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Cost/Benefit Analysis of Managing Invasive Annual Grasses in Partially Invaded Sagebrush Steppe Ecosystems

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Our objective was to evaluate the cost/benefit of a single herbicide application or targeted grazing of invasive annual grasses during restoration of partially invaded sagebrush steppe ecosystems used for livestock production. The cost/benefit model used is based on estimating the production of vegetation in response to implementing management and modeling cost/benefit economics associated with that prediction. The after-tax present value of added animal unit months (AUMs) obtained was lower than the present value of after-tax treatment costs after 20 yr for a single herbicide treatment, but higher than the present value of after-tax treatment costs for the grazing management scenario. Even at the highest weed utilization level, the value of added AUMs did not offset the cost of the treatment after 20 yr. However, the grazing treatment resulted in a value of added AUMs higher than the costs after 20 yr. Depending on the invasive weed utilization level, break-even points with targeted grazing occurred at anywhere from the first year to 7 yr. This assessment clearly shows that grazing management can be economically viable for managing annual grass-infested rangeland. In the future, models like the one used here can be improved by incorporating the rangeland management and restoration benefits on the wide variety of goods and services gained from rangeland.

Key words: Restoration cost/benefit, grazing, herbicides, invasive annual grasses.

Annual grass invasion, primarily cheatgrass (*Bromus tectorum* L.) and medusahead (*Taeniatherum caput-medusae* (L.) Nevski), is having a multidimensional, catastrophic effect on agriculture in the West, driving one of the largest changes in vegetation structure ever documented (D'Antonio and Vitousek 1992; Upadhaya et al. 1986). Vegetation dynamics involve deterioration of healthy intact shrub steppe plant communities into annual grass monocultures. This conversion has major negative impacts on ecosystem function and wildlife. Annual grass invasion creates heavy loads of fine dry fuel, promoting frequent and dangerous fires (Mosley et al. 1999). In a recent treatise on fire activity in the Great Basin region of the United States, Balch et al. (2013) concluded that cheatgrass burns more frequently than native land cover, essentially creating a cycle where annual grasses promote fire and fire promotes annual grasses (Balch et al. 2013). These altered fuel loads and fire regimes not only pose a direct threat to human life and property in the rapidly expanding wildland–urban interface on western rangeland, but also provide a significant threat to sagebrush-obligate wildlife species, such as greater sage grouse, sage thrashers, and pygmy rabbits (Crawford et al. 2004; Knick et al. 2003). Frequent fire return intervals from 5 to15 yr destroy the sagebrush portion of the plant community and keep the diverse community from recovering (Pellant 1990; Whisenant 1990).

During the invasion process, the abundance of annual grasses increases and perennial bunchgrasses decrease over time. On partially intact sagebrush steppe ecosystems enough desirable species generally exist to facilitate restoration once the abundance of invasive annual grasses is reduced (Sheley et al. 2011). These partially invaded systems are considered high priority for management because restoration of fully invaded ecosystems is often unsuccessful (Hardegree et al. 2011; Sheley and Smith 2012). The most commonly used methods for reducing the abundance of annual grasses are herbicide applications and grazing management.

Various herbicides, such as imazapic and glyphosate, are applied usually at rates ranging from 105–140 g ai ha^{-1} (imazapic), 121–248 g ai ha^{-1} glyphosate 0.44 to 0.88 L ha^{-1} (Kyser et al. 2007, 2012; Monaco et al. 2005; Morris et al. 2009). Applications control invasive annual grasses with minimal negative effects on perennial grasses because they are dormant. Repeated applications are often required for long-term control of annual grasses, and over time desired perennial grasses increase. However, single applications are the norm. Targeted grazing is also effective in controlling annual grasses (DiTomaso et al. 2008; Launchbaugh

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et al. 2006). Annual grasses are most palatable and nutritious when they are green. They are also most susceptible to damage by grazing while green because stress applied during the boot stage limits seed bank production (Diamond et al. 2012). Perennial grasses are less palatable and more grazing tolerant when they are brown because they are dormant. This creates a natural opportunity to graze annual grasses when green and perennial grasses when brown (Smith et al. 2012; Vail 1994). Once the perennial grasses initiate any growth, the animals must be moved to another pasture until the new growth becomes at least 10″ tall. Over time, perennial grasses tend to increase and annual grass abundance will decrease (Love 1944; McAdoo et al. 2007).

Although decisions for choosing best management practices are based on a wide variety of factors, understanding the cost/benefit of potential management options could provide critical information to livestock producers throughout the western United States. Unfortunately, the complexity of management strategies and their effects on vegetation dynamics has discouraged economic feasibility studies (Bucher 1984; Jenson 1984). The objective of this assessment was to evaluate the cost/benefit of a single herbicide application or targeted grazing of annual grasses during restoration of partially invaded sagebrush steppe ecosystems used for livestock production. We assumed the treatments would stimulate the plant community to reach maximum site potential of perennial species in 10 yr. We used the model developed by Griffith and Lacey (1991) for evaluating the economics of spotted knapweed control using picloram. This model evaluates capital investments on the basis of forage, rather than livestock, to eliminate the use of livestock enterprise budgets (Ethridge et al. 1984, 1987a, 1987b). Originally, we intended to evaluate scenarios with multiple herbicide treatments. Since a single application did not provide benefits over costs, it was impossible for multiple treatment programs to be cost effective because it would only add costs without additional benefit. Our intent was to develop a cost/benefit assessment for generalized management systems that yielded a likely response, rather than for a specific system to provide a generally applicable understanding of the economics associated with invasive annual grass management.

Methods and Procedures

Model Design. The model used for this analysis was adopted from Griffith and Lacey (1991). It is based on estimating the production of vegetation in response to implementing management and modeling cost/benefit economics associated with expected forage. Vegetation was estimated for a 404-ha management unit with 85% of the production from invasive plants at the start of management. The increase in vegetation production was estimated in weed or desired plant biomass using data from the literature that indicated a gradual and nearly linear decrease of invasive annual grasses and increase in desired perennial plants occurring over 20 yr (Kyser et al. 2007; Megee 1938; Monaco et al. 2005; Mosley 1996). In this analysis, all species were considered either weedy or desired as forage.

Costs were based on the materials, supplies, labor, machinery, and equipment. Materials, supplies, and labor are calculated on a per hectare basis. Machinery costs consider the costs of borrowing money for vehicles and use the purchase price, salvage value, and time in use combined with horsepower, fuels prices, and hours used for the application as variables. Similar data were also used for equipment.

Finally, the model uses the open market price of an animal unit month (AUM) as the basis for calculating the value of vegetation as forage. It combines information about marginal tax rates with the percent utilization levels of weedy vs. desired species. Each cost/benefit estimate begins the first year after treatment the vegetation can be grazed. The model also allows the loss of desired vegetation without treatment to estimate future production.

Assumptions. We conducted the analysis with the assumption that treatments were implemented on sagebrush steppe grasslands once dominated by native bunchgrasses, such as bluebunch wheatgrass [*Pseudoroegneria spicata* (Pursh) Á. Löve] and Sandbergs's bluegrass (*Poa secunda* J. Presi) but now dominated by invasive annual grasses, such as cheatgrass. We also assumed that 15% of the native desired vegetation was growing in association with the invasive annual grasses and that they were capable of increasing once the treatments reduced their ability to dominate the site.

In this assessment, the market price of an AUM was assumed to be \$20; the combined federal and state marginal tax rate was 21%, a nominal interest rate of 8%, and a 3% inflation rate (Table 1). We assumed the management unit was 404 ha and 100% of the area was treated (Table 2). It was also assumed that newly degraded hectares produced only 112 kg ha^{-1} of undesired species and an AUM requirement was 363 kg. This scenario was based on

Table 1. Assumed financial data for model's user input.

Economic parameters	Assumed values
Market price of animal unit months (AUMs) ($/AUM)	$20
Combined federal and state marginal tax rate	21%
Nominal interest rate	8%
Expected annual inflation rate	3%

a maximum site production of 1,792 kg ha^{-1} with a current actual production of 1,232 kg ha^{-1} and 50% utilization of desired perennial vegetation. Since invasive annual grasses vary in their palatability and preference by animals, we tested the cost/benefit of grazing at 20, 40, and 60% utilization of annual grasses. We based the invasive weed spread rate and the rate at which invasion decreased desired forage at 12.5%, which is the average of estimates from the invasion literature (Sheley and Petroff 1999). The minimum amount of vegetation produced with no treatment was set at 336 kg ha^{-1} (Table 3).

We assumed an annual cost of moving already existing livestock to be about $1.24ha^{-1} or $500 yr^{-1} for the entire 404-ha unit. Since moving livestock can range from costing nothing to being very expensive if they are trucked, we simply chose a reasonable number for this analysis. This is an estimate across all years. The costs of the herbicide treatment included the average price a herbicide and application cost (assuming machinery ownership), $91 ha^{-1} in year zero. These were the only costs associated with herbicide treatments (Table 4).

The vegetation composition and production response to grazing and a single herbicide application were estimated using known treatment responses for the first 2 yr for various invasive plants and were assumed to gradually change toward desired vegetation over the first 10 yr (Table 4). The model assumed the conversion was complete during the first 10 yr and production estimates remained stable from years 11 through 20. We assumed both management systems would result in the same vegetation response. In both scenarios, the assumed vegetation response was in the best possible outcome range over the 20-yr period. Thus, additional treatments would not improve forage production and our evaluations should be considered a "best case scenario." Adding any additional inputs will only increase costs without affecting benefits.

Table 2. Assumed values used in the economic model to predict the cost/benefit of management options.

Original land properties	Assumed values
Total hectares in this management unit	404
Percentage of total hectares treated	100%
Percentage of undesirable biomass utilized	(20, 40, 60%)
Average current biomass production (kg ha^{-1})	1,232
Minimum percentage of total biomass left to maintain the pasture quality	50%
Maximum biomass production after treatment (kg ha^{-1})	1,792
One animal unit month (kg ha^{-1})	363
Biomass production on newly degraded land (kg ha^{-1})	112

Table 3. Assumed values used in the economic model for productivity and site capacity if no action is taken to manage the invasive annual grasses.

Spread rates and predicted site capacity	Assumed values
Rate total biomass increases with better pasture management	0
Rate production will decrease if no control measures are taken	12.5%
Rate that new hectares will be degraded when no control measures are taken	12.5%
Minimum biomass this site will produce with no treatment (kg ha^{-1})	336

Table 4. Inputs into the economic model using a grazing treatment and a single herbicide treatment for 404 ha of rangeland. Inputs include costs of grazing and herbicide treatment over a 20-yr period and change in herbage between undesirable to desirable forage by year, that is, under a grazing treatment, 100% of hectares is grazed each year; under a herbicide treatment, in the first year, grazing is reduced on 50% of the acreage; in remaining years, grazing occurs on 100% of the acreage.

Year(s) treated	Grazing treatment cost/yr ha^{-1}	Herbicide treatment cost/yr ha^{-1}	Undesirable biomass	Desirable biomass
	$		kg ha^{-1}	
0	1.24	91.00	1,008	112
1	1.24	0.00	672	672
2	1.24	0.00	448	896
3	1.24	0.00	448	896
4	1.24	0.00	336	1,008
5	1.24	0.00	336	1,008
6	1.24	0.00	336	1,008
7	1.24	0.00	224	1,120
8	1.24	0.00	224	1,120
9	1.24	0.00	224	1,120
10	1.24	0.00	112	1,232
11	1.24	0.00	112	1,232
12	1.24	0.00	112	1,232
13	1.24	0.00	112	1,232
14	1.24	0.00	112	1,232
15	1.24	0.00	112	1,232
16	1.24	0.00	112	1,232
17	1.24	0.00	112	1,232
18	1.24	0.00	112	1,232
19	1.24	0.00	112	1,232
20	1.24	0.00	112	1,232

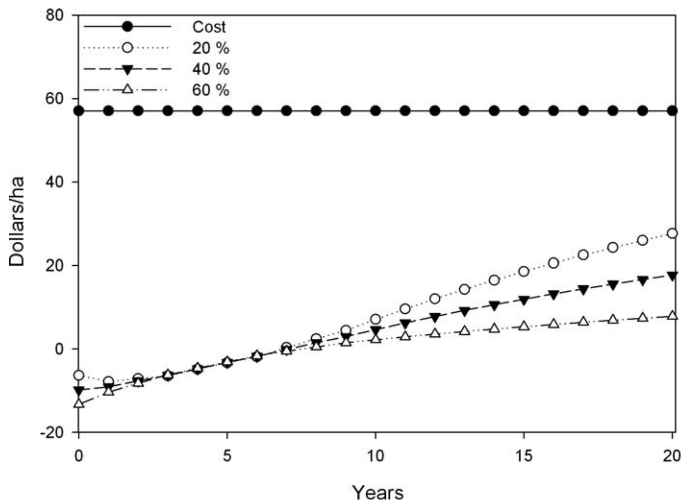

Figure 1. Cost/benefit analysis for a single herbicide treatment in year zero with livestock utilizing 20, 40, and 60% of invasive annual grass biomass.

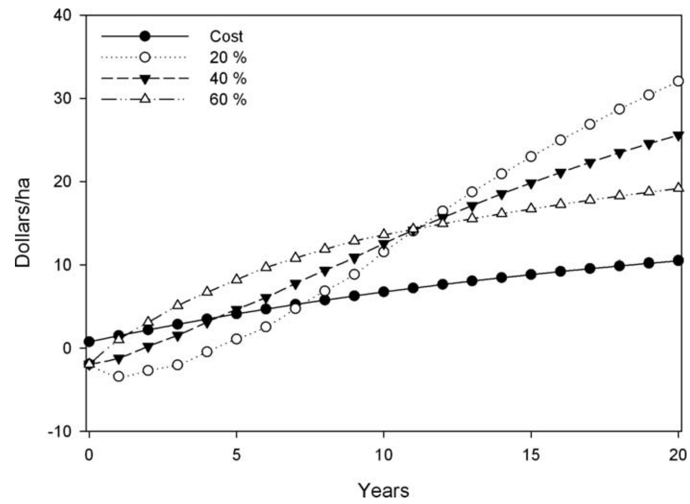

Figure 2. Cost/benefit analysis for managing invasive annual grass infestations with a grazing strategy with livestock utilizing 20, 40, and 60% of the annual grass biomass.

Limitations. For simplicity, the model is based on forage production, rather than on kilograms of beef produced to avoid specific estimates of any particular enterprise (Bucher 1984; Jenson 1984). In some cases, improved forage may provide an enterprise more benefit than another on the basis of their specific beef production system. However, the assumption that producers could lease more pasture instead of improving their own at the current price of an AUM is reasonable.

Management Scenarios. We assessed the cost/benefit of the two most commonly used management scenarios to manage annual grasses where a desired understory of vegetation exists. In the first scenario, we applied a single application of a herbicide to selectively control invasive annual grasses and stimulate desired species. Since we found that a single herbicide application would not yield any net benefits, it was not necessary to test multiple herbicide treatments. In the second scenario, we used targeted grazing of the invasive annual grasses to reduce the growth and reproduction of annual grasses with the goal of shifting the vegetation toward desired species. Since annual grasses are utilized by livestock, three levels of weed utilization by the livestock (20, 40, and 60% utilization) were assessed. No further strategies were utilized in this scenario and no additional revegetation efforts were included in either scenario.

Results

Single Herbicide Application. The after-tax present value of added AUMs obtained from a single herbicide application was lower than the present value of after-tax treatment costs after 20 yr (Figure 1). Present value of after-tax herbicide treatment costs were about \$56.83 ha^{-1}, whereas the value of added AUMs was about \$27.18, \$12.35, and \$2.47 ha^{-1}, for 20, 40, and 60% invasive annual grass utilization, respectively. The present value of after-tax treatment herbicide costs that could be paid to break even using our vegetation response scenario was \$44.30, \$28.44, and \$12.52 ha^{-1} in year zero for weed utilization levels of 20, 40, and 60%, respectively, using a single herbicide application.

Grazing Application. At all three levels of annual grass utilization, the after-tax present value of added AUMs obtained through grazing was higher than the present value of after-tax treatment costs after 20 yr (Figure 2). Present value of after-tax treatment grazing costs were about \$6.18 ha^{-1}, whereas the value of added AUMs was about \$32.12, \$22.24, and \$14.82 ha^{-1}, for 20, 40, and 60% invasive weed utilization, respectively. The break-even points for grazing occurred in the first year or two if livestock used 60% of the invasive annual grasses biomass, at about 5 yr if 40% of the annual grasses were consumed by livestock, and 7 yr if the animals only consumed 20% of the annual grasses. The present value of after-tax-treatment grazing costs that could be paid to break even using our vegetation response scenario was \$3.78, \$3.04, and \$2.27 ha^{-1} annually for weed utilization levels of 20, 40, and 60% respectively, using targeted grazing.

Discussion

The magnitude and complexity of annual grass invasion requires prioritization of strategies on the basis of cost/benefit analysis to optimize scarce resource allocation (Sheley and Smith 2012). In annual grass management, the first priority is to protect invasion of new areas. The second priority is controlling invasive plants in areas where enough desired species exist in the plant community to respond to weed reductions. Restoration of completely invaded systems is often considered the lowest priority because of the difficulty in establishing plants under these severely degraded conditions. We used the model developed by Griffith and Lacey (1991) to conduct a cost/benefit analysis of a single herbicide application or grazing for reducing invasive grass abundance in areas where desired species are growing in association with annual grasses, although in very low (15%) amounts. Our assumptions were geared toward a reasonable desired vegetation response scenario to invasive grass control in relatively productive sagebrush steppe ecosystems. We used the lowest reasonable cost estimates and the highest expected response. This was to ensure that if a treatment was deemed to not be cost effective, it was based on the "best case" scenario, making the results fairly inclusive and conclusive.

Several herbicides are available to control annual grasses selectively. Herbicides are the most extensively researched tool for controlling annual grasses aimed at reestablishing associated desired vegetation (Kyser et al. 2007, 2012; Monaco et al. 2005; Morris et al. 2009; Sheley et al. 2007). In the model we adopted, on highly productive sites, controlling spotted knapweed was economically feasible using cost and benefit assumptions that were reasonable in 1991 (Griffith and Lacey 1991). Unfortunately, most sagebrush steppe systems have lower production capability than the wetter grassland systems considered by Griffith and Lacey (1991). In sagebrush steppe, even a one-time treatment assumed to produce a desired vegetation change for the following 20 yr was not economically feasible on the basis of livestock forage. Bangsund et al. (1996) found that controlling leafy spurge (*Euphorbia esula* L.) did not yield enough desired forage for cattle to justify the costs of its control. Assuming livestock would only consume 20% of the annual grasses, the break-even costs of a single one-time treatment was $44.30 in present-day after-tax costs for controlling large infestations of annual grasses. The more annual grasses eaten by livestock, the lower the break-even costs. Conversely, the less annual grasses eaten by livestock, the more benefit the treatment provides. Of course, our model does not include periodic repeated applications, which would increase the costs without increasing production in this model. It is important to point out that this large-scale application does not apply to using herbicides in prevention or containment programs, which were found cost-effective in other analyses for other invasive weeds (Bangsund et al. 1996).

Grazing is becoming increasingly considered in restoration of degraded ecosystems throughout the world. Despite the commonly held view that overgrazing was, in part, responsible for widespread degradation of grasslands (Derner et al. 2009; Thornes 2007), it is becoming clear that in areas where the abiotic function of degraded grazing land has not been irreversibly damaged, appropriate grazing can provide an ecological solution in restoration situations, especially for invasive annual grasses (Diamond et al. 2012; Papanastasis 2009). Effective management of annual grasses depends on reducing seed production and this can be accomplished with targeted grazing. Our assessment suggests that grazing management of grasslands degraded by invasive annual grasses can be cost-effective on the basis of vegetation changes that shift plant communities toward desired forage for livestock. Utilization levels are affected by several factors, including grazing intensity and palatability. Palatability changes as a plant matures and typically as plants mature there is a decrease in palatability as a result of changing moisture and nutrient levels. Of the invasive annual grasses, cheatgrass is palatable and high in nutritional value before the seed hardens (Mosley 1996) and medusahead is generally less palatable because of the high silica content of the plant; however, it still can be utilized by livestock (Lusk et al. 1961). We found that regardless of the utilization levels of invasive annual grasses, the amount of desired vegetation produced in response to targeted grazing created enough forage to be economically beneficial. Our results for reducing annual grasses is consistent with that found by Bangsund et al. (1996) for managing leafy spurge-infested rangeland using grazing. The popularity of targeted grazing for invasive plants is increasing because its value is becoming increasingly apparent to many land managers (Launchbaugh et al. 2006).

The fundamental economic principle for weed management is simply to act only if the benefits exceed the costs (King et al. 1998). This assessment indicates that grazing management can be economically viable for annual grass-infested rangeland. In the future, models like the one used here can be improved by incorporating the rangeland management and restoration benefits on the wide variety of goods and services gained from rangeland (Havstad et al. 2007). The entire suite of benefits from rangeland, such as carbon sequestration, biodiversity, water quality and quantity, wildlife habitat, and their associated users must be recognized and monetized if economic assessments of rangeland are to provide a complete cost/benefit analysis of managing these ecosystems. Complex and costly management programs may be economically feasible once the true benefits are quantified. Regardless, the benefits from livestock grazing will outweigh those from more costly treatments, where animals can be used to achieve the desired vegetation goals.

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