Herbicide treatment of Western honey mesquite

By James D. Eddy, Dewey Stockbridge, Charles R. Hart, Joshua G. Cross, and Ryan S. Luna

On the Ground

- Once mesquite encroachment is initiated it is difficult to reverse and continually degrades grasslands, hindering grass production that benefits both livestock and wildlife.
- We evaluated the effectiveness of Sendero herbicide in the treatment of western honey mesquite.
- We compared two treatment types (Sendero and Sendero plus Remedy Ultra) and two application methods (individual plant treatment and aerial broadcast).
- Percent cover of grasses and some forbs increased throughout our study sites post treatment.
- All treatment types were successful at decreasing the percent canopy cover of western honey mesquite, and we found no difference between treatment types.

Keywords: Sendero, Remedy Ultra, Western honey mesquite, Brush encroachment, Herbicide, Habitat restoration

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Introduction

Encroachment of woody vegetation is a continuing problem throughout the Western United States.[1–5] The solution to this encroachment is an issue that will continue to evolve as new innovative management techniques are developed through increased awareness and public involvement.[6] Management and recovery of native grasslands overtaken by woody plants cannot be accomplished without human involvement.[6,7] This invasion by woody species has been attributed to many factors including overgrazing,[5,8–11] competition,[7] inadequate fire,[12] drought,[13] desertification,[4] and climate change.[14,15] Often these impacts can be irreversible, although proper methods implemented by managers may have a positive impact.[7]

The encroachment of woody species represents a significant threat to many native grasslands[12,16] and local fauna, including scaled quail (*Callipepla squamata*).[2] In part, this is because of changes in species richness and diversity as herbaceous species are replaced by woody species.[15] An increase in mesquite (*Prosopis* spp.) cover also reduces livestock forage productivity and may intensify drought effects due to annual increases in herbaceous biomass variability.[17] These implications warrant a continued study of woody encroachment management techniques that remain of paramount importance to range and wildlife management.

Mesquite and creosote (*Larrea tridentata*) are far more prolific in the western United States than other species of similar growth forms and life history.[18] Mesquite, juniper (*Juniperus* spp.), and some cacti (*Cactaceaeare* spp.) are the plant species expanding in most of the western United States.[13] Limiting the expansion of mesquite and other woody encroachment species for the purpose of returning grasslands to their previous state has proven to be difficult.[15] The continuous development of innovative and novel procedures or tools for restoring grasslands to their previous state through practices that reduce the impact of excessive mesquite populations should be sought.[19] The current measures used in mesquite control have shown varying levels of effectiveness at treating the drought tolerant and hardy western honey mesquite (*Prosopis glandulosa* var. *torreyana*) predominantly dependent on soil moisture and rainfall before treatment.[20] This is especially true in far West Texas where the western honey mesquite populations seem to be particularly resilient to management efforts owing to multistemmed varieties,[20] resulting in continued scaled quail habitat reduction.[8,14,21]

Elephant Mountain Wildlife Management Area

Our study was conducted on the 9,371 ha (23,156 acres) Elephant Mountain Wildlife Management Area (EMWMA) located approximately 40 km (24.8 miles) south of Alpine, Texas (Fig. 1). The EMWMA was historically utilized for cattle grazing and continues to be grazed at varying rates under Texas Parks and Wildlife Department management.[22–24] Ecological sites across EMWMA include stony hills, clay flats, sands, saline soils, loamy desert grasslands, gypsum flats, deep upland roughs, stony mountains, and gravelly outwashes.[25] Mean annual precipitation is 37.75 cm (14.86 in), with the majority occurring in July to August due to monsoons. Elevations range from 1,281 m (4,202 ft) in the flats to 1,891 m (6,204 ft) on the highest point atop Elephant Mountain.[22,26,27]

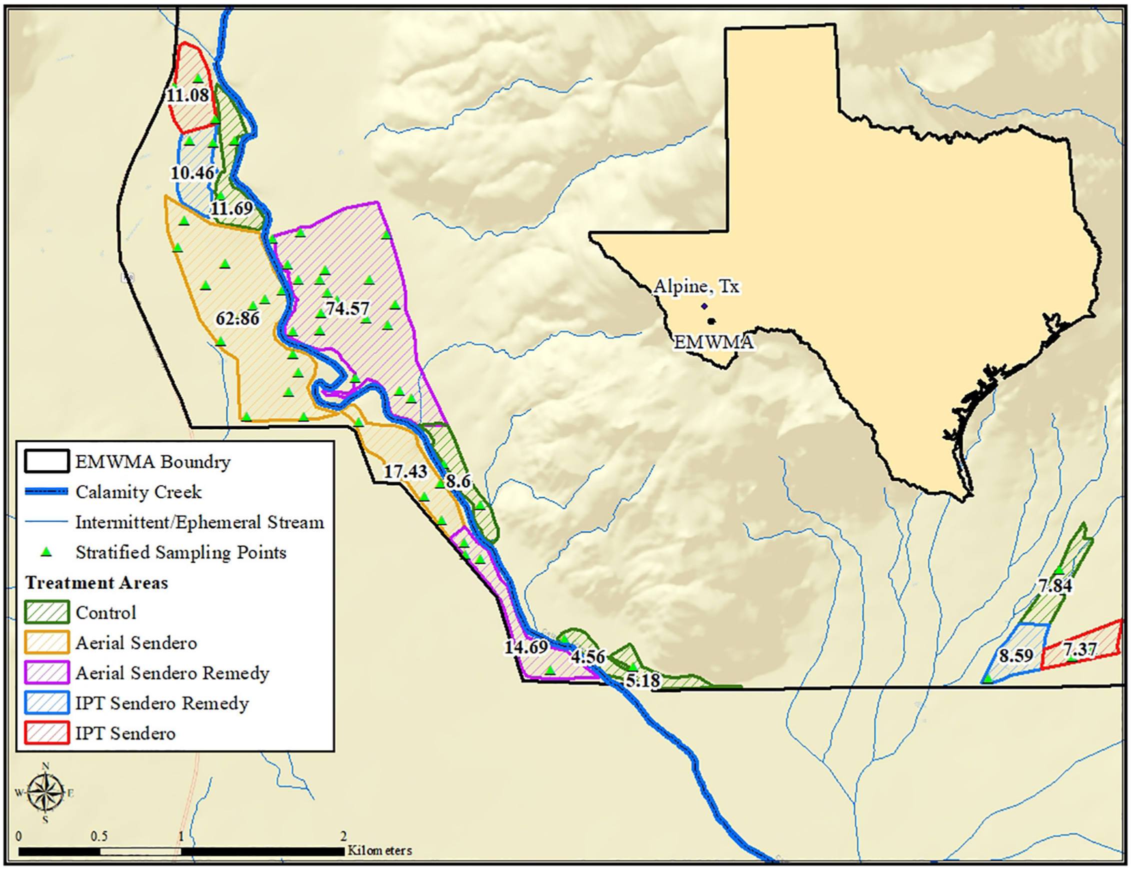

Fig. 1. Elephant Mountain Wildlife Management Area (EMWMA), Texas, herbicide treatment areas with area sizes (ha) shown. The eight treatment areas that received herbicide treatment were comprised of: two areas treated with Sendero using an aerial application (Aerial Sendero), two areas treated with a Sendero Remedy Ultra mix using an aerial application (Aerial Sendero Remedy), two areas treated with Sendero using an IPT application (IPT Sendero), and two areas treated with a Sendero Remedy Ultra mix using an IPT application (IPT Sendero Remedy). Random sampling points were generated in a stratified manner based on treatment area size to monitor vegetation response to herbicide treatment (Jan 2015–Nov 2016).

Our study focused on dense mesquite populations surrounding Calamity Creek south of the Texas Parks and Wildlife Department headquarters along EMWMA's southwestern boundary (Fig. 1). Calamity Creek is an intermittent stream that flows during intense rainfall.[22] Plant communities in the Calamity Creek watershed have historically been described as typical of the Chihuahuan Desert grasslands, which include creosote, lechuguilla (*Agave lechuguilla*), sotol (*Dasylirion wheeleri*), yucca *(Yucca spp.)*, mariola *(Parthenium incanum)*, dropseeds *(Sporobolus spp.)*, and tobosa *(Pleuraphis mutica)*, but mesquite encroachment has transitioned the vegetation communities to mesquite-dominated.[22–24] These vegetation communities are consistent throughout the flats of EMWMA, but differ from the communities found on the mountain slopes and top, which include Silver bluestem (*Bothriocloa laguroides*), sideoats gramma (*Bouteloa curtipendula*), beargrass (*Nolina texana*), Grama grasses (*Bouteloa* spp.), several oak species (*Quercus* spp.), and evergreen sumac (*Rhus sempervirens*).[23]

Our study site is primarily located in the loamy, desert grassland ecological site (R042XC250TX), but clay loam, desert grassland (R042XC757TX) is also represented (5 ha [12 acres]) in the treatment area that received aerial sendero treatment.[25] The treatment areas were primarily located in the Straddlebug soil series (a silty clay loam).[25] Butcherknife and Martillo (clay loam soil association) and Stovall (a silt loam soil series) soils are also represented in our treatment areas.

Herbicide application

We divided the study site into 13 different treatment areas (Fig. 1). Eight of the treatment areas were treated with herbicide, and five treatment areas were monitored as controls. Two herbicides were used with two different application methods, resulting in a total of four different treatment types. The herbicide products were Sendero (active ingredients aminopyralid and clopyralid) and a tank mix of Sendero and

Remedy Ultra (active ingredient triclopyr). The two application methods were aerial application and individual plant treatment (IPT). The eight treatment areas that received herbicide treatment were comprised of: two areas treated with Sendero using an aerial application (Aerial Sendero), two areas treated with a Sendero Remedy mix using an aerial application (Aerial Sendero Remedy), two areas treated with Sendero using an IPT application (IPT Sendero), and two areas treated with a Sendero Remedy mix using an IPT application (IPT Sendero Remedy; Fig. 1). The total area of all treatment areas was 245 ha (605 acres), of which 223 ha (551 acres) received herbicide treatment. All treatment areas varied in size and mesquite density. Treatment area size ranged from 4.56 to 74.57 ha (11.27–184.27 acres) and mesquite density ranged from 17% to 40% canopy cover. We selected the largest treatment areas with the densest overall vegetation to receive their herbicide treatment via aerial application.

Herbicide application was completed from 29 July to 17 August 2015. Herbicide treatment was completed during ideal conditions: dark-green and healthy foliage, deferred grazing, soil temperature at least 24 °C (75 °F) 0.30 m (12 in) below the surface while still maintaining moisture, no heavy rainfall, before the bean elongation period, wind speeds less than 16.09 kph (10 mph), relative humidity <20%, and ambient temperatures <35 °C (95 °F).[28–31] Because herbicide effectiveness is sensitive to the phenological stage of mesquite, it is critical that mesquite pods should be elongated but not filled or swollen.[31] The soil temperatures remained high throughout the treatment, ≥26.1 °C (79 °F). No new growth appeared after the last bean elongation period previous to our treatment. There was very little rain during the 3-week aerial and foliar treatment (<2 cm [0.79 inches]) and we applied herbicide when temperatures were between 20.6 and 33.3 °C (69.1–91.9 °F).

The aerial herbicide treatments applied 344.5 L (91 gal) of Sendero and 53.0 L (14 gal) of Remedy Ultra, which treated 169.2 ha (418 acres) at 37.31 L (10 gal) of total spray volume per hectare. This mix included a drift control agent and a non-ionic surfactant to aid in herbicide uptake through the leaf. Evidence of aerial treatment, primarily the yellowing of foliage and drooping leaves, was visible within a week after application throughout the four aerial treatment areas.

The IPTs were performed using 15 1/4 L (4 gal) commercial backpack sprayers and all-terrain vehicles equipped with sprayers. The Sendero treatment was 1% v/v and the Sendero plus Remedy Ultra treatment was applied with Sendero 1% v/v and Remedy Ultra 0.25% v/v.

Vegetation monitoring and evaluation

To document the vegetation response, we generated 60 random points in a stratified (by treatment area size) manner over the 206.4 ha (510 acres) of treated area and 37.9 ha (94 acres) of monitored control area (Fig. 1). A 20 m (66 ft) line transect and 15 uniformly located 0.125-m^2 (1.35 ft^2) Daubenmire quadrats were used at the 60 points to monitor vegetation (Fig. 2).[32] These methods were repeated twice a year in the spring and fall starting with pretreatment (April 2015), until final post-treatment monitoring (September 2016). The line intercept method[33] was used to monitor all shrubs along a 20 m (66 feet) transect which started from a permanent point (marked with a t-post) and was laid out in a randomly generated cardinal direction (Fig. 2). We recorded the starting and ending point of each transect, the cardinal direction and specific landmarks along the transect for ease in relocating transects each season. We recorded the percent canopy cover and number of individual mesquite plants intersecting the 20 m (66 ft) transect within 3 cm (1.18 inches) of either side of our measuring tape.

To make descriptive observations, we also collected information on grasses, forbs, bare ground, and litter along the 20 m (66 ft) transect through 15 uniformly located Daubenmire quadrats at each stratified random point (Fig. 2). At 5 m (16.4 ft) increments, starting at 0 m, we positioned three Daubenmire quadrats. The first of five Daubenmire quadrats were placed along the tape with the 0.5 m (1.64 ft) side of the quadrat running along the tape, left side first, and then alternating sides of the tape at each 5 m (16.4 ft) increment. The additional 10 quadrats were placed perpendicular to the tape both 1 m (3.3 ft) left and right of the tape. The percent of plant cover and number of individuals were recorded for each species of grass and forb within each quadrat. The remaining percentages were summed and recorded as bare ground or litter. All naming of plants follows United States Department of Agriculture Natural Resources Conservation Service plant database guidelines.[34]

Mortality estimates were determined utilizing multiple observers counting live and dead plants. Each treatment area ≤20.23 ha (50 acres) had four observers per treatment area. Treatment areas ≥20.23 ha (50 acres) also had four individual observers, but each observer took two count estimates. Multistemmed bunches were considered one plant and if any greenery was found on the plant it was not considered dead.

Mean percent cover of vegetation was calculated before data analysis at the replicate level.[35] The replicate level of mean percent shrub cover was comprised of the 20 m (66 ft) transect performed at each stratified point. The replicate level of mean percent grass and forb cover was comprised of all 15 quadrats taken at each stratified point. All data were analyzed as an estimated percent cover for each stratified point within a treatment area.

We used a univariate general linear mixed model (GLMM)[36] with a response of percent canopy cover of western honey mesquite to determine if there was an effect of pre- vs. post-treatment, or an effect of treatment types, at a significance level of $\alpha = 0.05$. Two GLMMs were performed because we did not want to include treatment types as a covariate while evaluating the pre vs. post effect. Percent canopy cover was arcsine transformed before analysis.[36] In both GLMMs we incorporated individual treatment area as a random effect to account for variation between treatment

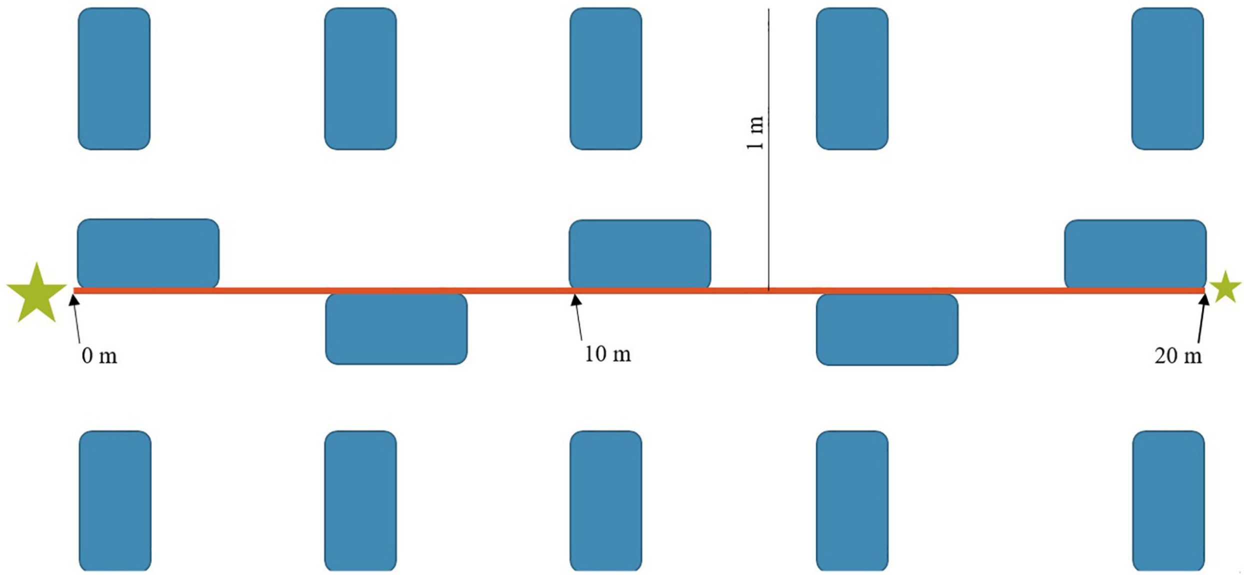

Fig. 2. Illustration of transect methods utilized to monitor vegetation response to herbicide treatments on the Elephant Mountain Wildlife Management Area, Texas (January 2015–November 2016). A 20 m (66 ft) line transect (shown as red line) and 15 uniformly located 0.125 m^2 (1.35 ft^2) Daubenmire quadrats (shown as blue rectangles) were established at stratified random points (starting point shown as large star, ending point as small star) within herbicide treatment areas.

areas. If an effect was detected, we performed a Tukey's post hoc test to explore the differences in treatment types.[36] We performed GLMMs in SPSS (IBM SPSS Statistics v26, New York, NY).

Treatment effects on vegetation

Although our study did not focus on the effect of herbicide treatment on grass and forbs, the following observations were made: estimated grass cover increased from 7.4% (range 0.2–40.1%, n = 60) pretreatment to 31.4% (range 0.1–57.0%, n = 60) 1 year post-treatment. Overall grass cover increased in the control treatment areas (average of 4.9–10.3%) but not to the degree seen on treatment areas (average of 9.5–34.9%). Estimated forb cover decreased from 19.0% (range 0.1–35.9%, n = 60) pretreatment to 11.1% (range 0.3–38.7%, n = 60) 1 year post-treatment. Forbs increased post-treatment on control treatment areas (average of 22.7–27.7%) while they decreased on all treatment areas (average of 18.2–9.4%).

The total percent shrub cover estimates, which included mesquite and other shrubs on control sites, increased from 53.0% (max = 81.2%, min = 0.2%, n = 60) pretreatment to 58.0% (max = 81.5%, min = 0.1%, n = 60) 1 year post-treatment overall (Table 1). This illustrates an increase in percent canopy cover post-treatment of various shrub species, other than mesquite, competing for resources made available in the different herbicide treatment sites. The live mesquite percent canopy cover estimates were found: the aerial Sendero treatment decreased from 25.7% (max = 77.2%, min = 7.3%, n = 19) pretreatment to only 6.1% (max = 46.2%, min = 2.3%, n = 23) 1 year post-treatment (Table 2); the aerial Sendero Remedy Ultra mix decreased from 17.7% (max = 81.2%, min = 3.5%, n = 23) pretreatment to only 0.3% (max = 7.9%, min = 0.0%, n = 23) 1 year post-treatment (Table 2); the IPT Sendero decreased from 21.9% (max = 46.3%, min = 7.3%, n = 5) pretreatment to only 4.0% (max = 19.9%, min = 0%, n = 5) 1 year post-treatment (Table 2); the IPT Sendero Remedy Ultra decreased from 24.2% (max = 29.6%, min = 19.5%, n = 4) pretreatment to only 6.8% (max = 27.0%, min = 0%, n = 4) 1 year post-treatment (Table 2); the controls increased slightly from 40.0% (max = 73.8%, min = 5.2%, n = 9) pretreatment to 40.1% (max = 62.7%, min = 3.8%, n = 9) 1 year post-treatment (Table 2). Percent canopy of broom snakeweed (*Gutierrezia sarothrae*), catclaw mimosa (*Mimosa aculeaticarpa* var. *biuncifera*), lotebush (*Ziziphus obtusifolia*), mariola (*Parthenium incanum*), tarbush (*Flourensia cernua*), and tasajillo (*Cylindropuntia leptocaulis*) all showed signs of residual treatment effects up to 1 year post-treatment with herbicide.

The first GLMM performed indicated a significant change in percent canopy cover of western honey mesquite between pre- and post-treatment ($P \leq 0.001$; Fig. 3). The second GLMM performed indicated a significant difference in percent canopy cover effect between treatment types ($P \leq 0.001$). The Tukey's test revealed that results from the control treatment type were significantly different from all other treatments, but all other treatments did not differ (Fig. 3).

Post-treatment conclusions

Our results showed that all treatment types (aerial Sendero, aerial Sendero Remedy Ultra, IPT Sendero, and IPT Sendero Remedy Ultra) decreased the percent canopy cover of western

Table 1. Descriptive statistics for all shrub percent canopy cover reduction and mortality estimates after herbicide treatment at Elephant Mountain Wildlife Management Area, Texas.

		Initial canopy reduction*			Spring 2016 canopy reduction*			1-year canopy reductions*			1-year mortality estimates*		
Treatment type	**Treatment area**	**n***	**Mean† (%)**	**SD (%)‡**	**n***	**Mean† (%)**	**SD (%)‡**	**n***	**Mean† (%)**	**SD (%)‡**	**n**	**Mean† (%)**	**SD (%)**
Aerial Sendero		19	82.7	38.3	17	81.9	34.4	17	84.6	29.2	12	33.0	12.7
	62.86 ha	15	77.4	42.8	13	77.4	38.4	13	80.4	32.4	8	28.2	12.1
	17.43 ha	4	100.0	–	4	96.5	3.9	4	98.4	3.1	4	42.5	8.1
Aerial Sendero Remedy		23	96.7	13.4	17	95.9	12.2	17	98.2	7.0	12	59.5	13.2
	74.57 ha	19	100.0	–	13	96.4	12.9	13	100.0	–	8	54.6	12.9
	14.69 ha	4	86.0	27.8	4	94.4	11.0	4	92.6	14.6	4	69.5	7.6
Controls		9	7.5	16.1	9	7.7	14.4	9	7.3	13.0	12	1.4	1.4
	Aerial Controls	4	4.7	5.4	4	4.2	4.9	4	4.5	5.5	4	1.0	0.8
	11.69 ha	3	0.0	–	3	2.6	4.5	3	2.7	4.7	4	1.2	0.9
	7.84 ha	2	24.6	34.8	2	22.3	31.5	2	20.1	28.4	4	2.0	2.3
IPT Sendero		5	85.1	33.2	5	85.2	33.1	5	88.9	24.7	8	62.2	6.9
	11.08 ha	3	75.2	42.8	3	75.3	42.7	3	81.5	32.0	4	57.2	3.7
	7.37 ha	2	100.0	–	2	100.0	–	2	100.0	–	4	67.2	5.5
IPT Sendero Remedy		4	68.7	47.3	4	75.0	50.0	4	75.0	50.0	8	52.1	17.0
	10.46 ha	2	50.0	70.7	2	50.0	70.7	2	50.0	70.7	4	44.7	17.2
	8.59 ha	2	87.4	17.8	2	100.0	–	2	100.0	–	4	59.5	15.4

* Canopy reduction estimates were performed at the following times: Initial (20 October-14 November 2015), spring 2016 (13–22 April 2016), 1-year (14 September-6 October 2016), and 1-year mortality estimates (30 September-1 October 2016).

† Mean values with an $n \leq 2$ yield unreliable SD (%).

‡ For values that remained constant across all samples the SD (%) values were omitted.

Table 2. Mean shrub percent cover at Elephant Mountain Wildlife Management Area, Texas, by species by season.

			Pretreatment Spring 2015[*]		Posttreatment Fall 2015[*]		Posttreatment Spring 2016[*]		Posttreatment Fall 2016[*]	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
Treatment Type	**Growth Stage**	**Species**[†]	**% Cover**	**(%)**	**% Cover**	**(%)**	**% Cover**	**(%)**	**% Cover**	**(%)**
Aerial Sendero (n = 19)	Live	tarbush (*Flourensia cernua*)[‡]	1.9	4.2	1.4	3.1	–	–	0.8	2.5
		creosote (*Larrea tridentata*)	6.5	7.6	6.9	9.3	6.4	8.5	7.2	9.3
		fourwing saltbush (*Atriplex canescens*)	0.9	2.9	0.8	1.9	0.7	1.6	1.4	3.2
		lotebush (*Ziziphus obtusifolia*)	2.6	8.6	4.5	10.4	0.9	4.1	7.3	18.3
		Western honey mesquite (*Prosopis glandulosa* var *torreyanna*)	25.6	17.4	6.8	16.0	6.8	11.7	6.1	12.1
		whitebrush (*Aloysia gratissima*)	–	–	–	–	–	–	0.1	0.1
	Decadent	tarbush	–	–	0.6	2.8	2.0	3.8	0.2	1.1
		lotebush	–	–	–	–	3.8	10.5	–	–
		Western honey mesquite	–	–	22.6	18.5	1.2	5.4	–	–
	Dead	tarbush	–	–	–	–	–	–	0.4	2.0
		creosote	0.4	2.1	0.4	1.9	0.4	2.0	0.2	1.0
		lotebush	0.3	1.5	–	–	–	–	–	–
		Western honey mesquite	3.4	3.4	0.1	0.6	22.6	18.5	24.9	18.0
Aerial Sendero Remedy (n = 23)	Live	allthorn (*Koeberlinia spinosa*)	0.6	1.6	0.6	1.6	0.6	2.1	0.5	1.5
		tarbush	7.3	0.1	7.0	9.7	–	–	6.3	9.2
		broom snakeweed (*Gutierrezia sarothrae*)	0.1	7.8	0.1	0.8	–	–	–	–
		catclaw mimosa (*Mimosa aculeaticarpa*)	7.5	15.5	–	–	0.2	0.9	1.4	4.0
		tasajillo (*Cylindropuntia leptocaulis*)[c]	0.1	12.6	0.1	0.4	0.1	0.2	0.1	0.3
		creosote	22.4	2.5	22.3	16.5	18.2	15.1	22.6	16.3
		fourwing saltbush	3.1	4.2	3.1	4.3	3.0	4.1	2.7	4.3

				Pretreatment Spring 2015*		Posttreatment Fall 2015*		Posttreatment Spring 2016*		
		hedgehog cactus (*Echinocereus* spp.)	0.1	9.9	0.1	0.7	0.1	0.4	0.1	0.8
		lotebush	1.4	0.3	0.7	3.6	–	–	1.3	4.2
		mariola (*Parthenium incanum*)	0.1	16.0	0.1	0.3	–	–	–	–
		Western honey mesquite	17.6	0.2	0.4	2.2	0.7	2.5	0.3	1.6
		whitebrush	4.8	1.8	6.2	14.2	–	–	5.1	12.4
		yucca (*Yucca* spp.)	0.5	0.4	0.5	1.7	1.4	1.5	0.6	1.9
	Decadent	allthorn	–	–	–	–	0.7	2.5	0.3	1.6
		tarbush	–	–	0.9	2.3	8.1	8.4	0.7	2.2
		broom snakeweed	–	–	–	–	0.1	0.7	–	–
		catclaw mimosa	–	–	8.1	8.6	3.6	7.4	4.5	7.7
		creosote	–	–	–	–	1.8	8.6	–	–
		fourwing saltbush	–	–	–	–	0.3	1.7	0.2	1.2
		lotebush	–	–	0.7	2.5	1.4	4.0	0.2	1.1
		mariola	–	–	–	–	0.1	0.2	0.1	0.1
		Western honey mesquite	–	–	17.2	15.3	–	–	0.1	0.4
		whitebrush	–	–	–	–	5.0	12.8	–	–
	Dead	allthorn	0.5	2.0	0.5	2.3	–	–	0.5	2.4
		tarbush	–	–	–	–	–	–	0.2	0.9
		broom snakeweed	–	–	–	–	–	–	0.1	0.6
		catclaw	0.6	0.5	0.7	2.8	5.1	7.6	2.5	4.2
		tasajillo	–	–	–	–	0.1	0.2	–	–
		creosote	0.1	0.4	0.2	0.7	0.4	1.4	0.1	0.7
		escobilla butterflybush (*Buddleja scordioides*)	–	–	–	–	0.1	0.4	–	–
		fourwing saltbush	0.1	1.6	0.1	0.6	0.1	0.9	–	–
		lotebush	–	–	–	–	–	–	0.1	0.7
		mariola	–	–	–	–	0.1	0.3	–	–
		unknown shrub	–	–	0.2	1.3	–	–	–	–
		Western honey mesquite	0.3	4.7	–	–	17.4	15.6	16.9	15.2

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Table 2 (*continued*)

			Pretreatment Spring 2015*		Posttreatment Fall 2015*		Posttreatment Spring 2016*		Posttreatment Fall 2016*	
			Mean	SD	Mean	SD	Mean	SD	Mean	SD
Treatment Type	**Growth Stage**	**Species**†	**% Cover**	**(%)**	**% Cover**	**(%)**	**% Cover**	**(%)**	**% Cover**	**(%)**
Control (n = 9)	Live	tarbush	2.2	2.7	3.1	4.6	0.2	0.6	4.4	5.4
		tasajillo	–	–	0.2	0.8	–	–	0.1	0.4
		creosote	6.5	6.8	8.9	5.5	6.1	6.0	7.9	7.4
		fourwing saltbush	2.3	4.8	2.2	5.2	3.3	7.5	4.2	9.3
		lotebush	0.5	1.5	0.5	1.6	0.6	1.9	0.4	1.2
		mariola	–	–	0.1	0.2	–	–	–	–
		Western honey mesquite	40.0	23.5	38.3	22.9	40.4	21.0	40.1	20.3
	Decadent	tarbush	–	–	–	–	2.8	4.1	–	–
	Dead	tarbush	–	–	–	–	–	–	0.3	1.1
		creosote	–	–	–	–	0.7	2.2	0.8	2.5
		Western honey mesquite	1.6	2.0	1.9	2.4	2.3	2.6	2.6	2.6
IPT Sendero (n = 5)	Live	tarbush	0.1	0.2	0.5	1.1	–	–	1.7	3.5
		tasajillo	0.1	0.3	0.1	0.3	–	–	–	–
		creosote	7.3	8.7	8.4	9.4	9.1	10.4	11.2	13.6
		mariola	0.6	1.2	0.9	1.8	–	–	0.7	1.4
		Western honey mesquite	21.9	14.9	4.1	8.2	5.1	10.2	3.9	7.9
	Decadent	tarbush	–	–	–	–	0.7	1.4	–	–
		mariola	–	–	–	–	0.9	1.8	–	–
		Western honey mesquite	–	–	18.7	15.2	–	–	–	–
	Dead	Western honey mesquite	–	–	–	–	23.0	15.4	26.3	15.3
IPT Sendero Remedy (n = 4)	Live	tarbush	3.2	5.5	4.6	7.1	–	–	7.0	12.1
		creosote	12.2	10.0	9.3	8.8	8.9	7.3	9.1	7.5
		fourwing saltbush	1.6	2.9	0.8	1.4	1.5	2.7	1.4	2.4
		lotebush	–	–	1.2	2.2	–	–	2.7	4.6
		mariola	4.2	6.9	5.2	9.1	1.5	2.6	1.3	2.3

				Pretreatment Spring 2015*		Posttreatment Fall 2015*		Posttreatment Spring 2016*		
		purple prickly pear (*Opuntia macrocentra*)	2.1	3.6	0.6	1.1	0.5	0.9	0.6	1.0
		Western honey mesquite	24.2	4.9	9.6	11.4	7.9	13.7	6.7	11.6
	Decadent	tarbush	–	–	–	–	4.0	7.0	–	–
		fourwing saltbush	–	–	–	–	–	–	2.4	4.1
		lotebush	–	–	0.1	0.2	2.7	4.7	–	–
		mariola	–	–	–	–	1.0	1.8	–	–
		Western honey mesquite	–	–	18.1	10.3	–	–	–	–
	Dead	tarbush	–	–	–	–	1.2	2.1	–	–
		fourwing saltbush	–	–	4.4	7.7	5.1	8.9	0.8	1.5
		lotebush	–	–	1.2	2.2	0.3	0.6	–	–
		mariola	–	–	–	–	–	–	0.6	1.1
		unknown shrub	–	–	0.3	0.6	0.5	0.9	–	–
		Western honey mesquite	–	–	–	–	16.9	11.8	18.4	17.0

* Mean shrub percent cover estimates were performed at the following times: Pre-treatment Spring 2015 (30 April–20 May 2015), Post-Treatment Fall 2015 (20 October–14 November 2015), Post-treatment Spring 2016 (13–22 April 2016), and Post-treatment Fall 2016 (14 September–6 October 2016).

† All naming of plants follows United States Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) plant database guidelines (USDA NRCS 2017).

‡ Few conflicts between NRCS plant database and standard Texas common names arose but when needed common names from the manual of the vascular plants of Texas were used (Correll and Johnston 1979).

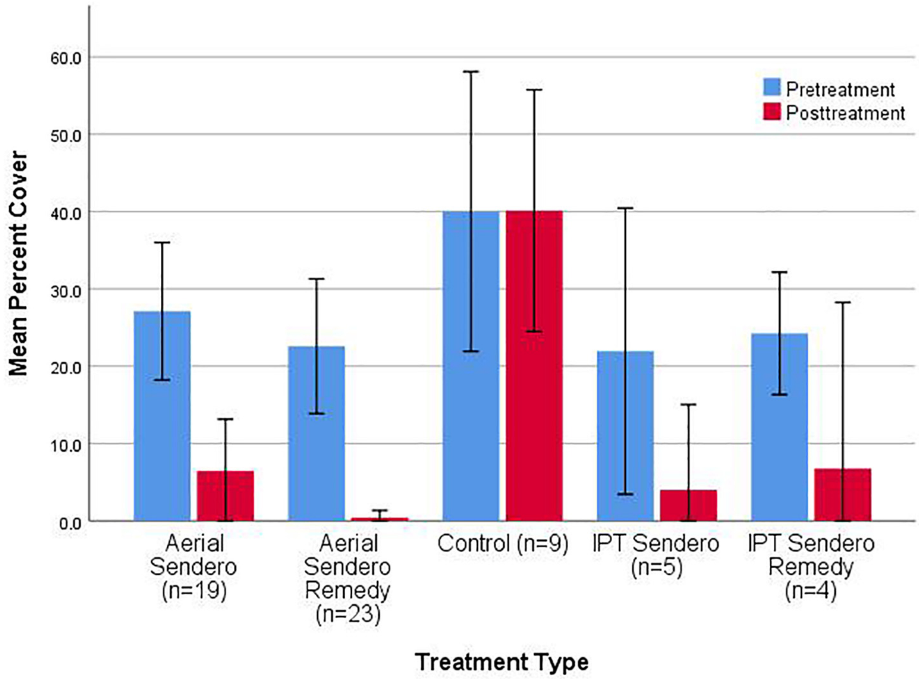

Fig. 3. Mean percent canopy cover of western honey mesquite pre and post treatment, across four treatment types, on the Elephant Mountain Wildlife Management Area, Texas (January 2015–November 2016). Error bars are 95% confidence intervals.

honey mesquite. We also showed no difference between the four treatment types. Aerial treatments and IPTs resulted in higher percent cover reduction of mesquite on southern treatment areas than their respective northern treatment areas. For IPTs, this is likely because of differences in height of mesquite between treatment areas. The southern IPT treatment areas consisted of 1-m (3.3 feet) tall multistemmed bunches of mesquite. The northern IPT treatment areas had thicker and taller (≥1.83 m [6 feet]) bunches of mesquite, which made applying herbicides challenging. All aerial treatments were performed primarily within the Straddlebug soil series, with only 5 ha (12 acres) of Butcherknife and Martillo soil series falling within treatments. In the aerial treatments, this north-south difference could be related to mesquite densities and shape of the aerial treatment areas. The northern Sendero aerial treatment area, for example, had taller mesquite shrubs that sheltered lower growing bunches of mesquite. This treatment area had visible leaf growth and basal resprout.

Overall, native grass percent cover increased greatly across the treatment areas at EMWMA (7.4%, range 0.2–40.1%, n = 60 pretreatment to 31.4%, range 0.1–57.0%, n = 60 1 year post-treatment), especially in the areas that exhibited a decrease in mesquite canopy cover. Grass growth and spread into interspaces after herbicide treatment could help control further invasion or reestablishment of mesquite, especially persistent perennial grasses.[6,37] Some notable perennial grasses that increased in these areas include plains bristle grass (*Setaria vulpiseta*), Arizona cottontop (*Digitaria californica*), bush muhly (*Muhlenbergia porteri*), alkali sacaton (*Sporobolus airoides*), and green sprangletop (*Leptochloa dubia*). Grasses benefited from rainfall that occurred post-treatment and the increase in soil moisture as a result of mesquite canopy cover reduction. Precipitation plays a significant role in grass and forb response to treatment.[6] Previous research has shown that herbicide treatments with >30% mortality rates of mesquite can significantly increase percent cover of grasses, especially with rainfall post-treatment.[38] Rainfall can increase browse capacities of grasses and also increase the growth of grasses, which can create favorable long-term effects after herbicide treatment.[6]

Percent cover of forbs decreased throughout the herbicide treatment sites (18.1%, range 0.1–35.9%, n = 51 pretreatment to 9.4%, range 0.3–37.4%, n = 51 1 year post-treatment) and slightly increased on the control sites (22.7%, range 0.1–30.9%, n = 9 pretreatment to 27.7%, range 0.1–38.7%, n = 9 1 year post-treatment). This may indicate forb injury (i.e., a temporary reduction in forb health and production) due to herbicide treatment but may also be related to differences in precipitation. Triclopyr can reduce annual broadleaved weeds, which may also contribute to lower percent cover of forbs post-treatment.[6] Interestingly, there was an absence of Russian thistle (*Salsola* spp.) after treatment, especially on the aerial Sendero Remedy Ultra treatment areas yielding a positive result to this forb injury. Additionally, the increased estimates of herbaceous percent cover 1 year post-treatment included native grasses and euphorbs important for wildlife, including pigweed (*Amaranthus texensis*), croton, plains bristle grass, Arizona cotton top, green sprangle top, feather fingergrass (*Chloris virgate*), and bush muhly.[39]

Additionally, the percent canopy cover reduction for western honey mesquite canopy was high throughout our treatment area but especially on the Sendero Remedy Ultra treatment areas and southern IPT treatment areas. Western honey mesquite is considered difficult to remove and usually requires multiple treatments over several years because of its root to shoot ratio, which leads to less herbicide reaching the basal bud zones.[20] Additionally, the more stems present, the less effective the herbicide, no matter the active ingredients in the herbicide,[38] which may have been a contributing factor at EMWMA and should be considered in future management plans for mesquite throughout the Trans-Pecos region. Mesquite plants not killed by an herbicide treatment will develop new stems from root crown or unaffected branches, which may require retreatment in 4 to 7 years.[40] Herbicide combinations have also been recommended to assist in controlling multistemmed mesquite.[20]

Management implications

Management goals, soil type, shrub height, shrub densities, and growth type should be taken into consideration when considering an herbicide treatment for mesquite control.[38] IPTs are effective, but the herbicide applications can be challenging because of timing, expense, human error, and effort.[6] Nevertheless, IPTs can be a viable option on small properties with low, shorter densities of mesquite.

The 1-year duration of our study did not allow for an assessment of treatment longevity. Treatment effectiveness, however, is not only related to mortality rates but also the length of time that the honey mesquite canopy growth is suppressed. Canopy reduction benefits, such as understory grass and forb establishment, are important to consider when choosing a treatment method for an area because brush control in dense stands is most likely to produce the best forb and grass recovery results.[39,41] This canopy reduction does not require a complete elimination of honey mesquite, but rather canopy reduction significant enough to allow a positive forb and grass response. The interspaces between mesquite plants could potentially recruit grass and forb given enough time.[39]

The shrub encroachment of western honey mesquite has been reduced with canopy reductions, which allows other species to establish on the landscape. Our results illustrate the potential benefit of Sendero and Sendero plus Remedy Ultra herbicide treatments for wildlife habitat improvement on western honey mesquite throughout the Chihuahuan Desert ecoregion.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Additional Reading

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Authors are from Department of Natural Resource Management/Borderlands Research Institute, Sul Ross State University, Alpine, TX 79832, USA; Texas Parks and Wildlife Department, Alpine, TX 79830, USA; Corteva Agriscience, USA