United States Department of Agriculture

Soil and Water Resources Conservation Act
National Conservation Program
August 2012

RANGELAND CONSERVATION ANALYSIS #2
CONTROLLING CHEATGRASS AND WOODY SPECIES INVASION IN THE GREAT BASIN

REVIEW DRAFT

The Issue

Invasive species, widely distributed across the western United States, pose critical conservation challenges on both non-Federal and Federal rangelands. Two of the biggest threats to ecosystem stability and integrity in the Great Basin (most of Nevada, a large part of Utah, and smaller sections of Oregon, Idaho, and California) are invasive annual grasses, particularly cheatgrass and medusahead, and invasive woody plants, particularly juniper species and pinyon pine. Invasions of both types of plants can lead to soil erosion problems, increase the likelihood of damaging and dangerous wildfires, reduce forage availability, and significantly alter wildlife habitat. Frequent fires degrade soil health by destroying litter which would otherwise naturally decompose and contribute nutrients and carbon back to the soil. Soil health is also degraded by increased rates of wind and water erosion following fire. Although soil may recover from the direct impacts of fire, persistent occupation by invasive species can have lasting consequences for soil health and rangeland ecosystems (Allen et al. 2011).

Altered fire regimes associated with settlement of the West and active management of lands are intertwined with the expansion of invasive plant species. Fire suppression and historical grazing patterns have contributed to increased density of pinyon-juniper stands. As a result of higher fuel loads, when fires do occur they are more severe, opening the landscape to introduction of alternate species for longer periods of time (Miller et al. 2008; Keane et al. 2002; Schoennagel et al. 2004). The number of fires and total area burned increased from 1980 through 2007 for most of the sagebrush steppe biome, including the Sage Grouse Conservation Area. Average fire size has increased for the southern Great Basin (Miller et al. 2011), and fire intervals have decreased to as little as 5 years in the Snake River plains area of Idaho (Whisenant 1990).

Commercial cattle production is the predominant agricultural use of Great Basin rangelands, but invasive species and wildfires affect many stakeholders including home and business owners; birders, hunters, and fishers; and conservation and land management agencies. Across the West, loss of human life and extensive damage to natural resources, property, and city infrastructures have been documented in relation to intense rainfall events following wildfires in areas that have not had sufficient time to revegetate (Moody and Martin 2001; Pierson et al. 2002; Cannon et al. 2011).

Mitigating these potential post-fire impacts is of particular concern along the ever-expanding wildland-urban interface in the West (Stockmann et al. 2010). The immediate costs of large wildfires can exceed $20 million per day (Running 2006), but economic impacts extend beyond control of wildfires. Billions of dollars are spent each year on wildfire suppression, and millions are spent on post-fire mitigation (General Accounting Office 2003; Stockmann et al. 2010).

Cheatgrass

Cheatgrass is an exotic annual grass that is widely distributed on Federal[1] and non-Federal rangelands across the western United States. An estimated 65 percent of the Great Basin has conditions suitable for invasion by cheatgrass, and more than 88 million acres in the Great Basin are currently impacted by cheatgrass (Pellant et al. 2004; Meinke et al. 2009). Across the 17 western states, cheatgrass occurs on 66 million acres of non-Federal rangelands (fig. 1, NRCS NRI 2003–06 data). It is a prolific seed producer, can germinate in spring or fall, and develops extensive lateral root systems that can grow in the winter. Cheatgrass germinates and grows more quickly in response to water availability than do most native species, robbing native species of the water and nutrients needed for germination and establishment. Thus, cheatgrass invasion alters ecosystem scale nutrient cycling, creating a new system in which it is difficult for native species to re-establish.

[1] The National Resources Inventory does not currently include data for Federal rangelands.

Cheatgrass also completes its reproductive process earlier than most native plants do and is often dry by mid-July, becoming flammable 4 to 6 weeks earlier than native perennials. It thus provides a fine-textured, spatially continuous fuel that increases the chance and frequency of ignition and extends the duration of the wildfire season (Young et al. 1987; Melgoza et al. 1990; Clements and Young 1997). Historical wildfire frequency in sagebrush/bunchgrass communities is estimated at 60 to 110 years (Whisenant 1990). Fires were virtually absent in salt desert shrub areas due to lack of fine fuels (Billings 1994), but cheatgrass invasions now provide fine fuels in these communities, shortening historic fire cycles and ultimately disrupting ecosystem stability and creating the possibility of establishing a cheatgrass monoculture with significant loss of ecosystem services (fig. 2) (Whisenant 1990; Link et al. 2006; Miller et al. 2011).

Adverse impacts associated with invasion include increased fire risk, reduced biodiversity and forage for livestock and wildlife, degraded soil health and water quality, reduced recreational and aesthetic values, and significant economic losses (DiTomaso 2000; Eiswerth et al. 2005; Brunson and Tanaka 2011). Cheatgrass matures early and alters both the seasonal timing and total amount of available forage for domestic livestock and wildlife. Additionally, following a wildfire, the range is often closed to livestock for a minimum of 2 years. Wildfires severely disrupt ecosystem services and increase the risk of water and wind erosion. Cheatgrass fires have removed critical habitat for the sage grouse, contributing to this species becoming a candidate for listing for Federal protection (USFWS 2011), and are a major cause of the decline in mule deer populations (Wasley 2004).

The Wyoming sagebrush-dominated plant community (WSS), common in the Great Basin, is prone to cheatgrass invasion, particularly when stressed by major disturbances. Figure 3 depicts a generalized WSS description of the plant community adapted from Stringham et al. (2003), for which the reference condition (WSS-1) is a healthy sagebrush community with a 107-year wildfire return interval.[2]

Overgrazing this system removes grasses and forbs from the spaces between the sagebrush. This decreases seed sources to repopulate the grass and forbs and changes the competitive balance in favor of sagebrush. Overgrazing also alters the hydrology of the system by exposing more bare ground, which increases soil surface temperatures, decreases water infiltration, and promotes increased water and wind erosion of soils and associated nutrients. Un-

[2] The mean wildfire return interval is the average interval between two successive wildfires in a given area.

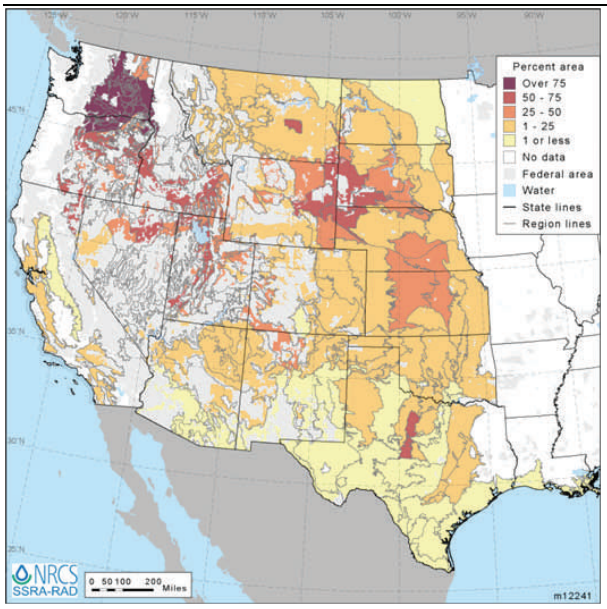
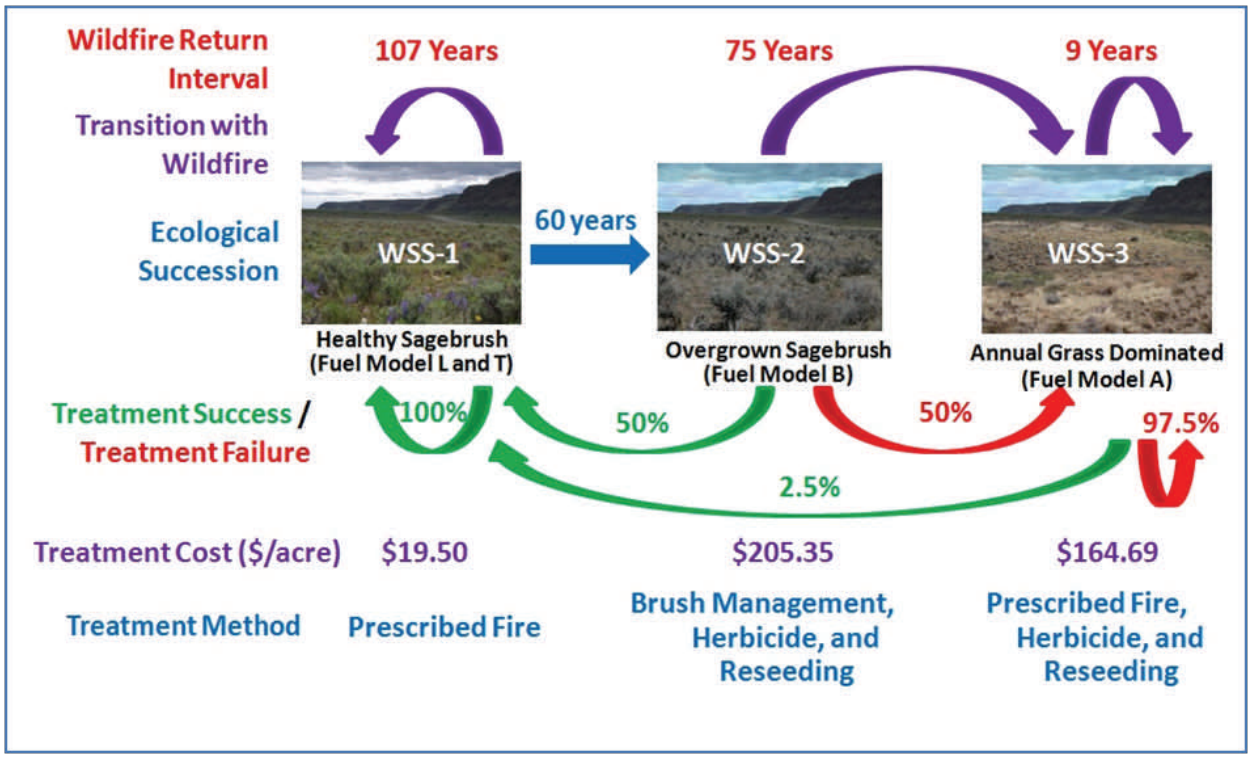


Figure 1 (above). Cheatgrass on non-Federal rangeland. SOURCE: USDA-NRCS NATIONAL RESOURCE INVENTORY RANGELAND SAMPLE AREA (2003–06).

Figure 2 (right). Cheatgrass-dominated hillslope with dense fine fuels (top), and wildfire burning in mountains north of Reno, NV, in cheatgrass-dominated rangelands (bottom). *ARS PHOTOGRAPHS, BOB BLANK*

Figure 3. Economic cost of treatment for alternative states within a Wyoming sagebrush plant community (WSS) (4,700 – 6,500 feet)



checked, overgrazing can degrade a healthy sagebrush system into a decadent sagebrush state (WSS-2). This new state can have a shorter 75-year wildfire return interval if cheatgrass has filled in open spaces between the sagebrush (Limbach 2011). Appropriate management (reseeding native grasses and forbs, brush management, prescribed grazing, wildfire suppression) might be able to reverse the degradation and return a WSS-2 site to its reference state. Without appropriate management, the site may continue to degrade.

With continued overgrazing, hydrological impacts become exacerbated, resulting in increased runoff and reduced soil moisture availability. Exotic annual grasses are well adapted to capitalize on disturbances and outcompete native species for scarce soil moisture. The increase in fine fuel loads associated with cheatgrass and medusahead invasion increases fire frequencies, eliminating remaining sagebrush, and has negative impact on native forbs and grasses, which are ill adapted to such closely timed burns. Once the system has transitioned to a cheatgrass monoculture (WSS-3), it has crossed an ecological threshold from which it is difficult, if not impossible, to recover. The shift in plant communities, accompanied by the changes in hydrology, nutrient cycle, and fire cycle, has created a fundamentally different system. Even significant conservation investments may not be able to return the site to its reference condition.

Woody Plants

Woody plant encroachment into semiarid and arid rangelands is a major problem on U.S. rangelands and brings with it severe hydrological, biological, and environmental consequences (Pierson et al. 2011). The expansion of native conifers, including juniper species and pinyon pine, reduces herbaceous forage plant diversity and cover, significantly altering wildlife habitat and soil biota, accelerating surface runoff and soil erosion, and increasing the risk of catastrophic wildfires (fig. 4) (Chambers et al. 1999; Miller et al. 2011). Fire suppression and historical grazing patterns have contributed to increased density of pinyon and juniper stands. As a result of higher fuel loads, when fires do occur they are more severe, opening the landscape to unimpeded introduction of alternate species for longer periods of times (Miller et al. 2008; Keane et al. 2002; Schoennagel et al. 2004).

The expansion of pinyon and juniper is neither small nor localized, and is occurring on both private and government-managed rangelands. Pinyon and juniper woodlands currently occupy an estimated 47 million acres in the Intermountain West (Miller et al. 2011). As much as 90 percent of this area was dominated by sagebrush vegetation types historically (sagebrush steppe and Great Basin sagebrush vegetation types). Most of the western lands affected by cheatgrass and woodland expansion are Federal lands (fig.

5). The area under Federal control is 72 percent of the Great Basin and about 90 percent of Nevada. Pinyon and juniper woodlands occupy 22.8 million acres of non-Federal rangelands in the southwestern United States (table 1). Many of the woodlands are in an early phase of expansion and development; tree densities and canopy cover are continuing to increase, resulting in loss of sagebrush plant communities and associated ecosystem services (Miller et al. 2008). However, extensive die-offs associated with drought have also been documented (Breshears et al. 2005). Mortality can be higher on recently invaded sites to which the trees are less well adapted.

Figure 4. Great Basin juniper woodland with dense canopy structure and bare interspace prone to accelerated soil erosion (a), with ladder fuels (b), following high-severity wildfire (c), and after postfire cheatgrass invasion (d). ARS PHOTOGRAPHS, FRED PIERSON

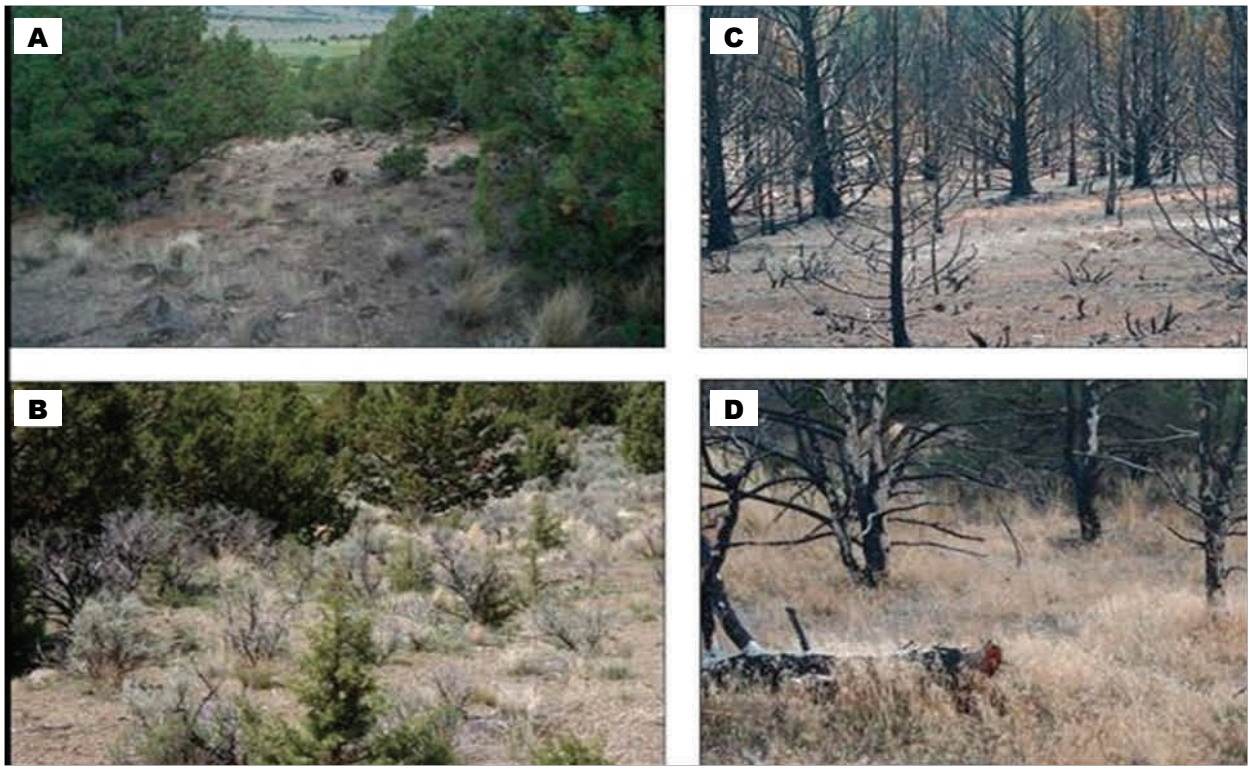
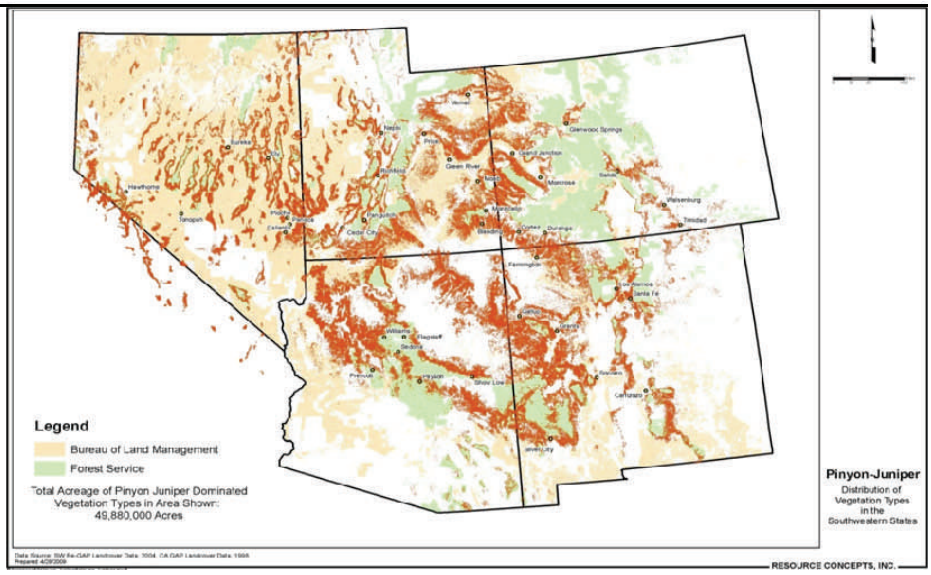


Figure 5. Distribution of pinyon and juniper woodlands on Federal lands in the southwestern United States



Tree and shrub encroachment is often associated with declining productivity, increased interspace between plants, loss of desirable understory species, decreased biodiversity, increased soil water repellency, altered hydrology, and increased erosion with associated soil carbon and nutrient losses (Mack et al. 2000; Brooks et al. 2004; Pierson et al. 2011). In pinyon and juniper woodlands, bare intercanopy zones can have up to 24 times more sediment loss than vegetated canopy zones (Reid et al. 1999). On degraded and disturbed rangelands, increased connectedness of bare soil patches allows the formation of concentrated flow paths; this process initiates gully formation and increased runoff and soil loss (Wilcox et al. 2003; Pierson et al. 2009; Urgeghe et al. 2010). Once the ecosystem's flow paths have been altered, subsequent storms reinforce gully formation, further accelerating soil loss and decreasing water infiltration rates.

Table 1. Extent of non-Federal rangelands in the southwestern United States occupied by pinyon and juniper woodlands (NRI 2003–06 rangeland data)

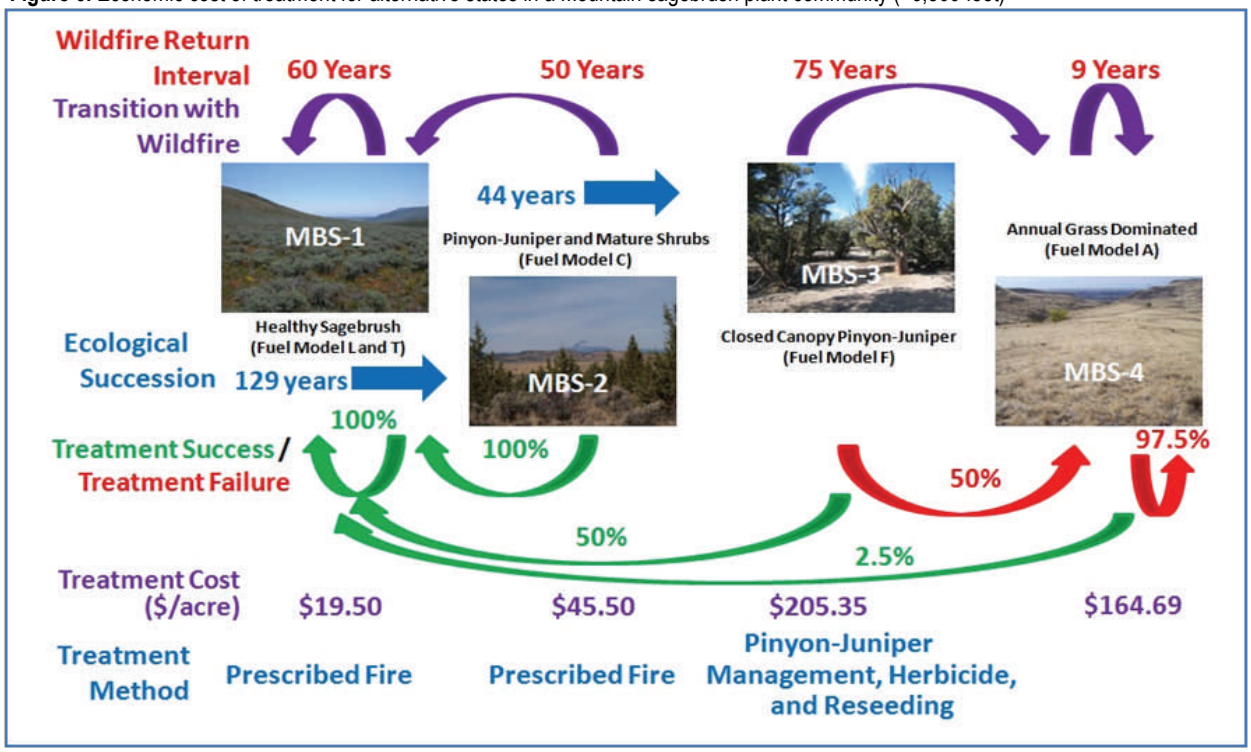
State	Acres
Nevada	409,000
Utah	4,224,000
Colorado	4,248,000
New Mexico	7,887,000
Arizona	6,066,000

REVIEW DRAFT

Mountain big sagebrush (MBS) is a common plant community type prone to native conifer expansion. Figure 6 presents a generalized description of different states of this plant community for estimating the economic cost of pre-fire fuel reduction treatments. The reference condition (MBS-1) is a healthy high-altitude sagebrush community with a 60-year wildfire return interval (Major et al. 2011). Sagebrush may act as nurse plants to conifer seedlings; germinating in the shade of sagebrush, conifers enjoy increased soil moisture, nutrients, and shade. The MBS-1 state may shift to one in which immature conifers and sagebrush co-exist (MBS-2). Low-intensity fires can remove conifer seedlings (though they may also injure sagebrush), so prescribed fire or wildfire can return an MBS-2 site to the MBS-1 reference condition.

Without intervention, conifers mature and may outcompete sagebrush for light, water, and nutrients. Overgrazing and/or decreased fire frequencies may drive the MBS-2 system across an ecological threshold wherein conifers mature and the canopy closes (MBS-3). Closed canopies alter hydrology, light regimes, fire cycles, and nutrient cycles, and may lead to increased bare ground by choking out understory growth. Bare ground can increase water and wind erosion, which may alter nutrient cycling and deplete native seed banks. Loss of grasses and forbs under the conifers may decrease fire frequencies, allowing the conifers to further mature.

Figure 6. Economic cost of treatment for alternative states in a Mountain sagebrush plant community (>6,500 feet)



Returning a mature conifer system (MBS-3) to a healthy sagebrush system (MBS-1) is harder than transitioning an immature conifer-sage system (MBS-2) back to its reference condition. Mature conifer stands tend not to have low-intensity ground fires because of the lack of fine fuels. When fires do occur, they tend to be high-intensity crown fires that kill both conifers and native shrubs, including sagebrush. Thus, mechanical treatments are generally used to treat closed canopy conifer systems. Exotic annual grasses are highly adapted to capitalize on disturbance, including recently burned bare ground and skid trails from tree removal. Cheatgrass or medusahead may quickly dominate inappropriately managed MBS-3 systems, transitioning them to a low diversity, annual grass-dominated MBS-4 system. The resultant changes in nutrient, water, and fire cycles make the re-establishment of native species highly unlikely.

Benefits of Conservation

The economic benefits of pre-fire fuel management conservation practices (fuel treatments) have been estimated for the Wyoming Sagebrush Steppe and Mountain Big Sagebrush plant communities. The economic benefit of fuel treatments is measured as the difference in the expected net present value of wildfire suppression with and without treatment. This estimate must account for (1) how wildfire influences ecological change in rangeland ecosystems, and (2) how rangeland ecological condition influences the frequency of wildfire and the costs of wildfire suppression.

Wildfire suppression costs, wildfire probabilities, and fuel management treatment costs vary with ecological condition. The wildfire suppression costs for each vegetation state were obtained from data on 400 wildfires occurring from 1995 through 2007 in U.S. Forest Service (USFS) Region 4 (the Intermountain Region, which includes Wyoming, Utah, Idaho, Nevada, and portions of Colorado and California). Wildfire return intervals and times for ecological transition between ecological states specific to the Wyoming Sagebrush Steppe and Mountain Big Sagebrush systems were obtained through the USFS's LANDFIRE rapid assessment vegetation model. Per-acre costs for the fuel treatments used in the analyses (e.g., herbicide treatments, reseeding, prescribed fire, and mechanical brush removal) were obtained from the 2011 NRCS conservation practice cost data.[3]

For Wyoming Sagebrush Steppe (WSS) communities, fuel treatment is economically efficient only before cheatgrass has become established. Fuel treatments have expected net benefits in terms of wildfire suppression costs averted of $272 per acre for sites in the healthy reference state (table 2). In contrast, fuel treatment costs exceed wildfire suppression cost savings in the two degraded ecological states (the decadent sagebrush state, WSS-2, and the annual grass-dominated state, WSS-3).

Recent studies suggest that current fire return intervals on western rangelands are shorter than historic averages as a result of invasive plants, changes in disturbance regimes, climate change, and other factors. As intervals between wildfires shorten, pre-fire suppression treatments are becoming cost-effective for the decadent sagebrush state (WSS-2). Results indicate that treatment is economically efficient in WSS-2 for wildfire return intervals of 50 years or shorter (fig. 7).

In the Mountain Big Sagebrush system, the expected net benefits of treatment are small but positive in the healthiest rangeland state ($90 per acre), and are largest in the early stages of pinyon-juniper expansion ($358 per acre) (table 3). Fuel treatments are not cost effective in the two degraded ecological states. In the closed canopy state (MBS-3), average wildfire suppression costs are higher with fuel treatment than without. This counterintuitive result is due to the possibility of treatment failure in MBS-3. Treatment failure in MBS-3 results in the systems transitioning to MBS-4, the annual grass-dominated state, which entails more frequent wildfire and higher wildfire suppression costs. Because of the high cost of treatment failure in MBS-3, average wildfire suppression costs are lower if the lands remain untreated, even though the system may eventually transition to MBS-4 after a natural occurring wildfire.

Water erosion following wildfire is a serious potential problem on cheatgrass-dominated landscapes (Pierson et al. 2011). Tree and shrub encroachment is often associated with declining productivity, increased interspace between plants, loss of desirable understory species, decreased biodiversity, increased soil water repellency, altered hydrology, and increased erosion with associated soil carbon and nutrient losses. For a typical WBS site near Austin, NV, water-induced soil loss was 2.4 to 3 times greater on a burned site previously dominated by cheatgrass than in the reference state, and had 1.2 to 1.6 times more runoff during intense summer thunderstorms (table 4). This additional runoff could increase downstream flooding and reduce available soil moisture essential for successful revegetation of post-fire areas. Soil loss diminishes nutrient availability and carbon sequestration at the site as well.

In mountain sagebrush sites that have been invaded by pinyon-juniper trees, the type and distribution of canopy and ground cover are altered. In the reference state, more uniformly distributed vegetation makes concentrated flows unlikely and minimizes soil loss and runoff. When pinyon

[3] Practice cost data utilized payment rates from the Agricultural Management Assistance program, the Environmental Quality Incentives Program, and the Wildlife Habitat Incentives Program for Utah and for other western states, including Nevada.

REVIEW DRAFT

Table 2: Wyoming sagebrush plant community results for fuel load reduction treatments ($ per acre; Net Present Value (NPV) over 200 years; 2010 dollars; 3% rate of discount)

	Initial ecological state		
Treatment level	WSS-1 Healthy sagebrush	WSS-2 Mature woody brush with annual grass	WSS-3 Annual grass dominated
Average total suppression costs (NPV) – no treatment	$345	$364	$390
Average total suppression costs (NPV) – with treatment	$56	$231	$251
Average wildfire suppression costs savings (NPV)	$294	$133	$139
Average treatment costs (NPV)	$22	$204	$2,527
Average wildfire suppression costs savings net of treatment costs (NPV)	$272	-$71	-$2,388
Average benefit-cost ratio	13.3	0.65	0.06

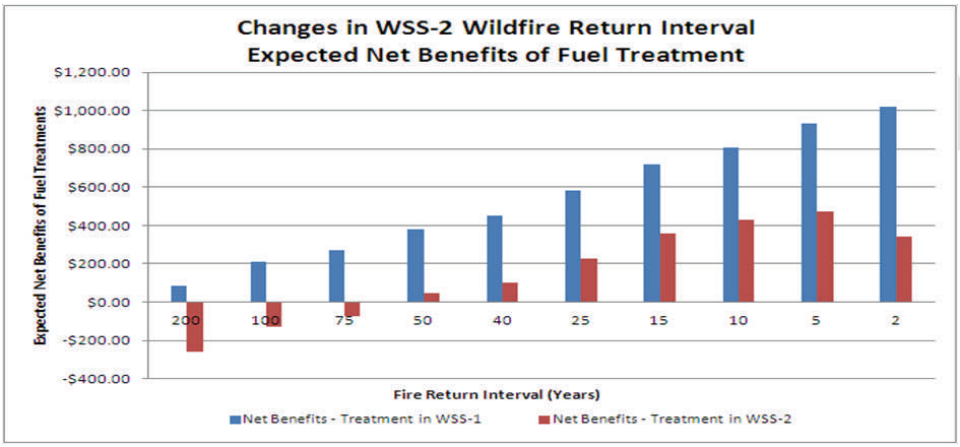


Figure 7. Expected net benefits from implementing preventative conservation practices within Wyoming Sagebrush Steppe (WSS) community as a function of wildfire return interval

Table 3. Mountain big sagebrush plant community results for fuel load reduction treatments ($ per acre; Net Present Value (NPV) over 200 years; 2010 dollars; 3% rate of discount)

	Initial Ecological State			
Treatment level	MBS-1 Healthy sagebrush	MBS-2 Pinyon juniper with annual grasses	MBS-3 Closed-canopy pinyon-juniper with annual grasses	MBS-4 Annual grass dominated
Average total suppression costs (NPV) – no treatment	$273	$561	$576	$1,448
Average total suppression costs (NPV) – with treatment	$164	$158	$793	$894
Average wildfire suppression costs savings (NPV)	$109	$403	-$217	$554
Average treatment costs (NPV)	$19	$45	$202	$2,886
Average wildfire suppression costs savings net of treatment costs (NPV)	$90	$358	-$419	-$2,332
Average benefit-cost ratio	5.7	9.0	-1.1	0.2

Table 4. Plant community and site attributes and modeled hydrologic response of a Wyoming sage plant community near Austin, NV

Site attributes	Sagebrush	Cheatgrass	Burned Cheatgrass
Slope (%)	20	20	20
Slope shape	linear	linear	linear
Soil texture	Sandy clay loam	Sandy clay loam	Sandy clay loam
Canopy cover (%)	30	25	0
Basal cover (%)	8	5	0
Litter cover (%)	7	0	0
Cryptogams cover (%)	2	0	0
Hydrologic response			
2-year storm			
Rainfall (mm)	25.6	25.6	25.6
Runoff (mm)	6.76	9.02	11.09
Soil loss (tons per acre)	0.11	0.17	0.33
10-year storm			
Rainfall (mm)	38.2	38.2	38.2
Runoff (mm)	20.43	23.04	25.0
Soil loss (tons per acre)	0.40	0.56	0.98
50-year storm			
Rainfall (mm)	52.7	52.7	52.7
Runoff (mm)	30.91	33.52	36.76
Soil loss (tons per acre)	0.79	1.08	1.88

REVIEW DRAFT

Table 5. Plant community and site attributes and modeled hydrologic response of a Mountain big sagebrush plant community near Elko, NV

Site attributes	Sagebrush	Pinyon-Juniper Invasion	Burned Pinyon-Juniper
Slope (%)	30	30	30
Slope shape	linear	linear	linear
Soil texture	Sandy loam	Sandy loam	Sandy loam
Canopy cover (%)	50	50	0
Basal cover (%)	12	7	0
Litter cover (%)	12	5	0
Cryptogams Cover (%)	20	0	0
Hydrologic response			
2-year storm			
Rainfall (mm)	19.10	19.10	19.10
Runoff (mm)	1.77	3.64	6.87
Soil loss (tons per acre)	0.03	0.06	0.28
10-year storm			
Rainfall (mm)	29.70	29.70	29.70
Runoff (mm)	9.77	11.88	16.80
Soil loss (tons per acre)	0.17	0.25	0.79
50-year storm			
Rainfall (mm)	43.3	43.3	43.3
Runoff (mm)	22.95	28.1	29.43
Soil loss (tons per acre)	0.45	0.71	1.70

and juniper trees invade, the canopy and ground cover become more clumped and understory cover (grasses and forbs) declines (Miller et al. 2000). This increases the probability of concentrated flows in the connected bare spaces and results in accelerated runoff and soil erosion (Pierson et al. 2011). After a wildfire, runoff may increase on the order of 4 to 10 times and soil loss can increase 4 times, increasing the probability of downstream floods (table 5).

Conclusions

Given current and impending economic impacts of the intertwined cheatgrass and wildfire cycle on private and public lands across the West, large landscape-scale adaptive management approaches are needed to impede exotic annual grass and native tree species expansion before entire landscapes are degraded and destabilized by invasion. Unfortunately, few conventional cheatgrass or medusahead eradication methods have been shown to be effective or practical for widespread application. Wildfire prevention on healthy sites is the most cost-effective tool we have today. Additional research on cost-effective means to prevent expansion of cheatgrass and reduce damages where it is already established is needed to protect and enhance the ecosystem services and benefits—clean air and water, abundant wildlife, and a secure food production system—we derive from public and private rangelands.

USDA has an active research program across the Intermountain West working to develop cost-effective practices for restoring native rangelands and reducing impacts of exotic invasive annual grasses and expanding native invasive tree populations. The most cost-effective conservation is prevention, early detection, and eradication, which is why USDA has developed training opportunities through the Agricultural Research Service Area Wide program. The Ecologically Based Integrated Pest Management Program (http://www.ebipm.org/) provides hands-on field schools across the West to teach the latest techniques in combating invasive weeds. USDA, through the NRCS, also offers technical services to help design and implement conservation practices when they are warranted.

Restoration on a landscape level to protect ecosystem services is an environmental protection imperative of many Federal agencies. At the same time, opportunities exist to use the biomass generated from fuel treatments as biofuel feedstock. Pinyon and juniper species are increasingly recognized as providing biomass that can be harvested in environmentally appropriate ways. Using some portion of rangeland in this way can not only improve range condition (where the species are invasive) but also bolster local economies where Federal lands are dominant. Care must be taken, however, to avoid harvesting practices that increase the risk of erosion, and invasion by non-native grasses and forbs, either through seed dispersal or by improving establishment conditions for invasive plants.

Systematic field based monitoring and remote sensing assessments are needed to improve our understanding of the response of biological functions to environment changes and management actions. Monitoring can support modeling efforts to predict changes induced by conservation practices across the landscape, which can enable more effective targeting of conservation dollars to maximize environmental and economic benefits.

References

Allen, E.B., R.J. Steers, and S.J. Dickens. 2011. Impacts of fire and invasive species on desert ecology. Rangeland Ecology and Management. 64:450-462.

Billings, W.D. 1994. Ecological impacts of cheatgrass and resultant fire on ecosystems in the western Great Basin. *In:* S.B. Monsen and S.G. Kitchen [eds]. Proceedings: Ecology and Management of Annual Rangelands; 18–22 May 1992; Boise, ID, USA, Gen. Tech. Rep. INT -GTR-313. Ogden, UT, USA: U.S. Department of Agriculture, Forest Service, Intermountain Research Station. p. 22–30.

Breshears, D.D., N.S. Cobb, P.M. Rich, K.P. Price, C.D. Allen, R.G. Balice, W.H. Romme, J.H. Kastens, M.L. Floyd, J. Belnap, J.J. Anderson, O.B. Myers, and C.W. Meyer. 2005. Regional vegetation die-off in response to global-change-type drought. Proceedings of the National Academy of Sciences USA 102:15144-15148.

Brooks, M.L., C.M. D'Antonio, D.M. Richardson, J.B. Grace, J.E. Keeley, J.M. DiTomaso, R.J. Hobbs, M. Pellant, and D. Pyke. 2004. Effects of invasive alien plants on fire regimes. BioScience 54:677–688.

Brunson, M.W., and J. Tanaka. 2011. Economic and social impacts of wildfires and invasive plants in American deserts: Lessons from Great Basin. Rangeland Ecology and Management. 64: 463-470.

Cannon, S.H., E.M. Boldt, J.L. Laber, J.W. Kean, and D.M. Stanley. 2011. Rainfall intensity-duration thresholds for postfire debris-flow emergency-response planning. Natural Hazards. DOI: 10.1007/s11069-011-9747-2.

Chambers, J.C., S.B. Vander Wall, and E.W. Schupp. 1999. Seed and seedling ecology of pinon and juniper species in the pygmy woodlands of western North America. Botanical Review 65:1-38.

Clements, C.D., and J.A. Young. 1997. A viewpoint: Rangeland health and mule deer habitat. Journal Range Management 50:129-138.

DiTomaso, J.M. 2000. Invasive weeds in rangelands: species, impacts, and management. Weed Science 48:255 -265.

REVIEW DRAFT

Eiswerth, M.E., T.D. Darden, W.S. Johnson, J. Agapoff, and T.R. Harris. 2005. Input-output modeling, outdoor recreation, and the economic impacts of weeds. Weed Science 53:130-137.

General Accounting Office. 2003. Wildland Fires: Better Information Needed on Effectiveness of Emergency Stabilization and Rehabilitation Treatments. Washington, DC, USA: US General Accounting Office, Report GAO-03-430.

Keane, R.E., K.C. Ryan, T.T. Veblen, C.D. Allen, J. Logan, and B. Hawkes. 2002. Cascading Effects of Fire Exclusion in Rocky Mountain Ecosystems: A Literature Review. Gen. Tech Rep. RMRSGTR-91. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 14 p.

Limbach, Eric. 2011. Wyoming Sagebrush Steppe. *In:* Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis [2011, August 2].

Link, S.O., C.W. Keeler, R.W. Hill, and E. Hagen. 2006. Bromus tectorum cover mapping and fire risk. International Journal of Wildland Fire. 15: 113-119.

Mack, R.N., D. Simberloff, W.M. Lonsdale, H. Evans, M. Clout, and F.A. Bazzaz. 2000. Biotic invasions: causes, epidemiology, global consequences, and control. Ecological Applications 10:689-710.

Major, Don J., Alan R. Sands, and David Tart. 2011. Mountain Big Sagebrush with Conifers. *In:* Fire Effects Information System, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Fire Sciences Laboratory (Producer). Available: http://www.fs.fed.us/database/feis [2011, August 2].

Meinke, C.W., Steven Knick, and D.A. Pyke. 2009. A Spatial model to prioritize sagebrush landscapes in the Intermountain West (U.S.A.) for restoration. Restoration Ecology. 17: 652-659.

Melgoza, G., R.S. Nowak, and R J. Tausch. 1990. Soil water exploration after fire: competition between *Bromus tectorum* (cheatgrass) and two native species. Oecologia 83:7-13.

Miller, R.F., S.T. Knick, D.A. Pyke, C.W. Meinke, S.E. Hanser, M.J. Wisdom, and A.L. Hild. 2011. Characteristics of sagebrush habitats and limitations to long-term conservation. Pp. 145–184 *in* S. T. Knick and J. W. Connelly (editors). Greater Sage-Grouse: ecology and conservation of a landscape species and its habitats. Studies in Avian Biology (vol. 38), University of California Press, Berkeley, CA.

Miller, R.F., R.J. Tausch, D.E. McArthur, D. Johnson, and S.C. Sanderson, S.C. 2008. Development of Post Settlement Pinyon-Juniper Woodlands in the Intermountain West: A Regional Perspective. Res. Pap., RMRS-RP-69. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 15 p.

Miller, R.F., T.J. Svejcar, and J.A. Rose. 2000. Impacts of western juniper on plant community composition and structure. Journal of Range Management 53:574-585.

Moody, J.A., and D.A. Martin. 2001. Initial hydrologic and geomorphic response following a wildfire in the Colorado Front Range. Earth Surface Processes and Landforms 26:1049–1070.

Pellant, M., B. Abbey, and S. Karl. 2004. Restoring the Great Basin desert, U.S.A.; Integrating science, management, and people. Environmental Monitoring and Assessment 99:16-179.

Pierson, F.B., C.J. Williams, S.P. Hardegree, M.A. Weltz, J.J. Stone, and P.E. Clark. 2011. Fire, plant invasions, and erosion events on western rangelands. Rangeland Ecology and Management. 64:439-449.

Pierson Jr, F.B., C.A. Moffet, C.J. Williams, S.P. Hardegree, and P. Clark. 2009. Prescribed-fire effects on rill and interrill runoff and erosion in a mountainous sagebrush landscape. Earth Surface Processes and Landforms 34:193-203.

Pierson, F.B., D.H. Carlson, and K.E. Spaeth. 2002. Impacts of wildfire on soil hydrological properties of steep sagebrush-steppe rangeland. International Journal of Wildland Fire 11:145–151.

Reid, K.D., B.P. Wilcox, D.D. Breshears, and L. MacDonald. 1999. Runoff and erosion in a pinyon–juniper woodland: Influence of vegetation patches. Soil Science Society of America Journal 63(6), 1869-1879.

Running, S.W. 2006. Is global warming causing more, larger wildfires? Science 313:927–928.

Schoennagel, T., T.T. Veblen, and W.H. Romme. 2004. The interaction of fire, fuels, and climate across Rocky Mountain forests. BioScience. 54: 661-671.

Stockmann, K., J. Burchfield, D. Calkin, and T. Venn. 2010. Guiding preventative wildland fire mitigation policy and decisions with an economic modeling system. Forest Policy and Economics 12:147–154.

REVIEW DRAFT

Stringham, T.K., W.C. Krueger, and P.L. Shaver. 2003. State and transition modeling: An ecological process approach. Journal of Range Management. 56:106–113

Urgeghe, A.M., D.D. Breshears, S.N. Martens, and P.C. Beeson. 2010. Redistribution of runoff among vegetation patch types: On ecohydrological optimality of herbaceous capture. Journal of Rangeland Ecology & Management. 63:497-504.

USFWS (United States Fish and Wildlife Service). 2011. http://www.fws.gov/mountain-prairie/species/birds/sagegrouse/GreaterSageGrouseFactSheet2011.pdf

Wasley, T. 2004. Mule Deer Population Dynamics: Issues and Influences. Nevada Department of Wildlife Biological Bulletin 14. Reno, Nevada, 76 pg.

Whisenant, S.G. 1990. Changing fire frequencies on Idaho's Snake River Plains: Ecological and management implications. *In:* McArthur, E.D., E.M. Romney, S.D. Smith, and P.T. Tueller, (comps). Proceedings – Symposium on Cheatgrass Invasion, Shrub Die-Off and Other Aspects of Shrub Biology and Management. Gen. Tech. Rep. INT-276. Ogden, Utah: U.S. Department of Agriculture, Forest Service, Intermountain Research Station.

Wilcox, B.P., D.D. Breshears, and C.D. Allen. 2003. Ecohydrology of a resource-conserving semiarid woodland: Effects of scale and disturbance. Ecological Monographs 73:223-239.

Young, J.A., R.A. Evans, R.E. Eckert, and B.L. Kay. 1987. Cheatgrass. Rangelands 9(6):266-270.

REVIEW DRAFT

The U.S. Department of Agriculture (USDA) prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and where applicable, sex, marital status, familial status, parental status, religion, sexual orientation, genetic information, political beliefs, reprisal, or because all or a part of an individual's income is derived from any public assistance program. (Not all prohibited bases apply to all programs.) Persons with disabilities who require alternative means for communication of program information (Braille, large print, audiotape, etc.) should contact USDA's TARGET Center at (202) 720-2600 (voice and TDD). To file a complaint of discrimination write to USDA, Director, Office of Civil Rights, 1400 Independence Avenue, S.W., Washington, D.C. 20250-9410 or call (800) 795-3272 (voice) or (202) 720-6382 (TDD). USDA is an equal opportunity employer.