Journal
California Agriculture, 0(0)

ISSN
0008-0845

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Publication Date
2025-01-27

DOI
10.3733/001c.129083

RESEARCH ARTICLE

Effectiveness of herbicide control methods for coyote brush on the North Coast of California

Herbicides can help control coyote brush in grazing areas where controlled burning and mechanical removal are not feasible.

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Online: https://doi.org/10.3733/001c.129083

Abstract

Coyote brush is a native shrub common on California coastal prairies. It is largely unpalatable to cattle and is an aggressive encroacher on open prairies; as such, it is a threat to livestock production on some of California's most productive rangelands. This experiment assessed the effectiveness of four common herbicides and three application methods to control coyote brush. Glyphosate, imazapyr, triclopyr, and 2,4-deoxynivalenol (2,4-D) were analyzed using foliar spray and drizzle applications. Only glyphosate and imazapyr were analyzed using basal bark injection. All applications resulted in a short-term decrease in coyote brush cover, but plants that were treated with the selective herbicides triclopyr or 2,4-D appeared to recover after a year. The nonselective herbicides glyphosate and imazapyr performed well 12 months after application. Glyphosate and imazapyr performed similarly in controlling both large and small plants. No difference existed when comparing foliar spray and drizzle application methods, but both outperformed basal bark injection. As in previous studies, the drizzle method proved the most effective, requiring less labor and chemical than foliar application, and less threat of drift to non-target species. These results suggest that coyote brush can be controlled through both foliar spray and drizzle applications of glyphosate or imazapyr.

Coyote brush (*Baccharis pilularis* ssp. *consanguinea* DC) is a California native shrub that is common throughout coastal rangelands. In these areas, Baccharis is often the primary invader of grasslands (McBride and Heady 1968; Williams et al. 1987). In the absence of fire disturbance, the coastal rangelands of California (particularly in the north) are prone to rapid encroachment of woody plants such as coyote brush, due to the moderate climate, coastal moisture, and innate hardiness of many coastal shrub species (McBride 1974; McBride and Heady 1968; Mensing 1998). The versatile and hardy nature of Baccharis, and its ability to aggressively resprout, have posed a consistent management challenge in California (Stackhouse et al. 2018). Unmanaged woody encroachment can cause massive negative effects to the plant biodiversity, wildlife abundance, and livestock forage production which make these grassland systems valuable (Hobbs and Mooney 1986; Kidder 2015; Narvaez et al. 2010; Sampson and Jespersen 1963; Sawyer et al. 2009).

This study looks at herbicide control methods that can complement burning and mechanical removal as strategies to control coyote brush. Burning can be

Coyote brush can dominate rangeland systems in the western United States. Understanding how to control this shrub is of primary importance to a range of grassland managers. *Photo*: Jeff Stackhouse.

helpful, but its limitations include liability (Biswell 1999), legality, narrow burn windows, air quality regulations, lack of qualified burning crews (Quinn-Davidson and Varner 2012), and lack of experience with fire (Stackhouse et al. 2018). Mechanical treatment, such as chipping and removal, is a common tool in coyote brush control in the northern coastal scrub region (Stackhouse et al. 2018), where coyote brush successfully establishes on bare soils, but steep and rocky slopes limit the use of heavy equipment (Blesher 1999; McBride and Heady 1968). Given these complications, chemical treatment is often the only feasible option for control.

Previous work on herbicide control of coyote brush has shown varied results. Success varies across season of application, application method, and target plant size (Gambril 1983; Gann et al. 2012; Minogue et al. 2000; Mortensen 1984). In an attempt to understand the utility of using herbicides to control coyote brush on very short and slightly longer timescales, we tested herbicide application techniques (foliar spray, drizzle, basal bark injection), and four common herbicides (glyphosate, imazapyr, triclopyr, and 2,4-deoxynivalenol [2,4-D]) on both small and large plants at two coastal sites in Northern California. To assess variable application strategies, chemicals, and cost of treatment, we mirrored much of the design and methods of Oneto et al. (2010).

Grazing sites on coastal ranges

We chose two study sites that are used exclusively as year-round grazing for cow-calf beef operations. Both had previous unsuccessful attempts to control coyote brush using herbicides. The sites were in Humboldt County, California, approximately eight miles south of Ferndale on coastal rangelands, and were specifically chosen due to their location within the fog belt. The western site (40.47°N, 124.37°W) was approximately three miles east of the Pacific Ocean shoreline, at 1,400 feet (427 meters) elevation. The other site was four miles to the east (40.46°N, 124.26°W), at 1,100 feet (335 meters) elevation. Both sites were on Peaked-Forhaux-Dolason complex loam soils with 30% to 50% slopes (Soil Survey Staff 2021). Although only four miles apart, there are substantial differences in evapotranspiration rates on the two sites due to differences in coastal fog presence and the direction the hillsides face. The eastern site (about 35% slope) experiences significantly less fog than the western site (about 55% slope). The study was initiated in summer 2016.

TABLE 1. Application methods, herbicides, and rates for Baccharis applications

Herbicide	Trade name	Manufacturer	Plant size	Rate (v ae/v)	Adjuvant* (v/v)	psi
Foliar application						
2,4-D	Weedar 64	Nufarm	Large + small	5%	5%	30
Triclopyr	Element 4	DOW AgroSciences	Large + small	5%	5%	30
Glyphosate	Roundup PRO	Monsanto	Large + small	5%	5%	30
Imazapyr	Rotary 2 SL	Alligare	Large + small	5%	5%	30
Drizzle application						
2,4-D	Weedar 64	Nufarm	Large	10%	5%	20
Triclopyr	Element 4	DOW AgroSciences	Large	10%	5%	20
Glyphosate	Roundup PRO	Monsanto	Large	10%	5%	20
Imazapyr	Rotary 2 SL	Alligare	Large	10%	5%	20
Basal bark injection						
Glyphosate	Roundup PRO	Monsanto	Large	41%	0%	N/A
Imazapyr	Rotary 2 SL	Alligare	Large	52.6%	0%	N/A

* Southern AG methylated seed oil.

Spraying, drizzle, and injection

The treatments (table 1) included three application techniques, four herbicides, two different plant sizes for the foliar spray, and a control. However, treatments were not completely crossed. Each of 10 blocks consisted of 14 treatments and two controls (explained in detail below). Within each block, a treatment was applied to an individual shrub (Oneto et al. 2010). Shrubs were randomly chosen for a treatment within a block. A total of 160 plants were included within the experiment (140 plants exposed to a treatment and 20 plants not treated, but monitored as controls).

Our primary interest was the control of large Baccharis plants (> 6 feet height), and therefore plants of this size were included in all treatments and controls. However, we also wanted to determine whether herbicide efficacy can vary depending on plant size. To address this, for the foliar spray application treatments, smaller-statured plants (< 3 feet height) with associated controls were included in the trial.

Methylated seed oil (Southern AG) adjuvant was added to each herbicide solution as a solution of 5% product per gallon of water (5% volume/volume [v/v]). Four herbicides were used in the foliar and drizzle application treatments: 2,4-D (Weedar 64), triclopyr ester (Element 4), glyphosate (Roundup PRO), and imazapyr (Rotary 2 SL; table 1). Herbicide application rates were held constant across chemical types at 5% v/v for foliar applications and 10% v/v for drizzle applications (table 1). For basal bark application injections, only large plants (> 6 feet height) were included, and no seed oil was used. Basal bark injection (targeted 1.0 milliliters [ml] acid equivalent [ae] per 3-inch diameter) included only glyphosate and imazapyr herbicides at a 41% and 52.6% v/v concentration, respectively.

Foliar and drizzle applications were applied as described in Oneto et al. (2010). Foliar applications were applied (spray-to-wet) using a CO_2 backpack sprayer with an 8002 nozzle at 30 pounds per square inch (psi).

Drizzle applications were applied from a CO_2 backpack sprayer with a spray gun fitted with an orifice disk (0.5 millimeters [mm]) at 20 psi. The stream from the spray gun was applied to the plants at approximately a 6-foot distance in a "W" shape spray pattern to disperse the droplets evenly across the foliage. Basal bark injections were applied using a tubular injector with a crescent-shaped blade fitted with a pressure release valve to administer > 1.0 ml ae per incision.

All herbicides were effective

Six months after treatment, all four herbicides significantly reduced live foliage of large plants compared to the control ($P < 0.001$; fig. 1A). A leaf was considered "live" if it had any bright green color. The spray and drizzle methods of herbicide application were significantly more effective in reducing live foliage compared to injection or the controls ($P < 0.001$; fig. 2A).

Some plants resprouted at 12 months post-treatment, after being considered "dead" at 6 months post-treatment. However, 12 months after treatment, all herbicides were still more effective than the control at reducing live foliage of large plants ($P < 0.001$; fig. 1B). Imazapyr (average live foliage = 9%) and glyphosate (average live foliage = 16%) were more effective than triclopyr (average live foliage = 24%) and 2,4-D (average live foliage = 26%).

At 12 months, the spray and drizzle methods of herbicide application were significantly more effective in reducing live foliage than injection and the control ($P = 0.001$; fig. 2B). This was particularly true for glyphosate, where spray ($P < 0.0001$) and drizzle ($P < 0.0001$) were almost 100% more effective than injection. For imazapyr, the spray method was 84% more effective ($P < 0.0001$) and the drizzle treatment was 100% more effective ($P < 0.0001$) than the injection method. For triclopyr, the spray method was 50% more effective than the drizzle method ($P = 0.007$).

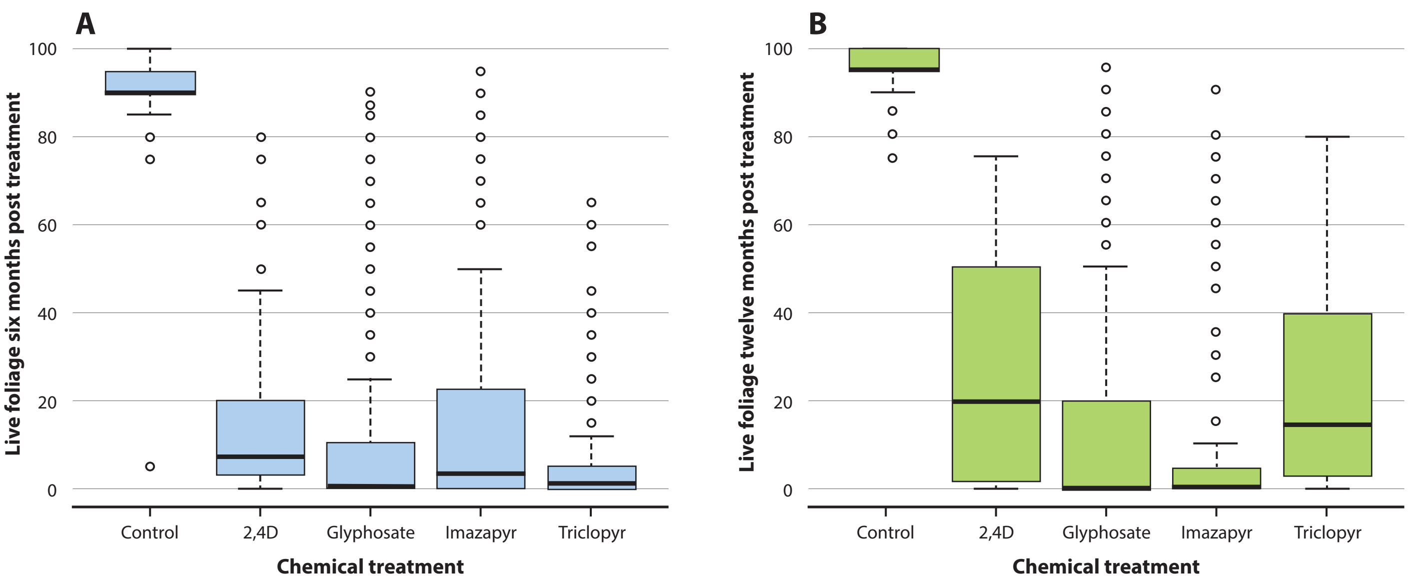

FIG. 1. Box plots of percent live foliage of large plants (A) 6 months and (B) 12 months post-treatment across herbicide types.

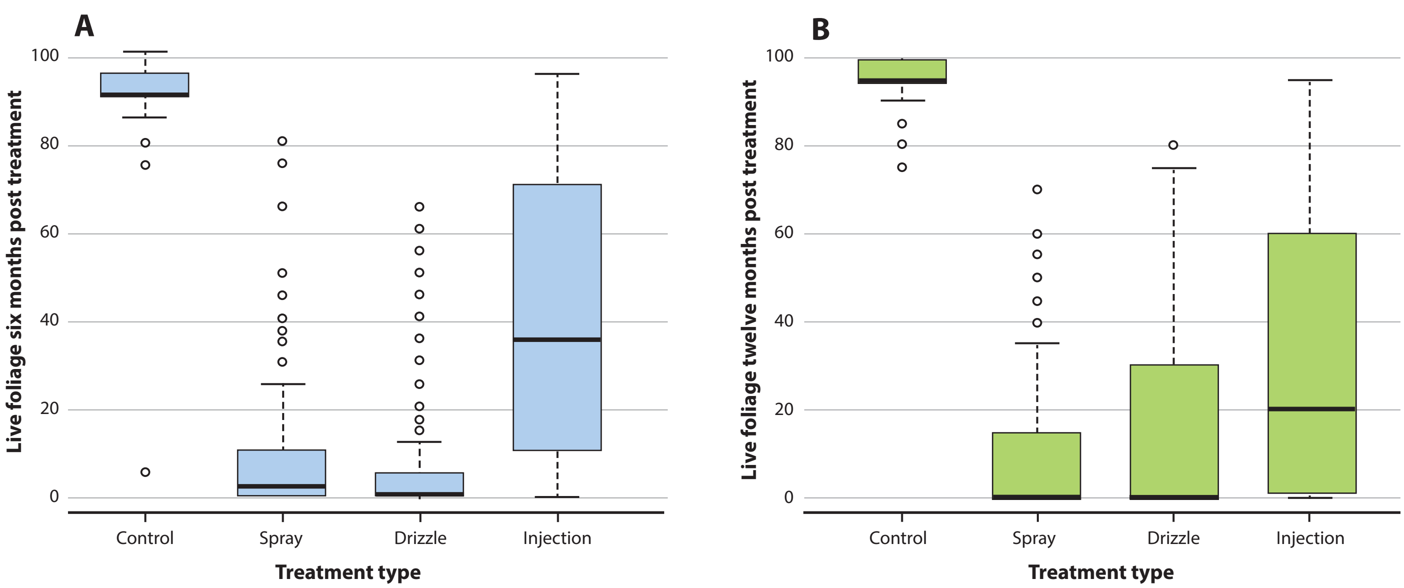

FIG. 2. Box plots of percent live foliage of large plants (A) 6 months and (B) 12 months post-treatment across application methods.

Co-author Jeff Stackhouse inspects brush for herbicide effectiveness. *Photo*: Josh Davy.

The four types of herbicides had similar effects at both sites, at both 6 and 12 months. However, at the more westerly (fog-exposed) site, spraying and drizzling were more effective at six months ($P < 0.001$) than injection or control. At 12 months, the spray method continued to be slightly more effective than other methods or control at the westerly site ($P = 0.001$).

There were no significant differences in results based on plant size.

These findings are based on several models using the *car* package (Fox and Weisberg 2019) in R version 4.2.2 (R Core Team 2022). First, we used an ANOVA to assess how herbicide identity and application might individually and interactively affect large plant percent foliage both 6 and 12 months after treatment (Hector et al. 2010). Two separate models were created for 6- and 12-month data. For each of these models, site was included as a fixed effect and block was included as a random effect. We used Type-III sums of squares to address the unbalanced data design (Lewsey et al. 1997). Tukey HSD tests were used to identify significant interactions. We then explored herbicide identity (with only the spray method) on small versus large plants at both 6 and 12 months after treatment. Two separate models were created for 6- and 12-month data. For these models, site was included as a fixed effect and block was included as a random effect. Tukey HSD tests were used to identify significant interactions.

Nonselective herbicides imazapyr and glyphosate were superior to the selective herbicides triclopyr and 2,4-D. Foliar spray and drizzle applications were more effective than basal bark injection.

Considerations in application

Coyote brush is found throughout all of California's coastal and some interior rangelands. Although desirable in limited quantities, solid stands can form monocultures that can decrease the forage production of these valuable coastal rangelands by taking up space that would otherwise be occupied by palatable grasses (Williams et al. 1987).

In this study, partial control of both large and small coyote brush plants was achieved with all herbicides and treatment methods. The nonselective herbicides imazapyr and glyphosate were superior to the selective herbicides triclopyr and 2,4-D. Foliar spray and drizzle applications were more effective than basal bark injection.

Effective application coverage was essential. Some coyote brush plants in this trial were almost ten feet tall; as a result, it was difficult to cover them using foliar spray. Additionally, on larger plants, foliar spray resulted in more drift and overspray to the desired herbaceous cover than did the drizzle application, which was limited to the dripline of the target shrub. Furthermore, the drizzle application required less traversing on steep slopes because numerous plants could be covered while standing and pivoting in one location, requiring less effort and labor time when compared with foliar spray applications. Although not quantified in this research, past work by Oneto et al. (2010) suggests that foliar application has a higher spray volume per plant, requiring more time to refill tanks and more chemical to achieve coverage when compared with drizzle. Applicators also noted much less work and effort navigating thick intertwined Baccharis, poison oak (*Toxicodendron diversilobum*), and Himalayan blackberry (*Rubus armeniacus*) when using the drizzle compared with the foliar spray or basal bark method.

Foliar spray is, however, more versatile than drizzle when coyote brush stands are less mature and there are smaller plants (less than three feet tall). Application technique should be selected based on stand structure, topography, and willingness to lose desired plant cover due to drift and overspray (Stewart et al. 2010).

Both imazapyr and glyphosate provided similar control of coyote brush when applied at similar rates, but glyphosate has two advantages. First, imazapyr is more expensive than glyphosate. Second, imazapyr exhibited longer soil residual when compared with glyphosate, further affecting non-target species. This is important because a faster recovery of desirable herbaceous plants means that more forage is available for livestock consumption. While glyphosate suppressed herbaceous growth early in our study, the herbaceous community recovered after 12 months. By contrast, areas treated with imazapyr remained void of palatable forages into the second year. A similar dynamic has been documented elsewhere (Lewis and McCarthy 2008; Patten 2003).

Although our treatments demonstrated relatively similar effects across locations, the results were slightly better on the more westerly site. It's very likely that the greater exposure to fog at this site provides greater foliar moisture uptake by coyote brush plants, compared to plants at the more eastern site (Emery 2016). This crucial water source reduces drought stress; interestingly, more drought-stressed plants tend to be less sensitive to herbicides (Benedetti et al. 2020). Possibly other important factors that differed between sites contributed to the small dissimilarity in herbicide effects, including grazing (Lehnhoff et al. 2019) and fire (McMillan et al. 2022) regimes. These results highlight the importance of considering site effects when assessing herbicide outcomes across locations.

Our results provide land managers with guidance on the efficacy and application of chemical control of Baccharis. With the implementation of this tool, managers can target the abundance and spread of this plant to attain desirable cover. Imazapyr and glyphosate controlled the shrub equally when foliar sprayed (5% v/v) or applied using drizzle techniques (10% v/v). Glyphosate was more cost-effective than imazapyr and the drizzle method was more cost-effective than foliar spray in both chemical use and labor. Both spring and fall applications of these chemicals provided adequate control, but spring application of glyphosate performed slightly better than fall. CA

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