Black Greasewood (*Sarcobatus vermiculatus*), Gray Rabbitbrush (*Ericameria nauseosa*), and Perennial Grass Response to Chlorsulfuron and Metsulfuron

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Black greasewood (greasewood) and gray rabbitbrush are important shrub components of several plant communities throughout western North America. Land managers may view these species differently depending on their goals. Greasewood and gray rabbitbrush shrub communities may be invaded by several invasive plants including Russian knapweed, perennial pepperweed, hoary cress, halogeton, and several annual mustards. Metsulfuron and chlorsulfuron are commonly used for controlling these and other invasive plants, but little is known regarding their impacts on greasewood and gray rabbitbrush. Our objective was to quantify the impact of these herbicides on greasewood and gray rabbitbrush communities from both an efficacy and nontarget impact perspective. Field studies were established in the spring of 2004 and repeated twice in 2005 near Laramie, WY, in a pasture with mixed stands of greasewood and gray rabbitbrush. Treatments included metsulfuron applied at 21, 42, 63, 84, 126, and 168 g ai/ha (0.3, 0.6, 0.9, 1.2, 1.8 and 2.4 oz ai/A), chlorsulfuron applied at 52, 105, and 157 g ai/ha (0.75, 1.5 and 2.25 oz ai/A), and an untreated control. All treatments contained methylated seed oil at 2% v/v. Treatments were applied in mid-June to 3.3 by 9-m (10 by 30 ft) plots with a handheld broadcast sprayer delivering 187 L/ha (20 gal/ac) in a randomized complete block, with three blocks per study. Plots were sampled 12 and 24 mo after treatment (MAT), utilizing visual control estimates and point frame sampling for vegetative cover of greasewood, gray rabbitbrush, perennial grasses, and bare ground. Metsulfuron at 42 g/ha and chlorsulfuron at 105 g/ha provided $> 75\%$ visual control of greasewood 24 MAT. For gray rabbitbrush, metsulfuron at 63 g/ha provided approximately 60% control 24 MAT, while chlorsulfuron provided negligible control at any rate. These results suggest differential impacts of these herbicides on greasewood and gray rabbitbrush, and provide land managers with a decision tool for noxious and invasive weed control when managing for or against greasewood and gray rabbitbrush.

Nomenclature: Chlorsulfuron; metsulfuron; halogeton, *Halogeton glomeratus* (Stephen ex Bieb.) C.A. Mey.; hoary cress, *Cardaria draba* (L.) Desv.; perennial pepperweed, *Lepidium latifolium* L.; Russian knapweed, *Acroptilon repens* (L.) DC.; black greasewood, *Sarcobatus vermiculatus* (Hook.) Torr. SAYVE; gray rabbitbrush, *Ericameria nauseosa* (Pallas ex Pursh) Nesom & Baird.

Key words: Alkaline, saline, plant community, nontarget impacts.

Black greasewood [*Sarcobatus vermiculatus* (Hook.) Torr.], hereafter referred to as greasewood, and gray rabbitbrush [*Ericameria nauseosa* (Pallas ex Pursh) Nesom and Baird], also commonly referred to as rubber rabbitbrush, are common native shrub components of many western North American plant communities including salt desert shrub, sagebrush, and desert grasslands. Greasewood, a member of the family Chenopodiaceae, is an erect, spreading, spinescent, deciduous shrub that is commonly found on heavy-textured saline soils in areas with shallow water tables. Gray rabbitbrush is a member of the family

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Interpretive Summary

Greasewood and gray rabbitbrush are common components of many plant communities in the western United States. Both may be either desirable or undesirable, depending upon management goals. Stands of both are often invaded by many weeds such as perennial pepperweed and Russian knapweed. Two herbicides widely used for invasive plant control are chlorsulfuron and metsulfuron; however, neither has been tested for their impacts on greasewood and gray rabbbitbrush. In repeated field studies, we found that metsulfuron was effective on both species while chlorsulfuron was effective on greasewood but had minimal impact on gray rabbitbrush. Predicted responses for each species were calculated for published rates needed to control several key invasive plants. Knowing the rate sensitivity of these two species to the two herbicides will allow selective control of invasive weeds through regulating the application rate. These comparisons provide land managers with important impact estimates of chlorsulfuron and metsulfuron on greasewood and rabbitbrush when used at common rates for invasive plant control.

Asteraceae and is an erect, deciduous shrub with wide ecological amplitude, having over 20 distinct subspecies and numerous ecotypes (Tirmenstein 1999). Both species vary widely in their function and services across ecosystems and provide important wildlife habitat (Sampson and Jesperson 1963). Both are a food source (Robertson 1983; Stubbendieck et al. 1997) and cover for many wildlife species (Blauer et al. 1976). Greasewood is also utilized for restoration of salt desert blowouts (areas impacted by severe wind erosion) (Breen and Richards 2008) and mineland reclamation (McKell 1986) while many species of *Chrysothamnus* including gray rabbitbrush are used extensively for soil stabilization and mineland reclamation (Romo and Eddleman 1988).

From a forage production viewpoint, both species are of limited value for livestock grazing. Greasewood may be eaten by cattle and sheep but is toxic in large quantities due to high concentrations of oxalate, especially in late summer (Couch 1922; Kingsbury 1964). Gray rabbitbrush is a poor forage for livestock (Stubbendieck et al. 1997) and heavy stands of gray rabbitbrush are also frequently associated with poor range management. These factors have led to management attempts (Cluff et al. 1983; Whisenant 1987); however, both species are very difficult to control (Ferrell and Whitson 1987). Difficulty in long-term control is partially attributed to the reproductive mechanisms of both species. Greasewood reproduces by seed, new shoots initiated from the root crown, and from creeping lateral roots (Robertson 1983). Gray rabbitbrush reproduces primarily by seed and by epicormic buds that are located on the stem and root crown (Young 1986).

Whether in range production systems or natural areas, several invasive plant species are associated with greasewood and rabbitbrush communities including Russian knapweed, [*Acroptilon repens* (L.) DC.], hoary cress [*Cardaria draba* (L.) Desv.], perennial pepperweed (*Lepidium latifolium* L.), halogeton [*Halogeton glomeratus* (Stephen ex Bieb.) C.A. Mey.], and swainsonpea [*Sphaerophysa salsula* (Pallas) DC.]. Additionally, many greasewood and gray rabbitbrush communities harbor numerous weedy annual mustards including tumble mustard (*Sisymbrium altissimum* L.) and African mustard (*Brassica tournefortii* Gouan). Given that both greasewood and rabbitbrush often increase following disturbance (Meyer et al. 1989; Robertson 1983; Wagner et al. 1978) they are commonly associated with many nonnative invaders. However, very little is known regarding their interactions with invasive plants. This is likely because of their limited value in range production and inherent weediness in overused systems. Both species could serve important roles as deeply-rooted shrubs in maintaining functionally diverse native plant communities that may reduce weed invasion (Krueger-Mangold et al. 2006).

Since considerable invasive weed control efforts are underway across the western United States for many species found within greasewood and gray rabbitbrush stands, a better understanding of how weed management strategies impact greasewood and gray rabbitbrush would be beneficial. Two key herbicides that are frequently used for control of many invasive plants are chlorsulfuron and metsulfuron (Dewey et al. 2006). Both herbicides are sulfonylureas and inhibit branched chain amino acid synthesis in susceptible species, resulting in arrested growth and subsequent plant death. Both herbicides are especially effective on species in the Brassicaceae family (Dewey et al. 2006). However, little is known concerning the impact of chlorsulfuron and metsulfuron on greasewood and gray rabbitbrush. Since these native species may be either desirable or undesirable components of an ecosystem, depending upon management goals, our objective was to determine the impact of chlorsulfuron and metsulfuron on greasewood, gray rabbitbrush, and native grasses commonly associated with these species. While economics may preclude treatment from a weedy perspective, aggressive control efforts on other weed species in greasewood and gray rabbitbrush stands, and information on subsequent nontarget impacts to them, would be very useful.

Materials and Methods

Three separate studies were conducted approximately 16 km (10 miles) west of Laramie, WY, from 2004 to 2007 on a heavily grazed native pasture that was dominated by greasewood and gray rabbitbrush. The soils within the three studies were in the Poposhia forelle complex (Fine-loamy, mixed Borollic Haplargids) and ranged from clay to sandy clay loam with a pH of 8 to 8.2, percent organic matter of 2.5 to 4.5%, and electrical conductivity values of 8.8 to 21.5 deciSiemens per meter (dS/m). In all three studies, the herbaceous understory was composed primarily of alkali sacaton [*Sporobolus airoides* (Torr.) Torr.], western

Table 1. Model parameters for the Weibull model (provided in Equation 1) applied to various response variables.

Response variable	Herbicide	b	c	d	e
		Parameter (standard error)			
Greasewood cover 12 MAT[a]	metsulfuron	0.34 (0.785)	−0.51 (9.44)	28 (2.44)	4.8 (9.50)
	chlorsulfuron	2.0 (5.21)	2.5 (1.83)	28 (2.44)	42 (22.6)
Greasewood cover 24 MAT	metsulfuron	0.66 (0.433)	1.7 (3.34)	30 (2.53)	19 (8.28)
	chlorsulfuron	2.1 (10.9)	4.1 (2.23)	30 (2.53)	44 (34.8)
Rabbitbrush cover 12 MAT	metsulfuron	3.1 (1.64)	3.2 (2.09)	31 (4.13)	33 (5.92)
	chlorsulfuron	−11 (76.4)	34 (2.92)	30 (2.94)	63 (90.8)
Rabbitbrush cover 24 MAT	metsulfuron	2.8 (1.14)	6.4 (1.55)	34 (3.01)	33 (4.57)
	chlorsulfuron	na[b]	na	na	na
Grass cover 12 MAT	metsulfuron	−2.8 (2.31)	15 (4.51)	37 (3.19)	24 (6.19)
	chlorsulfuron	na	na	na	na
Grass cover 24 MAT	metsulfuron	−3.2 (2.23)	19 (4.00)	39 (2.41)	24 (5.55)
	chlorsulfuron	−16 (151)	18 (2.81)	23 (2.81)	60 (114)
Bare ground 12 MAT	metsulfuron	−2.0 (2.79)	26 (5.51)	60 (5.35)	15 (7.54)
	chlorsulfuron	−0.52 (0.740)	26 (5.61)	100 (216)	280 (1230)
Bare ground 24 MAT	metsulfuron	−0.37 (0.631)	16 (3.39)	81 (81.2)	27 (90.9)
	chlorsulfuron	−0.47 (1.19)	16 (3.39)	62 (113)	86 (465)
Greasewood control 12 MAT	metsulfuron	−1.8 (0.863)	0 (3.87)	98 (3.94)	13 (2.89)
	chlorsulfuron	−3.1 (2.83)	0 (3.87)	91 (7.52)	41 (7.30)
Greasewood control 24 MAT	metsulfuron	−1.5 (0.610)	0 (5.53)	98 (7.81)	17 (2.48)
	chlorsulfuron	−3.2 (5.28)	0 (5.53)	82 (10.0)	39 (15.7)
Rabbitbrush control 12 MAT	metsulfuron	−2.1 (0.604)	0 (5.36)	98 (6.04)	26 (3.11)
	chlorsulfuron	−1.1 (99.3)	0 (5.41)	19 (3.84)	54 (17.9)
Rabbitbrush control 24 MAT	metsulfuron	−1.9 (0.923)	0 (7.66)	91 (20.2)	52 (16.7)
	chlorsulfuron	na	na	na	na

[a] Abbreviation: MAT, mo after treatment.

[b] Where parameters are listed as "na", the Weibull model was not significantly better than a linear regression model, and therefore a linear regression model was fit to the data instead.

wheatgrass [*Pascopyrum smithii* (Rydb.) A. Löve], and foxtail barley (*Hordeum jubatum* L). Very few forbs were present. The study was initiated in June 2004 and repeated twice beginning in June 2005. For each study, treatments were applied in mid- to late June when both greasewood and gray rabbitbrush were rapidly growing and new leaf expansion was nearly complete. This application timing is typical for many invasive plants and also coincides with the period of maximum susceptibility of greasewood and rabbitbrush to other herbicide treatments such as 2,4-D (Roundy et al. 1981). Herbicide treatments were broadcast applied using a CO_2-pressurized backpack boom sprayer delivering 187 L/ha at a pressure of 276 kPa (40 psi). Plot size was 3.3 by 9 m. Treatments included chlorsulfuron[1] applied at 52, 105, and 157 g ai/ha, metsulfuron[2] applied at 21, 42, 63, 84, 126, and 168 g ai/ha, and an untreated check. Methylated seed oil[3] (MSO) was also added to each treatment at 2.34 L/ha. These rates encompass the range used for many invasive plants in the western United States (Dewey et al. 2006). The experimental design was a randomized complete block with three replications in each study.

Greasewood and gray rabbitbrush control was visually evaluated 12 and 24 MAT. Visual control was evaluated for each treatment by comparing each treated plot to the nontreated check using a rating scale of 0 (no control) to 100 (complete absence of living shoots). Plant cover and bare ground were assessed by using point frames (10 points per frame) randomly placed at 90-cm (3 ft) intervals along a transect running diagonally along the length of the plot for a total of 100 points per plot.

Statistical Analyses. Perennial grass cover by species was highly variable across plots and was pooled within plots to provide an overall grass community response to each treatment. Forb cover encountered during point frame sampling was extremely low (mean ± standard error across all plots = 0.4 ± 0.28%) and forbs were excluded from the analyses. Percent visual control of greasewood and gray rabbitbrush, and percent cover of greasewood, gray rabbitbrush, perennial grasses, and bare ground, were analyzed as a function of metsulfuron or chlorsulfuron rate using the drc package in the statistical program R (R

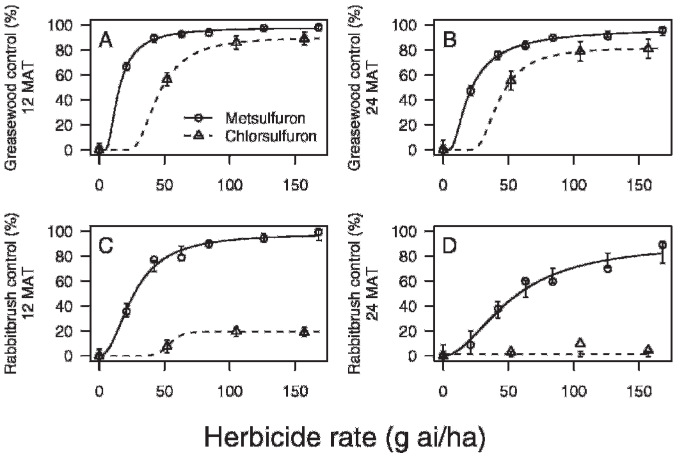

Figure 1. Greasewood (A and B) and gray rabbitbrush (C and D) control with chlorsulfuron and metsulfuron 12 and 24 mo after treatment.

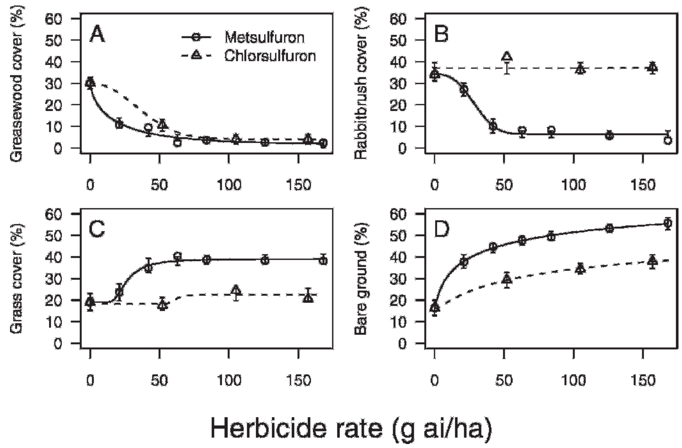

Figure 3. Greasewood (A), gray rabbitbrush (B), perennial grass (C), and bare ground (D) cover response to chlorsulfuron and metsulfuron 24 mo after treatment.

Development Core Team 2007; Ritz and Streibig 2005). A four parameter Weibull function of the form

$$f(x) = c + (d - c)\cdot\exp(-\exp\{b[\log(x) - \log(e)]\}) \quad [1]$$

was fit to each response variable, where x is the herbicide rate in g ai/ha; b is the relative slope around the inflection point; c and d are the horizontal asymptotes on the right and left sides, respectively; and e is the inflection point of the fitted curve. The Weibull function was chosen because the parameters are biologically meaningful, and it allows for asymmetry around the inflection point, which was clearly evident at the beginning of our data analysis. Standard errors of the predicted response for each variable were extracted from the fitted models and plotted. Model parameters and their standard errors are provided in Table 1. Additionally, predicted responses for greasewood and rabbitbrush control were calculated from the 24 MAT data using the PR() function in the drc package.

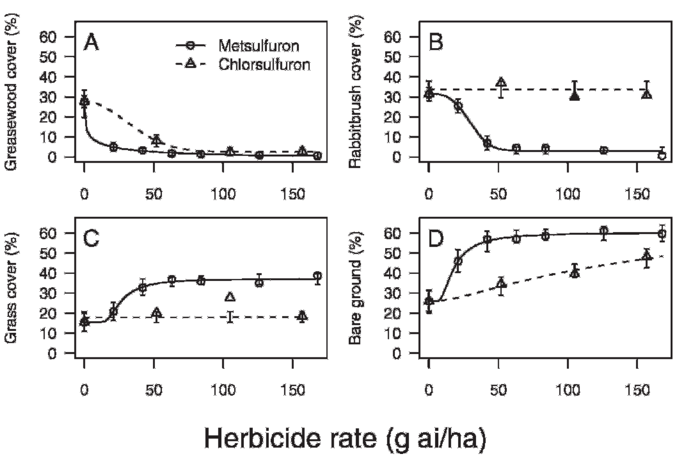

Figure 2. Greasewood (A), gray rabbitbrush (B), perennial grass (C), and bare ground (D) cover response to chlorsulfuron and metsulfuron 12 mo after treatment.

Results and Discussion

Metsulfuron strongly impacted greasewood and gray rabbitbrush in these studies. Twelve MAT, metsulfuron at the lowest rate tested (21 g/ha) controlled greasewood greater than 60% (Figure 1A). All higher rates provided 80 to 90% at 12 MAT and greater than 75% control 24 MAT (Figure 1B). Gray rabbitbrush exhibited a higher degree of tolerance than greasewood to metsulfuron with the low rate controlling less than 40% at 12 and 24 MAT (Figures 1C and 1D). Rates of 63 g/ha and higher were needed to provide 80% gray rabbitbrush control 12 MAT. Only the highest rate (168 g/ha) of metsulfuron maintained at least 80% gray rabbitbrush control 24 MAT.

Chlorsulfuron impacts on greasewood and rabbitbrush were less than metsulfuron at 12 and 24 MAT. The lowest rate of chlorsulfuron (52 g/ha) resulted in slightly less than 60% greasewood control at both 12 and 24 MAT (Figures 1A and 1B). Higher rates resulted in approximately 80% greasewood control 12 and 24 MAT. Chlorsulfuron impacts on gray rabbitbrush were very limited with a maximum of approximately 20% control 12 MAT. However, this control was short-lived as there were no apparent effects 24 MAT at any chlorsulfuron rate (Figures 1C and 1D).

Visual control data was comparable to changes in greasewood and gray rabbitbrush cover. Both greasewood (Figures 2A and 3A) and gray rabbitbrush (Figures 2B and 3B) cover were reduced from approximately 30% in the untreated controls to less than 15% for all metsulfuron rates greater than 21 g/ha at 12 and 24 MAT. Compared to the untreated control, perennial grass cover was doubled with rates of metsulfuron of 42 g/ha and higher 12 MAT

Table 2. Predictive response of greasewood and gray rabbitbrush to chlorsulfuron and metsulfuron 24 mo after treatment at typical rates for invasive plant control.

	Chlorsulfuron rate (g/ha)				Metsulfuron rate (g/ha)			
Target	26	52	79	105	14	21	32	42
	% Control							
Greasewood (SE)	2 (35)	56 (8)	74 (16)	79 (8)	26 (8)	47 (4)	66 (3)	76 (3)
Gray rabbitbrush (SE)	1 (2)	2 (2)	2 (2)	2 (2)	3 (8)	11 (9)	26 (7)	37 (7)

and was maintained at that level at 24 MAT (Figure 2C and 3C). The greatest change in cover observed was the increase in bare ground following metsulfuron treatment. All rates increased bare ground at 12 and 24 MAT (Figure 2D and 3D).

Gray rabbitbrush cover remained stable at approximately 30 to 40% across chlorsulfuron rates at 12 and 24 MAT. Grass response to chlorsulfuron was also minimal as total grass cover changed little at 12 and 24 MAT across rates (Figures 2C and 3C). No negative grass response to chlorsulfuron was observed, even at the highest rate. Chlorsulfuron increased bare ground at all rates at 12 and 24 MAT.

The predicted response of greasewood and gray rabbitbrush 24 MAT was calculated from the fitted models for several common use rates of each herbicide (Tables 2 and 3). Chlorsulfuron rates recommended for control of perennial pepperweed, hoary cress, and Russian knapweed would result in 56 to 79% control of greasewood (Tables 2 and 3). Therefore, chlorsulfuron use for control of these invasive weeds will have a large negative effect on greasewood. However, the chlorsulfuron rate needed for annual mustard control is predicted to cause only 2% control of greasewood, indicating a high level of safety for this species. For metsulfuron, rates recommended for control of perennial pepperweed, hoary cress, and halogeton will result in 47 to 76% control of greasewood, while the lowest-use rate recommended for annual mustard control is predicted to cause 26% control of greasewood. For gray rabbitbrush, chlorsulfuron had negligible impact at any rate tested. This is especially useful for land managers using the relatively high rates of chlorsulfuron required for Russian knapweed control. Metsulfuron rates required for control of perennial pepperweed, hoary cress, halogeton, and annual mustards are predicted to cause less than 40% injury to gray rabbitbrush.

These results indicate that both chlorsulfuron and metsulfuron may be useful to land managers in situations where greasewood and gray rabbitbrush are present. For land managers interested in greasewood and rabbitbrush control and increased grass cover, metsulfuron may be the better choice, as 42 g/ha resulted in good control and an increase in grass cover. However, grass response is likely strongly linked to site conditions (Eckert et al. 1973). This rate of metsulfuron will also be effective on halogeton, hoary cress, and perennial pepperweed, but not Russian knapweed (Table 2). For land managers trying to control invasive weeds in areas with considerable greasewood cover, chlorsulfuron applied at 52 g/ha may provide a less negative impact on greasewood than metsulfuron. However, rates higher than this may result in increased greasewood control. Where rabbitbrush is present and desirable, chlorsulfuron may be a better choice than metsulfuron given its reduced impact.

Table 3. Rates of chlorsulfuron and metsulfuron required for controlling invasive plants commonly found in greasewood and gray rabbitbrush communities.

Species	Chlorsulfuron rate (g/ha)	Reference(s)	Metsulfuron rate (g/ha)	Reference(s)
Perennial pepperweed	52–105	Renz and DiTomaso (2006); Wilson et al. (2008)	42	Dewey et al. (2006)
Hoary cress	52	Dewey et al. (2006)	32–42	Dewey et al. (2006); Whitson et al. (1989)
Russian knapweed	79	Dewey et al. (2006)	NR[a]	S. F. Enloe, unpublished data
Halogeton	ND[a]	None	21–42	Dewey et al. (2006); Sebastian and Beck (1995)
Annual mustards	13–26	Anonymous (2005)	14–21	Anonymous (2001)

[a] Abbreviations: NR, not recommended; ND, no data available.

Sources of Materials

[1] Chlorsulfuron, Telar®, Dupont.
[2] Metsulfuron, Escort®, Dupont.
[3] Methylated seed oil, Destiny®, Winfield Solutions, LLC.

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