest management is being implemented at Swanton Pacific Ranch, Cal Poly's (California Polytechnic State University, San Luis Obispo) demonstration school forest and ranch (Big Creek Lumber Company 1991). The ranch, located 12 miles north of Santa Cruz, has numerous stands of coast redwood and Douglas-fir in competition with tanoak and was thus chosen as the site for this tanoak control experiment.

The study plots are located in the Little Creek watershed area at Swanton Pacific Ranch. This area had been clearcut and burned between 1907 and 1923 (Big Creek Lumber Company 1991). An intense fire occurred in the area in 1948. The vegetation resulting from these major disturbances is a varied tree-size stand of mixed tanoak, coast redwood, and Douglas-fir with scattered understory brush and herbaceous vegetation. A recent timber harvest (1990/91) implementing uneven-age forest management has been completed in the stand (i.e., Stand B) adjacent to the study plots.

The average site index (base age 100 years) for the Little Creek drainage area is 133 feet with a range of 94 to 200 feet (Lindquist and Palley 1963). The predominant soil types are Ben Lomond-Catelli-Sur complex and Maymen stony loam (Bowman and Estrada 1980). The topography for the immediate area of the study plots is best characterized as a very steep (i.e., greater than 35 percent), northeast aspect. The mean annual precipitation for this area is 60 inches. Fog is also an important regulator of climate and vegetation for this area.

Experimental Design

Twelve square plots (50 ft by 50 ft) were established in a randomized block design on 0.7 acres. Three replications of the three application methods plus an untreated control were randomly assigned to the 12 plots. The three methods of application include cut-stump, frill, and basal treatment. The treated tanoak trees ranged in diameter from 0.25 inches to 18 inches, with an average diameter at breast (DBH) of 4.25 inches and a height of 21 feet.

An unpaired *t*-test was used to analyze the statistical significance of the data obtained. This statistical test was chosen because treatments were compared only to the results obtained for the one control plot of that treatment category.

Cut-Stump Method

Trees were felled in four of the plots, and the freshly cut stumps in three of these plots were sprayed to wet the cambial layer with undiluted triclopyr amine (Garlon 3A) plus a blue dye. The fourth plot was considered the control and received no herbicide treatment. A rubber-tired skidder was used to endline larger diameter logs. These logs were eventually bucked-up, split, and sold as firewood. Smaller slash was lopped and scattered (and kept below the 30-inch level) throughout the cut-stump plots.

Frill Method

A series of adjacent, overlapping hatchet cuts, 1-2 inches in length, and 2-4 feet above the ground were made on the trunks of all live trees within each frill plot. Undiluted triclopyr amine (Garlon 3A) (2 ml) was applied (i.e., squirted) into the exposed cambium area in the frill cut immediately after the cut was made. Three of the plots were treated with the herbicide, while a fourth plot served as the control and was chopped as above, but received no herbicide.

Basal Method

A mixture of 25 percent Garlon 4 (triclopyr ester) and 75 percent diesel (similar to Pathfinder⁹ sold by DowElanco) was applied to the outer bark of each tree with a backpack sprayer. The application was made to the lower 24 inches of each tree and care was taken to treat the entire circumference. The fourth plot served as the control and received no treatment of any kind. A machete was used on a few larger diameter trees to make cuts in the cambium at approximately 4 feet above the ground to increase herbicide uptake. It should be noted, in the case of larger trees where cuts were made, that the basal method is not the same as the frill method. Only a small percentage of trees in the basal method were cut. The cuts were not uniform in size or shape, nor did they girdle the tree.

⁹Pathfinder is a Trademark name of a product of DowElanco Company.

Efficacy Rating System

The plots were monitored every 3 months for one year. Quantitative evaluations were done at 6-month intervals for 1 year (i.e., June 1991 and December 1991).

The methods of rating the plots varied with the treatment type. Every tanoak tree in each 50-foot × 50-foot plot was subject to an efficacy rating. To evaluate the effectiveness of the cut-stump method, the number of live resprouts per cut stump was counted. Additionally, sprout height was measured for each sprouting stump to determine whether a significant difference existed between the average sprout heights of the treated and untreated stumps. In a few of the test plots, some of the stump resprouts had been browsed by deer within 6 months after treatment. There was even more browsing in the test plots 12 months after treatment. Where browsing occurred, the sprouts were counted but not used to determine sprout height.

To determine the amount of control obtained with the frill and basal methods, a visual estimate of the percentage of crown dieback was made after treatment. The idea was to estimate the level of mortality resulting from the herbicide treatment on each tree. The final estimate for each tree was reached by consensus decision of two evaluators. It is difficult to differentiate between dieback because of the applied herbicide and mortality resulting from the existing natural stand conditions.

Results and Discussion

Cut-Stump Method

Six months after the triclopyr amine (Garlon 3A) application, good control was evident. Only 12 percent of the 198 treated cut stumps showed evidence of live resprouts (*table 1*). Sprouts averaged 5.3 inches in height (*table 1*). A total of only 138 sprouts was identified on the 12 percent of the treated cut stumps that sprouted (*table 1*). By comparison, 85 percent of the control stumps had a total of 617 visible sprouts 6 months after cutting (*table 1*). The average height of the sprouts for the control stumps was 4.8 inches. Approximately 90 percent of the sprouts on the treated and untreated stumps appeared healthy and vigorous. The remaining 10 percent of the sprouts were brownish-green and appeared to be dying.

Table 1—Tanoak control obtained at Swanton Pacific with a cut-stump application of Garlon 3A

Replication number	Month recorded	Number of stumps in plot	Number of stumps that sprouted	Percent stumps that sprouted	Total number live sprouts	Average sprout height per sprouted stump
						<i>inches</i>
1	6	54	10	19	80	5.3
2	6	62	2	3	11	4.2
3	6	82	11	13	47	6.5
	Totals:	198	23		138	
	Averages:			12		5.3
1	12	53	5	9	83	5.4
2	12	61	3	5	11	4.3
3	12	80	12	15	59	6.5
	Totals:	194	20		153	
	Averages:			10		5.4
Untreated	6	54	46	85	617	4.8
Untreated	12	52	50	96	915	5.2

Plots were reevaluated 12 months after treatment. Stumps sprayed with triclopyr amine (Garlon 3A) continued to show limited resprouting. Only 10 percent of the 194 treated stumps had sprouts (*table 1*). Four stumps of the original 198 treated cut stumps could not be found. The average sprout height for the cut-stump treatment was 5.4 inches. The untreated control stumps had a total of 915 sprouts. Only two of the control stumps had no resprouts, and the average sprout height was 5.2 inches. Two nontreated cut stumps from the original 54 treated stumps could not be located.

An unpaired t-test was used to compare sprouting of treated versus control stumps 12 months after treatment. The results yielded a *t*-value of -12.998 at a significance level of $P = 0.0005$. The number of sprouts from cut-stumps treated with triclopyr amine (Garlon 3A) were significantly less than the number of sprouts in the control plot. There was no significant difference between the mean sprout height for treated stumps and the control stumps.

In summary, 10 percent of the triclopyr amine (Garlon 3A) treated cut stumps sprouted compared to more than 96 percent for the control cut stumps which had statistically significant sprouting. There was no statistical difference in sprout height between the two groups. There could be several reasons for sprouting from triclopyr amine (Garlon 3A) treated cut stumps. It is possible that the cambial layer of some stumps was not completely covered with a sufficient amount of the herbicide, allowing some untreated areas to resprout. Another factor promoting sprouting of treated stumps was mechanical damage that resulted from the removal of the cut tanoak trees and associated slash. The damaged, exposed areas on the triclopyr amine (Garlon 3A) treated stump group could have stimulated sprout development. When using cut-stump treatment, careful application is necessary to achieve optimum results.

Frill Method

Six months after treatment, 92 percent of the trees treated with triclopyr amine (Garlon 3A) using the frill method showed leaves browning within the upper and lower crowns (*table 2*). Treated tanoak trees had 53 percent crown browning or dieback owing to this treatment. However, 45 percent of the trees in the control plot (i.e., frill cut made with no herbicide) also showed signs of dieback. The average amount of crown dieback in the frill, nonherbicide treated plot was 26 percent (*table 2*).

Table 2—Tanoak control obtained at Swanton Pacific with a frill application of Garlon 3A

Replication number	Month recorded	Number of trees in plot	Number of trees with any noted crown dieback	Percent of trees with dieback	Average percent crown dieback per browning tree
1	6	44	40	91	34
2	6	64	59	92	58
3	6	51	47	92	66
	Totals:	159	146		
	Averages:			92	53
1	12	41	37	90	70
2	12	61	56	92	82
3	12	48	47	98	75
	Totals:	150	140		
	Averages:			93	76
Untreated	6	60	27	45	26
Untreated	12	57	22	39	40

Twelve months after treatment, 140 (93 percent) of the 150 herbicide treated trees showed signs of dieback. An average of 76 percent of the 140 crowns were browning or showing dieback symptoms. In contrast, the untreated plot had 39 percent of its trees browning in the crown while average crown dieback was 40 percent (*table 2*).

An unpaired *t*-test of the 12-month data was run comparing treated trees to the frill-untreated trees. The results yielded a *t*-value of 9.941 with a significance level of $P = 0.0005$. Frilled trees treated with triclopyr amine (Garlon 3A) showed significantly more dieback than untreated trees.

Most of the dieback seemed to be in the upper half of the crown of the tree. Dieback seemed to start from the top and work toward the base of the crown. This top-down dieback result differs from what has been reported in past herbicide research. Tanoak treated by the frill method in these earlier studies, reportedly, starts to brown at the base of the crown and follows the flow of the chemical up the bole of the tree (Tappeiner and others 1987). The difference in this experiment may have been due to the application of undiluted triclopyr amine (Garlon 3A) in December when the evergreen tanoak trees are less physiologically active. Thus, when the trees resumed growth, the triclopyr amine (Garlon 3A) had already translocated throughout the stem and taken effect in the upper crown first.

Tanoaks smaller than 8 inches in diameter had much more dieback than treated trees more than 8 inches in diameter. This reduced dieback in larger trees may be related to the difficulty of making hatchet frill cuts that effectively penetrate the cambial layer. Further research evaluating dieback differences in trees of different sizes may be needed to explain the results observed in this study.

Basal Method

Six months after treatment, 34 percent of the trees treated with the basal method had leaves browning within the crown (*table 3*). The average amount of crown dieback per tree was estimated to be approximately 26 percent. In contrast, 21 percent of the control trees (10 out of 47 trees) showed signs of crown dieback. On average, about 28 percent of each tree crown in the control group had dieback (*table 3*).

Twelve months after herbicide treatment, 45 percent of 181 trees were browning. The amount of browning for each herbicide-treated tree averaged 49

Table 3—Tanoak control obtained at Swanton Pacific with a basal method application of Garlon 4 and diesel

Replication number	Month recorded	Number of trees in plot	Number of trees with any noted crown dieback	Percent of trees with dieback	Average percent crown dieback per browning tree
1	6	73	16	22	18
2	6	42	22	52	30
3	6	79	23	29	29
	Totals:	194	61		
	Averages:			34	26
1	12	68	19	28	18
2	12	39	28	72	60
3	12	74	25	34	68
	Totals:	181	72		
	Averages:			45	49
Untreated	6	47	10	21	28
Untreated	12	44	9	20	42

percent of the live crown. Nine (20 percent) of the 44 trees in the control plot had about 42 percent crown dieback (*table 3*).

An unpaired *t*-test with the 12-month basal treatment data produced a value of 1.878 with significance values between $P = 0.025$ and 0.050 . Dieback due to the basal treatment was not significantly different from the dieback identified in the control plot.

Larger-diameter tanoak trees were not as greatly affected by the basal application of triclopyr ester (Garlon 4) as the smaller-diameter trees. As with the frill treatment, the browning first took place in the upper portion of the crown and then progressed down toward the base of the tree

Research Implications

The results of this study substantiate earlier work (Cafferata and Yee 1991; Helgersson 1990; Radosevich and others 1976; Tappeiner and others 1987; Warren 1980a, 1980b; and Wurm 1976). Tanoak in Santa Cruz County coast redwood stands can be controlled with triclopyr (i.e., Garlon 3A and Garlon 4). The degree of tanoak control has been shown, in this and earlier studies, to be affected by several factors such as the chemical form of triclopyr used, month of application, timing of triclopyr application in relation to when the frill cut or stump cut is made, size of tree, and the extent of follow-up work (e.g., slash clean-up) that follows triclopyr application. Size of tree, adequate herbicide coverage, and uniformity of treatment appear to be major variables affecting the extent of dieback observed for both the frill and basal methods of application in this study.

Today there is pressure to rely more and more on uneven-aged forest management or the maintenance of a constant forest cover. These systems require scrutiny and control of a desired number of stems over a broad range of diameter classes. Having too many trees of either an undesired species or wrong size can impair the successful short- and long-term implementation of uneven-aged management. And, landowner objectives may not be met in a timely and economically feasible manner.

Thus, it is critical to control the number of undesired trees over a broad range of diameter classes. Much of the previous research on controlling unwanted brush and trees has focused on even-age forest management. More information is needed on the successful use of herbicides and other control strategies over a broad range of tree sizes as well as information about their cost effectiveness, given the expected income stream for uneven-aged managed forests. More research is needed on why, when, and where it is appropriate to undertake vegetation (i.e., tanoak) control using the uneven-aged forest management system. Some concerned citizens are advocating that natural processes (i.e., deer browsing) may be all that is necessary to control species and structural composition. Very little research exists to validate this type of plant control on a long-term basis in uneven-aged managed forests.

Acknowledgments

Appreciation is extended to Bob Brenton, formerly with DowElanco Company; Scott Johnson, from Wilbur Ellis Company; Phil Cody, Pest Control Advisor; Kevin Piper, Swanton Pacific Ranch Manager; Al Smith, former owner (deceased) of Swanton Pacific Ranch; Mike Jani, Registered Professional Forester for Big Creek Lumber Company; Bud McCrary and Lud McCrary, owners of Big Creek Lumber Company; Ann Warshaw; Meredith Welsh; Brian Strathmeier; and Joe Ramos. These individuals provided invaluable assistance at various stages of the project. Appreciation is also extended to Professors Tim Plumb and Ron Taskey,

California Polytechnic State University, San Luis Obispo and to Sandy Young, editor at the USDA Forest Service Pacific Southwest Research Station, Albany, for their thoughtful review comments. This project was financially supported by a grant from the Cal Poly CARE Grant Program, with contributions of materials and labor provided by DowElanco Company, Wilbur Ellis Company, and Big Creek Lumber Company. This research paper is based on the project results as they were initially presented in technical reports by Smith and others (1993) and Huff and Robinson (1993).

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