Great Basin Factsheet Series 2016

Information and tools to conserve and restore Great Basin ecosystems

Edited by Jeanne C. Chambers

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Overview

Land managers are responsible for developing effective strategies for conserving and restoring Great Basin ecosystems in the face of invasive species, conifer expansion, and altered fire regimes. A warming climate is magnifying the effects of these threats and adding urgency to implementation of management practices that will maintain or improve ecosystem functioning. This Factsheet Series was developed to provide land managers with brief summaries of the best available information on contemporary management issues to facilitate science delivery and foster effective management. Each peer-reviewed factsheet was developed as a collaborative effort among knowledgeable scientists and managers. The series begins with information on how to put ecosystem resilience and resistance concepts into practice. Subsequent factsheets address key threats to Great Basin ecosystems – limiting medusahead invasion and restoring perennial communities, reducing woody fuel loads and establishing effective fuel breaks, assessing and mitigating soil erosion, managing threats to aspen communities in a changing environment, and seeding and transplanting techniques for restoring sagebrush communities.

Topic Areas

Great Basin, invasive annual grasses, conifer expansion, wildfire, grazing management, fuels management, seeding and transplanting techniques, resilience science, sagebrush ecosystems, aspen ecosystems

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Putting Resilience and Resistance Concepts into Practice

Purpose: Land managers are increasingly interested in improving resilience to disturbances, such as wildfire, and resistance to invasive species, such as cheatgrass and medusahead. This factsheet is designed to assist land managers in using resilience and resistance concepts to assess risks, prioritize management activities, and select appropriate treatments.

Estimates of resilience and resistance provide information on how an area is likely to respond to disturbances and management. Relative resilience depends on the underlying characteristics of a site or landscape like climate, soils, and the type of vegetation. In the topographically diverse Great Basin, resilience has been shown to increase with elevation and to differ among vegetation types (Chambers et al. 2014 a, b). Higher precipitation and cooler temperatures, coupled with greater soil development and plant productivity, result in greater resources and more favorable environmental conditions for plant growth and reproduction at mid to high elevations (Figure 1).

In contrast, lower precipitation and higher temperatures result in lower available resources for plants at low elevations. Aspect, slope, and topographic position influence these relationships because of their effects on solar radiation, effective precipitation, soil development, and vegetation composition and structure. Resilience can be decreased by disturbances that result in high mortality of native vegetation. These can include frequent or severe wildfires or long and severe droughts. They also can include inappropriate grazing by livestock or wild horses and burros.

Resistance to invasive annual grasses is particularly important in the Great Basin due to the widespread threat of altered fire regimes and risk of conversion to invasive annual grass dominance in low to mid elevation ecosystems. Invasive annual grasses increase the amount and continuity of fine fuels and, in many low to mid elevation areas, are resulting in

Resilience and Resistance of Great Basin Ecosystems

Resilience is the capacity of an ecosystem to regain its fundamental structure, processes and functioning when altered by stresses and disturbances. Resilient ecosystems reorganize after stessors like drought and disturbances like wildfire without crossing a threshold to an alternative state with different structure and function.

Resistance is the capacity of an ecosystem to retain its fundamental structure, processes, and functioning (or remain largely unchanged) despite stressors, disturbances, or invasive species. Resistance to invasion is particularly important in Great Basin ecosystems and is a function of the attributes of ecosystems that limit invading species.

Applying resilience thinking as a land managers requires one to acknowldedge that change is continually occurring and that ecosystems are adjusting to this change at scales ranging from the landscape to the site. Resilience and resistance concepts help managers understand key drivers of ecosystem change, identify relative risks of crossing thresholds to undesired states, and design appropriate management actions to promote desired ecosystem trajectories.

In Brief:

- Resilience and resistance concepts help managers understand key drivers of ecosystem change, identify relative risks of crossing thresholds to undesired states, and design appropriate management actions.
- An understanding of the relationships of environmental characteristics to vegetation types and their inherent resilience and resistance gives us the capacity to assess risks and prioritize management actions across large landscapes.
- Management tools such as Ecological Site Descriptions (ESDs) and state and transition models (STMs) give us the capacity to evaluate a sites' resilience and resistance when coupled with field surveys.

more frequent and larger wildfires. Resistance to an invasive species in general depends on (1) the climatic suitability of an area – whether or not it has the necessary soil temperature and moisture regimes for establishment, growth and reproduction of the invader, and (2) the composition and ecological condition of the native plant community – whether or not it has the capacity to effectively compete with and minimize the invader (Chambers et al. 2014a). Similar to resilience, resistance to invasive species is decreased by stressors and disturbances, especially those that decrease the ability of the native community to compete with the invader. These can include removal of sagebrush due to wildfire or insects like Aroga moth. They can also include grazing or frequent and repeated fires associated with invasive annual grasses that reduce the abundance of perennial grasses and forbs.

These species, especially deep-rooted perennial grasses such as bluebunch wheatgrass, are especially important as they typically recover after fire and are the best competitors with invasive annuals. The factors influencing resistance to invasive annual grasses are best understood for cheatgrass, the most widespread invasive annual grass in the Great Basin (Figure 1).

How can Resilience and Resistance be used to prioritize management actions at large scales?

An understanding of the relationships of environmental characteristics to vegetation types and their inherent resilience and resistance gives us the capacity to assess risks and prioritize management actions across large landscapes. We can use these relationships to evaluate how likely an area is to recover following disturbances or management treatments, and how likely it is to be invaded by annual grasses. Because resilience to disturbance and resistance to invasive annual grasses are highly correlated with soil temperature and moisture regimes, we can use these regimes to evaluate how resilience and resistance vary across landscapes and within planning areas (Chambers et al. 2014c).

For example, evaluating these regimes in relation to potential conifer removal projects

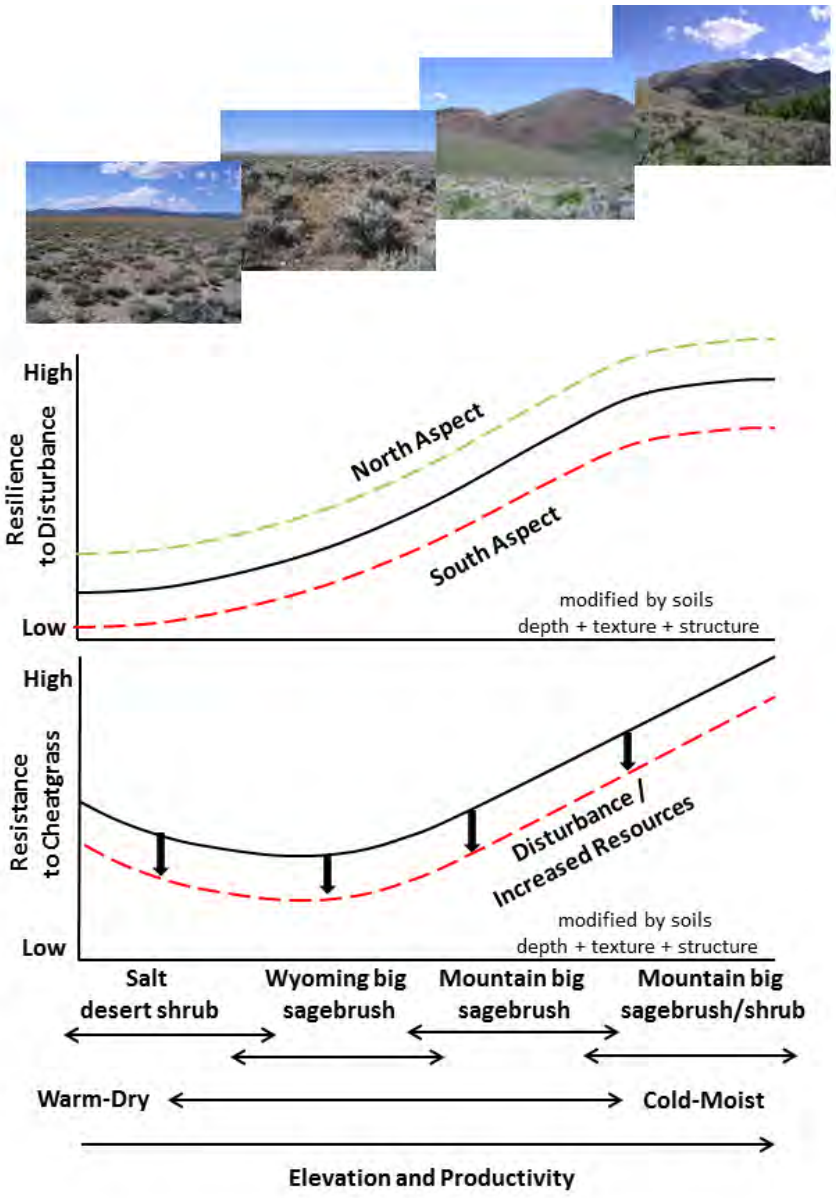

Figure 1. Resilience and resistance of the dominant vegetation types in the Great Basin. Resilience to disturbance is lowest in salt desert shrub types with warm (mesic) and dry (aridic) soils and highest in mountain big sagebrush/mountain brush types with cool (frigid) to moist (xeric) bordering on cold (cryic) soils. Resilience is often lower for soils with shallow depths or coarse textures which reduce available moisture. Low and black sagebrush are typical on these soils and are slower to recover following disturbance than neighboring sagebrush species on deeper or finer textured soils.

Resilience also tends to be lower on warmer and drier south-facing slopes. Resistance to invasive annual grass follows a pattern similar to resilience, but is lowest in Wyoming big sagebrush types with warm and dry soils and highest in mountain big sagebrush/mountain brush types with cold soils. The annual invasive grass, cheatgrass, is climatically limited in low elevation salt desert types by frequent, low precipitation years, and at high elevations by low soil temperatures, but has near optimal conditions at mid elevations with relatively moderate soil temperature and soil moisture. Disturbances that remove perennial native species, like fire or inappropriate grazing, can increase available water and nutrient resources providing cheatgrass with a competitive advantage. Adapted from Chambers et al. 2014 a, b.

provides information on the risk of annual invasives for different treatments (prescribed fire or mechanical) and whether additional weed control or seeding will be needed post-treatment (Figure 2). Soil temperature and moisture data are fundamentally important in classifying and mapping soils, are available for most areas, and can be used as the first filter for evaluating the resilience and resistance and how they vary across project areas (Maestas and Campbell 2014).

Recently, resilience and resistance to annual invasive grasses have been linked to sage-grouse habitat requirements in a decision support matrix for prioritizing management strategies to minimize persistent habitat threats such as wildfire and invasive annual grasses (Figure 3; Chambers et al. 2014c). The matrix is a tool that allows land managers to evaluate risks and decide where to focus specific activities in order to promote desired ecosystem trajectories. The overall management goal is to improve the ecological conditions of a site and increase the contiguous amount of land supporting sagebrush (a primary requirement for sage-grouse). Potential management activities include fire operations, fuels management, post-fire rehabilitation, and habitat restoration among others. These scenarios illustrate how the matrix can be used to inform decisions on various sites:

• *High to moderate resilience and resistance, high sagebrush landscape cover.* May not require intervention at the time of assessment, but should be monitored regularly to inform and adapt management.

• *High to moderate resilience and resistance, moderate to low sagebrush landscape cover.* May recover favorably following wildfire given sufficient native grasses and forbs. Management activities in these areas may focus on increasing habitat connectivity by removing conifers, or accelerating the rate of recovery after disturbance by seeding or transplanting sagebrush.

• *Low resilience and resistance, moderate to high sagebrush landscape cover.* May require active and focused protection to minimize stress and disturbance. If these areas lack adequate perennial grasses and forbs, and are at risk of conversion to invasive annual grasses, preventative activities like creation of fuel breaks and pre-positioning of firefighting resources may be needed to reduce fire size and frequency. These areas would likely require seeding after disturbances.

• *Low resilience and resistance, low sagebrush landscape cover.* May no longer have the capacity to support the desired species or may be so altered that they are lower priori-

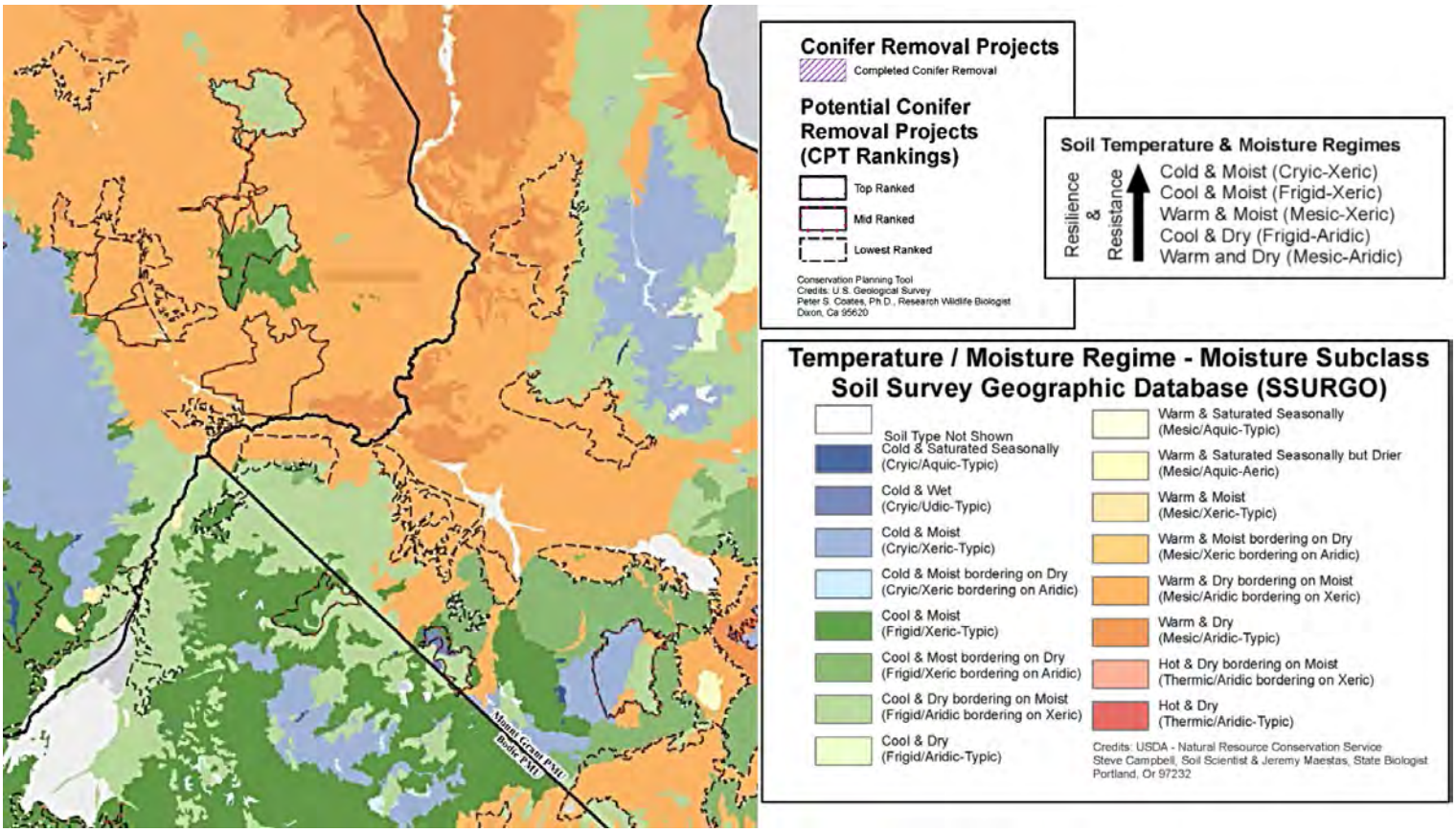

Figure 2. Soil temperature and moisture regimes and proposed conifer removal projects for the Pine Nuts Land Health Project within the planning area for the bi-state population of sage-grouse. Warm and dry areas (mesic-aridic) with low resilience and resistance recover more slowly and may require follow-up treatments to control weeds and restore native perennial species; cool and moist areas (frigid-xeric) with relatively higher resilience and resistance recover more quickly and may not require follow-up actions. All areas will require monitoring to determine management needs after treatment.

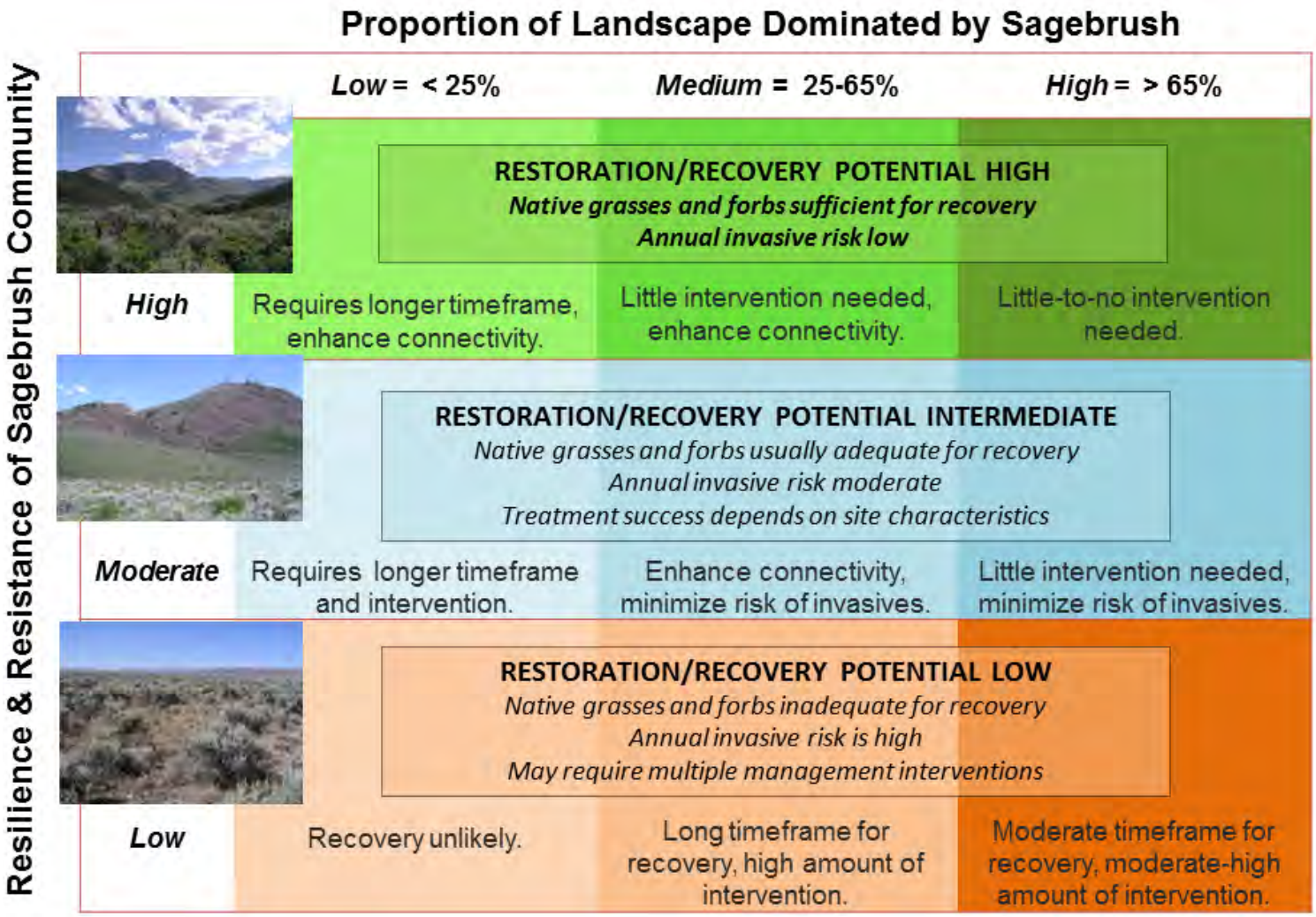

Figure 3. Matrix designed to link resilience and resistance with habitat for sage-grouse. The rows provide information on the restoration/recovery potential of ecological types with relatively high, moderate, and low resilience and resistance and are illustrated here by mountain big sagebrush/mountain brush, mountain big sagebrush, and Wyoming big sagebrush, respectively. The columns provide information on the amount of time and types of intervention required to increase sagebrush cover. Sagebrush landscape cover is one of the primary indicators of sage-grouse habitat. The probability of maintaining active sage-grouse leks or breeding areas is one of our best indicators of population viability and is closely related to sagebrush landscape cover; the probability of sage-grouse persistence varies with land cover of sagebrush (low = < 25%, intermediate = 25-65%, and high = > 65%). The management objective is to move from left to right within each resilience and resistance category and increase contiguous land cover of sagebrush (adapted from Chambers et al. 2014c).

ty for allocation of limited management resources. Managers may need to restore critical habitat in these types of areas, but must recognize that substantial investment and repeated interventions may be required to achieve habitat objectives.

How can Resilience and Resistance be used to select the best management practices at site scales?

The relative resilience and resistance of a site can be used to determine if a potential project area is appropriate for specific land treatments, such as conifer removal, post-fire seeding, etc. Assessing the resilience and resistance of an area begins with determining the ecological site types, and locating the relevant ecological site descriptions (ESDs). ESDs provide much of the baseline information necessary to evaluate changes in soil characteristics, such as temperature and moisture regimes, and vegetation attributes, like the composition and relative abundance of plant species, to evaluate the current resilience and resistance of a site. They are part of a land classification system that describes the potential of a set of climate, topographic, and soil characteristics and natural disturbances to support a dynamic set of plant communities. State-and-transition models (STMs) are a central component of ecological site descriptions that illustrate changes in plant communities and associated soil properties, causes of change, and effects of management interventions.

These models use state (a relatively stable set of plant communities that are resilient to disturbance) and transi-

tion (the drivers of change among alternative states) to describe the range in composition and function of plant communities within ESDs (Briske et al. 2008). STMs illustrate changes or transitions among states that are characterized by thresholds that may persist over time without active intervention. They also show restoration pathways that are used to identify the environmental conditions and management actions required for return to a previous state. Detailed STMs are not yet available for the entire Great Basin, but a generalized set of models has been developed that incorporate resilience and resistance and that are widely applicable to Great Basin ecosystems (Chambers et al. 2014b, c, Miller et al. 2014, 2015).

Because Great Basin ecosystems occur over a broad range of environmental conditions, and have differing land use histories and species composition, careful assessment of the project area will always be necessary to determine the appropriate management action. Factors that are used to develop STMs and to assess a site's relative resilience and resistance include various soil characteristics, current or potential vegetation, and wildfire severity or treatment impacts.

Table 1. Factors that can be used to "score" a site's relative resilience to disturbance and resistance to invasive annual grasses and to determine appropriate management actions (adapted from Miller et al. 2014, 2015).

Site Characteristic	Explanation
Temperature	
Soil temperature regime	Estimated from soil survey data, Ecological Site Descriptions (ESDs), or elevation within each Major Land Resource Area. It is necessary to adjust for aspect and to consider if you are in the lower (warm) or upper (cool) part of the temperature regime.
Species or subspecies of sagebrush	Derived from ESDs or site descriptions, but should be confirmed from site surveys. Sagebrush species and subspecies differ over elevation gradients, correspond to soil temperature and moisture regimes, and are influenced by soil depth and texture.
Effective Moisture	
Precipitation	Estimated from soil survey data, ESDs, or climate models but should be confirmed from site evaluation. Soil moisture regime can be used as an indicator of precipitation; moisture subclass level data is most appropriate at site scales.
Soil texture	Derived from soil descriptions or ESDs but should be confirmed through on-site soil pits. Loams often have a good balance between infiltration and water storage capacity; clay, sandy, or silt soils are more variable.
Soil depth	Depth to restrictive layer estimated from soil descriptions but should be confirmed through on-site soil pits. Soil depth is one of the major variables in determining water storage capacity and rooting depth.
Pre- treatment or Wildfire Vegetation (Plant Functional Groups)	
Deep-rooted perennial grasses Sandberg bluegrass Perennial forbs Invasive annual grasses	Derived from site surveys. The relative abundance of different plant functional groups determines site response to fire and management treatments. Resilience and resistance are highest if native grasses and forbs dominate the site. Resilience and resistance are lowest if deep-rooted perennial grasses are <2/m^2 for relatively cool and moist sites and <3/m^2 for relatively warm and dry sites, invasives are dominant ***or***, woody species (shrubs or trees) are near maximum cover.
Treatment or Fire Severity	
Treatment or fire severity adjustment	Derived from site surveys. *Low severity treatment or fire* results in little mortality of perennial grasses and forbs. *Moderate severity treatment or fire* can occur in Phase I and II woodlands and high density shrublands. *High severity treatment or fire* usually occurs in Phase III woodlands.

These same factors can be used to "score" a site's relative resilience and resistance and determine appropriate management actions (see Table 1; Miller et al. 2014, 2015). Generally, sites with high scores are those that are relatively cool and moist, have deep and/or fine textured soils, a high percentage of deep-rooted perennial native grasses and forbs, and little to no invasive plant species. These types of sites typically recover well after treatment or disturbance and often do not require seeding. Sites with low scores are those with some combination of relatively warm and dry conditions, shallow soils and/or coarse textured soils, few deep-rooted perennial native grasses and forbs, and/or an abundance of invasive plant species. These sites are often slow to recover after management treatment or disturbance, and are at risk of conversion to invasive annuals.

Management treatments require careful monitoring to determine if follow-up actions such as weed control and/or seeding are needed. Post-fire rehabilitation success on these sites will be weather dependent and may require repeated interventions and substantial investment to ensure success.

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Ecological site descriptions: http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/technical/ecoscience/desc/

Web soil survey: http://websoilsurvey.sc.egov.usda.gov/

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Information and tools to conserve and restore Great Basin ecosystems

Limiting Medusahead Invasion and Impacts in the Great Basin

Medusahead (*Taeniatherum caput-medusae*) is an exotic winter annual grass from Eurasia, and was first reported in North America in the 1880s. It occurs across a broad range of climatic and soil conditions. Medusahead can occur on sites receiving from 250 to 1000 mm (10-40 in) of precipitation. Medusahead is most problematic on fine-textured soils below 1524 m (5000 ft), but can occur at higher elevations and on more coarse-textured, well-drained soils.

It is critical to limit the spread and impact of medusahead invasion because it decreases biodiversity, degrades wildlife habitat, reduces livestock forage, increases the risk of frequent wildfires, and changes how ecosystems function (Young 1992; Davies and Svejcar 2008; Davies 2011). There are three primary tactics to limiting medusahead invasion and subsequent negative impacts: 1) reduce seed dispersal, 2) maintain or increase plant community resistance to invasion, and 3) use early detection and eradication of new infestations in non-invaded areas.

Reducing Seed Dispersal

Most medusahead seeds only disperse a few meters (Davies 2008) from the parent plant. Longer distance seed dispersal happens primarily by humans (often via vehicles) and animals (Davies et al. 2013).

Strategies for reducing short-distance dispersal:

• Reducing short-distance spread can be accomplished by applying selective herbicides around infestations. Applying pre-emergent herbicides in the fall can effectively control medusahead and minimize damage to perennial vegetation.

• Planting competitive vegetation, such as crested wheatgrass (*Agropyron cristatum*), around the infestations can also reduce the spread (Davies et al. 2010).

Strategies for reducing long-distance dispersal:

Reducing long-distance dispersal requires limiting contact by vehicles, animals, and humans with medusahead seeds and cleaning seeds off when contact occurs.

• Maintaining medusahead-free zones (usually with herbicides) along roads and trails can reduce the spread of medusahead seeds.

Purpose: To provide managers with strategies to reduce the spread and impact of medusahead.

In Brief:

- Medusahead invasions decrease biodiversity, degrade wildlife habitat, reduce livestock forage, increase the risk of frequent wildfires, and change how ecosystems function.
- Seed dispersal occurs primarily via vehicles and animals.
- Short-distance dispersal can be reduced by applying selective herbicides, and planting competitive vegetation (such as perennial grasses) around infestations.
- Long-distance dispersal requires limiting contact with vectors, maintaining “weed-free” zones, and controlling livestock rotations in infested areas.

Figure 1: Medusahead seed head in an invaded area.

• If medusahead-free zones cannot be maintained, some roads may need to be closed during times when seeds can be readily dispersed.

• Vehicles (especially fire suppression, off-road, and construction equipment) and gear, clothes, and shoes, should be cleaned after travelling through or working in medusahead invaded areas.

• Livestock should not be moved directly from infested fields to un-invaded areas. Pasture rotations should minimize livestock contact with infestations when seeds can be readily dispersed.

Resisting Medusahead Invasion

The composition of the plant community is critical in determining resistance to medusahead invasion. In the Great Basin, a reduction in medusahead establishment is linked to increases in perennial bunchgrass abundance (Figure 2). It is necessary to maintain intact perennial bunchgrass communities and restore degraded bunchgrass communities to limit medusahead invasion.

• Carefully managed livestock grazing is crucial to maintain resistance to medusahead invasion. Livestock grazing during the growing season should be moderate (~40% utilization) or less. Managers should avoid repeated use over growing seasons and incorporate periods of grazing rest. Complete grazing exclusion likely has varying effects, but the accumulation of fine fuels in the absence of livestock grazing may increase fire risk, potential fire severity, and post-fire annual grass invasion in some situations (Davies et al. 2009).

• Managers need to minimize disturbances (e.g., construction, catastrophic wildfire, non-selective herbicide application) that reduce the perennial herbaceous understory, because this will increase the probability of medusahead invasion.

• Perennial bunchgrasses need to be re-established after disturbances that result in significant bunchgrass mortality, otherwise medusahead or other exotic annual species may fill open spaces in the plant community.

• Managers can monitor trends in bunchgrass abundance, and improve management if a negative trend is detected.

Early Detection and Eradication

Management to limit the dispersal of medusahead, and increase the resistance of plant communities to invasion is highly effective, but will not prevent all medusahead establishment opportunities in previously uninvaded areas.It is very important to detect new infestations and implement management plans to eradicate them.

• A survey plan that outlines inventory techniques, the survey area, and survey time periods is critical for success (Sheley et al. 2003).

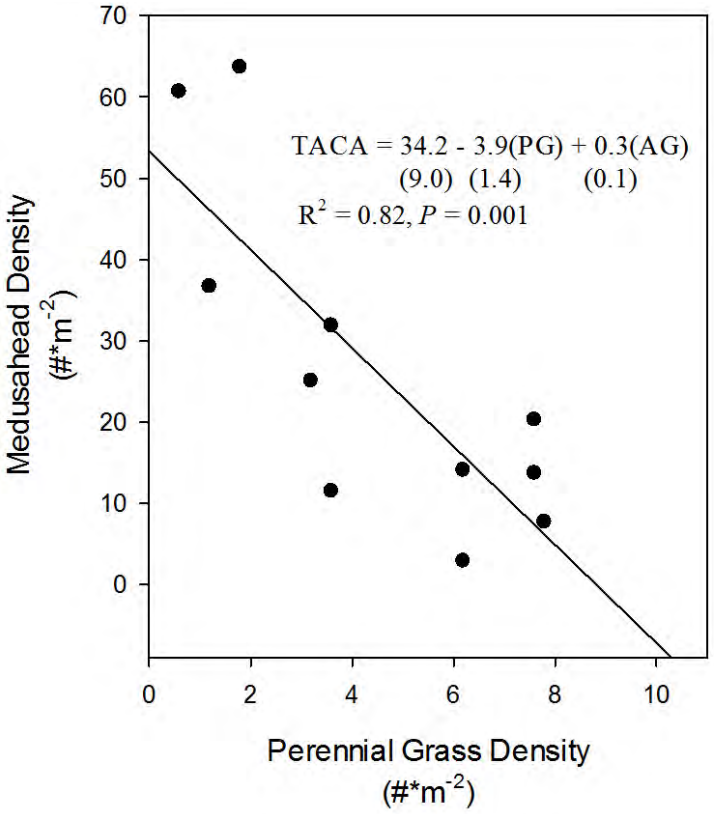

Figure 2. Relationship between medusahead density and perennial grass density. Adapted from Davies (2008). TACA = medusahead, PG = perennial grasses, AG = annual grasses excluding TACA.

• Priority for surveying should concentrate first along roads, secondarily along animal trails, and then at random locations, because roads are most likely the vector pathway for medusahead spread into new areas (Davies et al. 2013). Roadsides often are also an ideal environment for medusahead establishment.

• Managers might prioritize a survey near an existing infestation, because medusahead seed abundance and likelihood of establishing new infestations are much greater near existing infestations.

• They should survey more extensively within recently disturbed areas where susceptibility to invasion is greater.

• New infestations in uninvaded areas should be targeted for eradication.

• Areas that received control treatments should be routinely monitored to ensure treatments are successful and are re-treated as necessary. Revegetation may be necessary to prevent re-invasion of treated areas.

Limiting the spread and impact of medusahead requires involvement from all stakeholders. It is vital that stakeholders are informed about medusahead impacts and the efforts needed to prevent spread and negative impact.

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Great Basin Factsheet Series
Number 3 • 2015
Information and tools to conserve and restore Great Basin ecosystems

Reestablishing Perennial-Dominated Plant Communities in Medusahead-Invaded Sagebrush Rangeland

Purpose: To provide managers with tools and strategies to reestablish perennial-dominated plant communities in medusahead-invaded sagebrush rangelands.

Reestablishment of perennial-dominated plant communities in sagebrush rangelands that have been invaded by medusahead (*Taeniatherum caput-medusae*) (Figure 1) is needed to reduce the risk of landscape-scale wildfire, increase forage for livestock, improve habitat for wildlife, prevent reinvasion after medusahead control, and protect adjacent uninvaded areas.

An effective plan for reestablishing a perennial-dominated plant community should consider the following: 1) feasibility of native plant community restoration (restoration vs. revegetation), 2) selection of control treatments that maximize the likelihood of perennial plant response, and 3) commitment to post treatment monitoring and adaptive management.

In Brief:

- Medusahead invasions increase the risk of wildfire, decrease forage for livestock, reduce wildlife habitat quality, and are at risk of spreading into adjacent areas.
- Sites with surviving native perennial vegetation have the best chance for successful restoration.
- Medusahead control treatments should be chosen to boost perennial plant communities. Appropriate treatments vary depending on plant community characteristics, plant phenology and logistical constraints.
- Revegetating medusahead-invaded rangeland represents a significant investment, so committing to long-term effectiveness monitoring ensures that the investment is paying dividends.

Restoration vs. Revegetation

One of the most important decisions made when developing a plan for reestablishing perennial-dominated plant communities in medusahead-invaded sagebrush rangelands is whether or not restoration of the native plant community is practical. If the original native vegetation is markedly reduced or absent, revegetation may be necessary.

Site and plant community factors to consider

- Sites with residual native vegetation provide the highest likelihood for successful restoration of the native plant community. A rule of thumb to follow is if infestations have three or more large, mature native perennial bunchgrasses and three or more native perennial forbs per yard^2, they are good candidates for native plant community restoration (Davies et al. 2013a).
- Recruitment of native species from seed is sporadic and medusahead dominated sites may require multiple seeding events to establish a perennial-dominated community.

Figure 1. Medusahead in an invaded area.

- Native species mixes perform poorly when seeded after medusahead control in low elevation (warm/dry) Wyoming big sagebrush sites. When seeded on these sites, native vegetation has failed to establish, and reinvasion by medusahead has occurred (Davies et al. 2015).
- Seeding native plants after medusahead control is more effective in higher elevation sagebrush communities that receive more precipitation.
- On low elevation (warm/dry) Wyoming big sagebrush sites, rather than attempting restoration, one option is to drill-seed introduced seed mixes of crested and Siberian wheatgrass varieties to promote establishment of perennial plants sufficient to prevent reinvasion of medusahead (Davies et al. 2015).

Selecting Control Treatments

Medusahead control treatments should be selected to maximize the probability of reestablishing a perennial-dominated plant community, either from seed or from residual native vegetation. Appropriate treatments vary, depending on plant community characteristics, plant phenology and logistical constraints.

Infestations that have desirable residual perennial vegetation:

- When properly applied, soil-active pre-emergent herbicides (e.g., imazapic) can selectively control annual plants while minimizing damage to established, desired perennial vegetation. Such selectivity can be accomplished if pre-emergent herbicides are applied during the fall when desired perennial vegetation is dormant, and prior to fall moisture stimulating the emergence of medusahead.
- Low rates of 41% glyphosate (0.75 to 1 pt product/acre), applied at the tillering stage of medusahead, can achieve post-emergence control of 90-95% without injuring native perennial forbs and shrubs (Kyser et al. 2012). It is unclear how such applications of glyphosate may impact established native perennial grasses. In addition, a multi-year commitment will likely be required to deplete medusahead in the soil seedbank and prevent new seed production.
- Prescribed spring or fall burning followed by a fall imazapic application (6 oz. per acre) has provided the best control of medusahead and promoted residual perennial vegetation (Davies and Sheley 2011). Burning removes vegetation litter, which improves control effectiveness by increasing herbicide contact with the soil surface. Burning may also play a role in improving control effectiveness by directly removing medusahead seed.
- Focusing medusahead control efforts on infestations with residual desired perennial vegetation may reduce or even eliminate the need for seeding, and probably offers the highest likelihood of restoring a native-dominated plant community. However, it is important to realize that medusahead invasion is an indication of a functional deficiency or a management problem in the plant community. Therefore, multiple selective control treatments and careful management may be necessary for the plant community to recover its resistance to invasion.
- Carefully managed livestock grazing is critical for maintaining and promoting residual native perennials. Livestock grazing during the growing season should be moderate (~40% utilization) or less, and should avoid repeated growing season use. It should also incorporate periods of grazing rest.

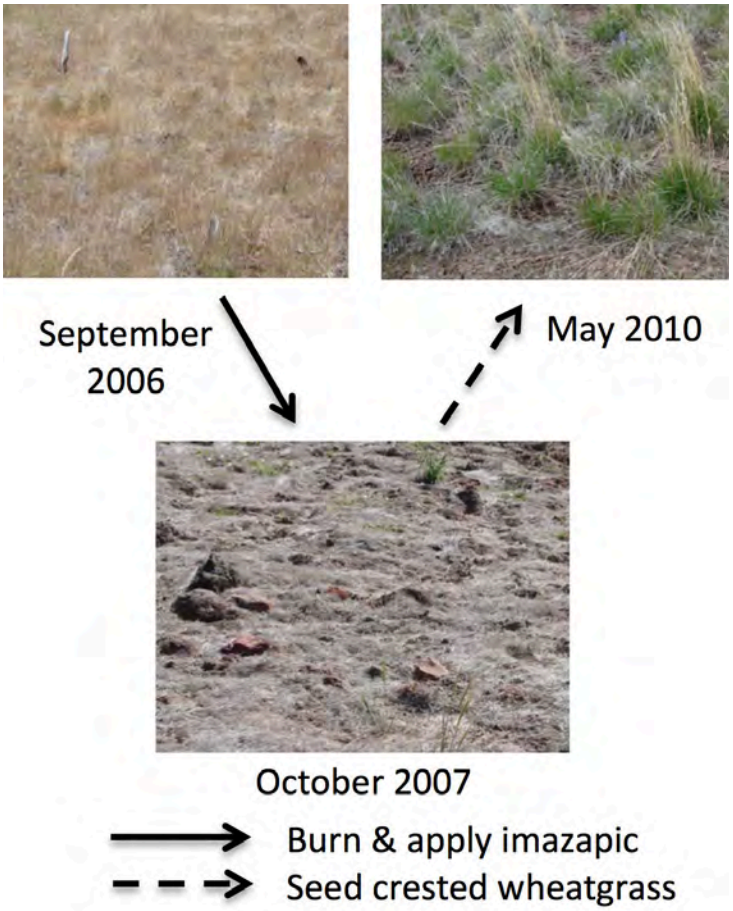

Figure 2. Example of management to revegetate medusahead-invaded sagebrush plant communities.

Infestations lacking sufficient desirable residual perennial vegetation

- Prescribed burning in the spring or fall, followed by a fall imazapic application (6 oz per acre) has provided the best control of medusahead and promoted establishment of a perennial-dominated plant community from seed (Davies 2010, Monaco et al. 2005, Kyser et al. 2007) (Figure 2).

- Seeding should be delayed one year after applying imazapic to reduce the phytotoxic effects of the herbicide on seedlings (Davies et al. 2014).
- Integrated burning and pre-emergent herbicide treatments often improve medusahead control compared to individual treatments. Applying spring burning, fall burning, or pre-emergent herbicide as a standalone treatment is not effective for promoting establishment of a perennial-dominated plant community (Davies 2010).
- Because burning prior to pre-emergent herbicide application increases the overall treatment and potential liability costs, capitalizing on opportunities created by wildfires in medusahead-invaded areas can reduce the cost of treatments by eliminating the need to apply a prescribed burn (Davies et al. 2013b).

Effectiveness Monitoring and Adaptive Management

Even the best planned endeavors to reestablish perennial-dominated plant communities in medusahead-invaded sagebrush rangelands carry a high risk of failure (Young 1992). Therefore, it is critically important to begin monitoring treatment effectiveness, and use this information adaptively early in the treatment implementation process.

The reality of implementing a large scale medusahead control and revegetation project using the techniques described above can yield harsh and expensive lessons. There can be many sources of error, including herbicide mixing inaccuracies, skips in the application pattern, undetected weed emergence, etc. Therefore, it is imperative that control effectiveness be evaluated the year following treatment to determine if follow-up treatments will be necessary. The growing season following treatment is also a good time to evaluate response in residual perennial vegetation; this is an opportunity to adapt by incorporating or canceling a seeding treatment depending on responses of the plant community to medusahead control.

Controlling and revegetating medusahead-invaded rangeland represents a significant investment. Therefore it makes sense to commit to long-term effectiveness monitoring to ensure the investment is paying dividends over time. A strong negative correlation exists between perennial grass density and medusahead abundance (Figure 3). Perennial grass density also serves as a key indicator for several important plant community functional responses and forage availability. So, perhaps the single best indicator of longer-term treatment effectiveness is the trend in mature perennial grass density over time.

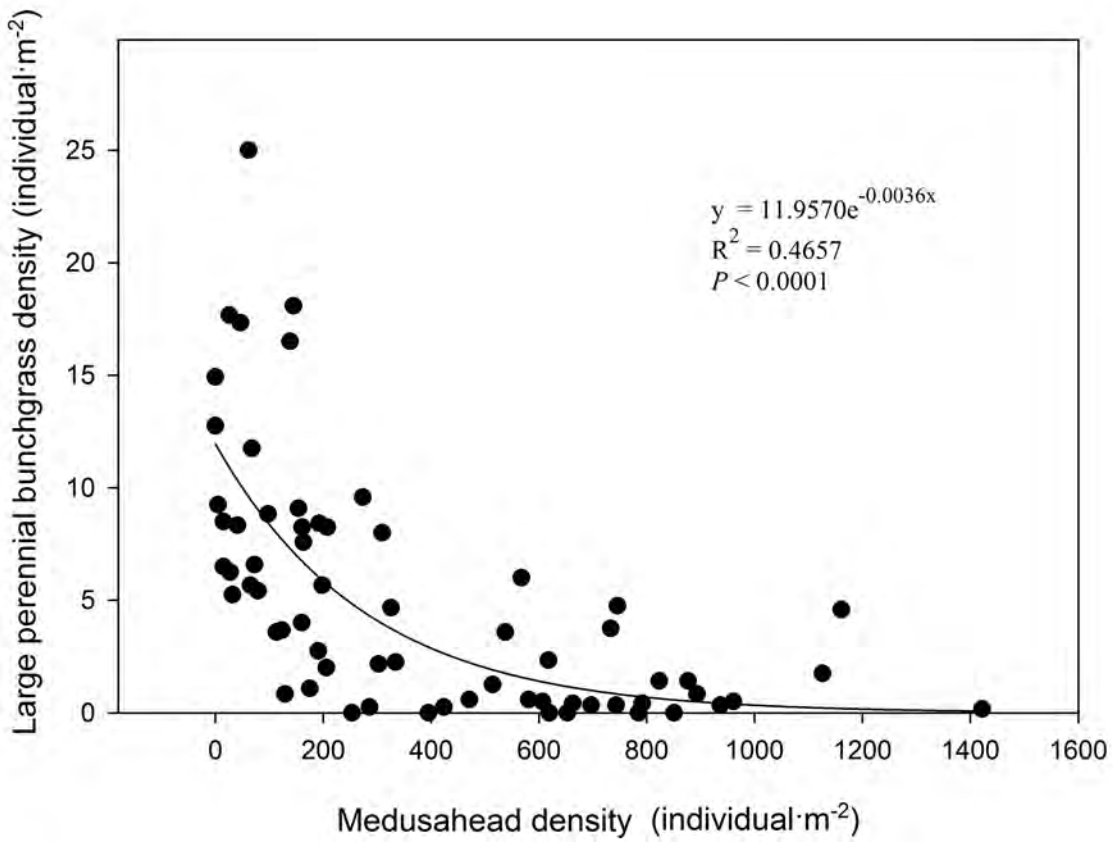

Figure 3. Relationship between medusahead density and perennial grass density. Adapted from Davies 2011.

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Information and tools to conserve and restore Great Basin ecosystems

Conifer Removal in the Sagebrush Steppe:
the why, when, where, and how

Purpose: To provide land managers with a brief summary of the effects of conifer expansion and infill in sagebrush ecosystems and of potential management strategies.

Why Manage Conifers?

Over the past 150 years, juniper (*Juniperus* spp.) and pinyon (*Pinus* spp.) woodlands have increased in area across the sagebrush steppe of the Intermountain West. Effects have been especially pronounced in the Great Basin where the area occupied by woodlands has increased up to 625% (Miller et al. 2008). Causes include a combination of human-induced interruptions to natural wildfire cycles and favorable climatic periods. The proliferation of trees has led to infill of many pre-settlement woodlands and sagebrush/tree savanna communities. In addition, juniper and pinyon have expanded into sagebrush sites that previously did not support trees, resulting in a gradual shift in land cover type from shrub steppe to woodland. As much as 90 percent of this change has occurred in areas that were previously sagebrush vegetation types (Miller et al. 2011).

This transition has broad impacts on ecosystem function and services, prompting widespread management concern. As woodland succession progresses, conifers use much of the available soil water, which allows them to outcompete native grasses, forbs, and shrubs. Increases in conifer cover and decreases in understory vegetation may result in soil erosion on slopes, leading to reduced site productivity and resilience to disturbance. Woodland succession also affects fire behavior as shrub-steppe ground fuels decline but conifer canopy fuels increase, resulting in fewer, but more intense wildfires, and increasing the potential for invasive annual grasses to dominate on warmer sites. Conifer expansion and infill are also a threat to shrub-obligate wildlife species, such as sage grouse and mule deer, which are suffering notable population declines due to deteriorating habitat quantity and quality.

When to Treat

Rates of conifer expansion and tree establishment appear to have slowed in recent decades compared to the first half of the 20th century, possibly due to less favorable climatic

In Brief:

- Benefits of addressing conifer expansion and infill include maintaining native understory plants, reducing risk of large and severe wildfires, improving habitat for declining species, reducing soil erosion and conserving soil water, and increasing ecosystem resilience to fire and resistance to cheatgrass invasion
- Early intervention to address Phase 1 and 2 sites (those with an adequate native shrub and herbaceous understory) achieves the most predictable results for the least cost
- A variety of trade-offs and risks must be considered when selecting the most appropriate management option to meet project goals and desired outcomes

conditions and fewer suitable sites for tree establishment (Miller et al. 2008). According to one dendrology study across several sites in the Great Basin, about 80 percent of sites affected by conifers were still in the early- to mid-phases of woodland succession but, over the next 30 to 50 years, these sites are expected to transition into closed canopy woodlands (Miller et al. 2008). Because shrub and perennial herbaceous cover decrease with increasing tree cover (Roundy et al. 2014a; Figure 1), a window of opportunity still exists on many sites to prevent further declines in sagebrush steppe vegetation if action is taken soon.

Three phases of succession have been described that help managers prioritize limited resources (Figure 2). Management recommendations include:

• Early intervention to address Phase 1 and 2 sites that still retain an adequate native shrub and herbaceous understory to achieve the most predictable results for the least cost. Sagebrush and other shrubs are among the first plants to decline due to conifer competition, so reduction of early succession conifers is often needed if shrub retention is a management goal. Perennial bunchgrasses, the lynchpin of ecosystem resilience and resistance to weed invasion, are also reduced in woodland succession and management actions are often necessary to prevent the loss of these key species.

• Phase 3 woodlands should not be ignored, but treatment of these sites may involve more resources (seeding, weed control, heavy slash removal) and potential risks, such as increased invasive weeds, so efforts should be carefully targeted to meet resource goals.

Where to Treat

Landscape Considerations

Decisions about where to treat woodlands should start with considerations of goals at landscape or watershed scales. Locating the project in the right setting is key to maintaining and enhancing a variety of resource benefits, including

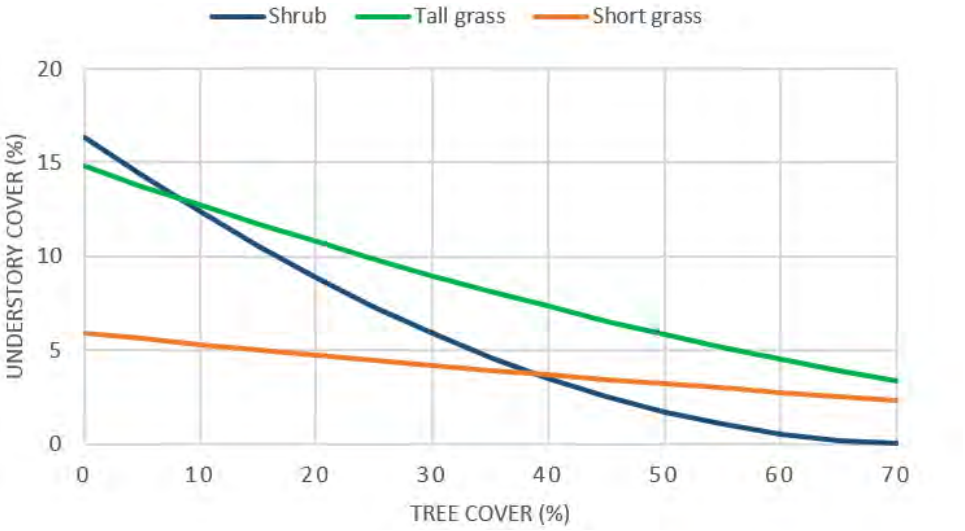

Figure 1. The effect of tree cover on understory cover of shrubs and grasses on 11 sites measured across the Great Basin (Roundy et al. 2014a). As expected, understory cover declined as tree cover increased. On many sites, shrub cover was reduced by 50% when tree cover exceeded 20%, while perennial herbaceous cover was reduced 50% when tree cover exceeded 40%. Although specific responses vary, in general, by the time woodlands have reached Phase 2, shrub and herbaceous cover are in sufficient decline to be concerned about loss of the sagebrush ecosystem.

Phase 1
- Shrub and herbaceous dominance
- Active tree recruitment
- Terminal (>10 cm) and lateral (>8 cm) leader growth
- Low cone production

Phase 2
- Tree, shrub and herbaceous co-dominance
- Active tree recruitment
- Terminal (>10 to 5 cm) and lateral (>10 to 2 cm) leader growth
- Cone production moderate to high
- Shrubs intact to thinning

Phase 3
- Tree dominant; herbaceous intact (cool-moist sites) to depleted (warm-dry sites)
- Limited tree recruitment
- Terminal (>10 to 5> cm) and lateral (<5 to 2< cm) leader growth
- Cone production low to none
- Shrubs >75% absent

Figure 2. Phases of woodland succession

wildlife habitat, hydrologic function, fuels reduction, plant community diversity, and forage production.

Conifer removal designed to benefit a particular wildlife species should consider seasonal habitat needs and the condition of surrounding lands. For example, sagebrush-obligate species like sage-grouse require large tracts of shrub-steppe virtually devoid of trees, especially for breeding (SGI 2014), and they largely avoid woodlands when moving between nesting and late brood-rearing habitats. Using sage-grouse seasonal habitat information combined with land cover maps showing areas of intact sagebrush and conifer expansion helps determine potential treatment areas that maximize benefits for the targeted species (Figure 3).

Similarly, conifer removal projects designed to reduce fuels and fire hazards, minimize erosion, and increase water capture and storage also benefit from a landscape perspective, especially when areas of concern extend beyond a single landowner or administrative district.

Site Considerations

Additional considerations must be made at the project site scale. One of the first steps is determining what ecological site types characterize the project area. Ecological sites are mapped based on soils and other physical characteristics and define the distinctive kind and amount of vegetation you should expect on the site. Ecological site descriptions can help determine the extent to which conifers should be present on the site and also may assist in predicting site responses to management (see NRCS website).

Distinguishing woodland from sagebrush sites experiencing conifer expansion is important to determine what level and method of tree removal is appropriate. Persistent woodland ecological sites are often characterized by the presence of 'old-growth' trees (i.e., those more than 150 years old) in stands or savannas, and scattered downed wood, snags, and stumps. Sagebrush ecological sites have few to no old trees, stumps, downed wood, or snags, and often have deeper soils with higher herbaceous production. Persistent woodlands are valuable components of the landscape and support a diversity of wildlife. Ancient trees have become increasingly vulnerable during fire as stands get thicker and fire intensities increase. Thinning of infill trees may be an appropriate treatment in woodland sites. In contrast, on sagebrush sites all of the conifers may be removed with the goal of restoring the plant community to the sagebrush ecological state. Tree control on expansion sites adjacent to old-growth stands might also be a priority to limit spread.

Priority sites for treatment have an understory composition that is sufficient for shrub-steppe plant communities to recover without requiring additional seeding or weed control. Conifer sites that have understories comprised of mostly exotic annual grasses have a weed management problem regardless of treatment; so simply removing trees may not achieve desired ecological benefits.

Combining ecological site information with an inventory of current vegetation allows managers to determine the relative resilience of the site to disturbance, risk of invasive species such as cheatgrass, and the likelihood of getting a favorable treatment response (Miller et al. 2014a). In general, warmer and drier sites are less resilient to disturbance and resistant to invasion by non-native annuals than cooler and moister sites. Also, sites with adequate densities of deep-rooted perennial bunchgrasses are more likely to yield a successful treatment response. Aspect, soil depth, and texture are other important considerations, as north slopes and deep, loamy soils generally produce better herbaceous responses.

Special consideration should be given to unique features, such as sites of cultural significance or nest trees for species of concern when selecting appropriate sites for conifer removal.

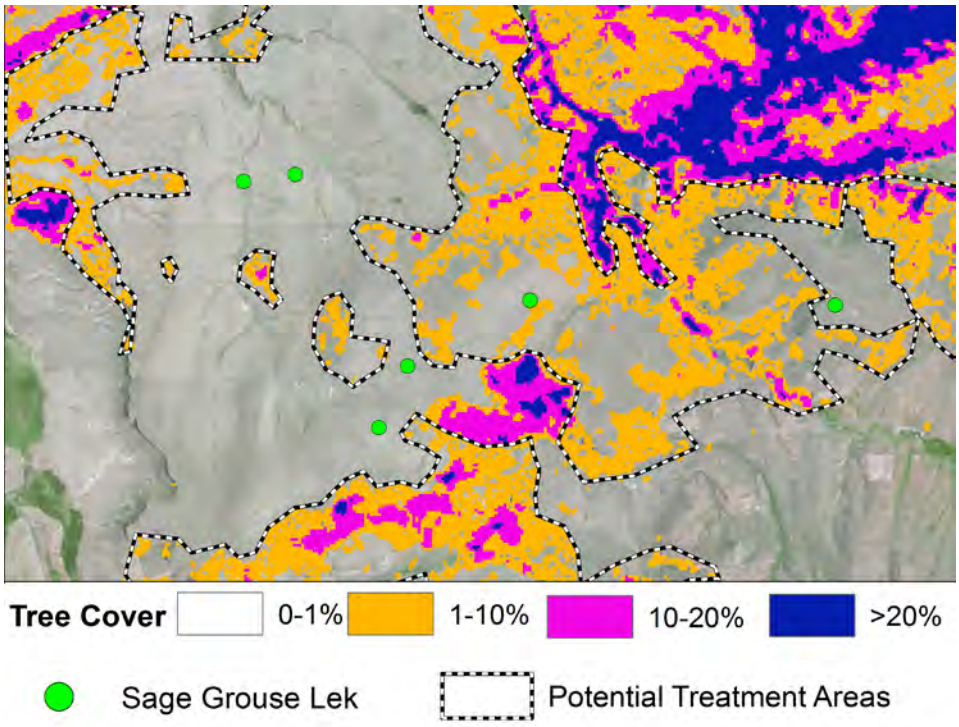

Figure 3. High-resolution tree canopy cover model overlaid with sage-grouse lek locations in central Oregon. Remote-sensing products estimating conifer cover are increasingly available to aid with large-scale planning and can be used as a starting point to plan targeted conifer removal treatments to benefit breeding habitats, as shown here.

How to Remove Conifers

First and foremost, management decisions should be based on the project goals, site conditions, and desired outcomes (see Miller et al. 2014a). There are various trade-offs and risks to consider when selecting the most appropriate management option (Table 1). Primary techniques used to manage conifers are prescribed fire and mechanical treatments (e.g., chainsaw cutting, masticators, and feller-bunchers). It may be desirable to use a combination of techniques to meet short and long term goals.

Table 1. Common conifer treatment options, costs, and trade-offs (adapted from SageSTEP 2011). It may be necessary to implement a combination of techniques over time to achieve desired results in the short and long term. Consult local experts for information when considering other treatment options (e.g., chaining, bulldozing).

Treatment Option	Costs	Advantages	Disadvantages
No Treatment 	-No expenditure of funds in short term, but deferred treatment option becomes increasingly expensive as woodland succession progress	-No disturbance -No change to aesthetics -No operational risk	*Allowing transition from Phase 1 to 3:* -Increases risk of severe wildfire -Decreases and eliminates understory vegetation -Increases risk of invasive weed dominance -Accelerates soil erosion -Reduces available soil water -Decreases habitat for shrub-steppe wildlife -Significantly reduces AUMs for grazing
Prescribed Fire 	**Low end:** $10-$25/ac **High end:** $125-$175/ac **Influencing factors**: **Vegetation Type:** Low Cost: Grass; Medium Cost: Shrub; High Cost: Closed woodland **Size of Treatment Area:** Per acre costs decrease as treatment area increases **Operational Difficulty:** Burn units on steep slopes, with mid-slope control lines, or adjacent to homes will have higher costs	-Effectively reduces fuel loads and intensity of future wildfire -Closely mimics natural processes -Removes small trees which can greatly extend the time period before retreatment -Works well on relatively cool and moist sites with adequate herbaceous vegetation -*Phase 1 and 2:* Perennial herbaceous cover may increase 2-3 fold within 3 years -*Phase 3:* May result in increases in herbaceous cover but response unpredictable. Risk of weed invasion and treatment failure increases	-Liability and smoke management concerns -Imprecise and variable treatment as fires may burn hotter or cooler than planned -Narrow time period for application -Non-sprouting shrubs lost; recovery often 2-4 decades -Increases weed risk, especially on warmer and drier sites and sites with depleted perennial grasses -*Phase 3:* Initial thinning required to carry fire. Seeding typically needed. Not appropriate on warm-dry sites with depleted perennial grasses
Chainsaw Cutting 	**Low Cost:** $10–$40/ac **High Cost:** $100–$175/ac **Influencing factors**: **Tree Density:** Cost increases with density of trees to be cut **Terrain:** Steep terrain and distance from roads or difficult accessibility may increase cost **Post-Cut Treatment:** If trees are to be stacked, chipped, burned or scattered, cost increases with labor intensity. Removal of downed trees for firewood or biomass can reduce or eliminate post-cut cost	-Shrubs maintained; little ground disturbance -Precise treatment with ability to control target trees and cut boundary extent -Wide window for implementation -Cut trees can be left on site to protect soil and herbaceous vegetation -Little risk of weed dominance, except on warmer sites with limited perennial grasses -Altered fuel structure can aid in fire suppression -*Phase 1 and 2:* Prevents loss of understory vegetation. Slight-to-moderate increases in production over time -*Phase 3:* May result in considerable increases in herbaceous production but response unpredictable	-Fuel loads unchanged in short term without additional post-cut treatment -Small trees may be missed, which shortens treatment lifespan -*Phase 2 and 3:* High density of cut trees left on site can limit mobility of large herbivores and smother and kill desirable plant species. Invasive weeds can increase on warmer sites where perennial grass response is limited, but seeding may reduce weed risk. Leaving cut trees on site increases fire hazard and intensity especially in first two years before needles drop
Heavy Equipment: Masticator/Feller-Buncher 	**Cost:** $200–$500/ac **Influencing factors**: **Tree Density:** Cost increases with density of trees to be cut **Terrain:** Steeper slopes and rough terrain increase cost and can even prohibit use of machinery **Fuel Prices:** High fuel prices and remoteness of treatment site increase cost **Post-Cut Treatment:** Feller-buncher: Removing piles can increase cost. Removal of piles for firewood or biomass can reduce or eliminate post-cut cost	-Shrubs impacted, but mostly maintained -Precise treatment with ability to control target trees and cut boundary extent -Flexibility in timing of treatment -Slight risk of weed dominance due to disturbance, especially on warmer sites with limited perennial grasses -Mastication can be very effective in reducing fuel loads -Feller-buncher allows for bundling of cut tree piles facilitating post-treatment removal -Altered fuel structure can aid in fire suppression -Reduces need for additional post-cut treatment -*Phase 1 and 2:* Prevents loss of understory vegetation. Slight-to-moderate increases in production over time -*Phase 3:* May result in considerable increases in herbaceous production but response unpredictable	-Utility very limited in steep, rough or rocky terrain, roadless areas, and when soils are wet -Small trees and green limbs on downed trees often left, which shortens treatment lifespan -Piles or mulch chips can increase fire intensity if burned; risk of weeds and erosion can be reduced with seeding -*Phase 1:* Typically cost prohibitive for widely scattered trees -*Phase 2 and 3:* High density of chips or piles left on site can smother and kill desirable plant species. Long-term effects of mastication mulch is unknown. Invasive weeds can increase on warmer sites where perennial grass response is limited but seeding may reduce weed risk

A thorough inventory of the understory vegetation, site potential, and woodland stand condition are essential to treatment planning (Miller et al. 2014a). Practical considerations in choosing fire or mechanical methods are related to ease of implementation, cost, and desired treatment outcomes.

Predicting post-treatment response is most reliable in Phase 1 and 2 woodlands but becomes increasingly difficult as woodland development advances to Phase 3, especially when fire treatments are applied. Regardless of treatment technique or woodland phase, conifer removal increases the time of soil water availability in spring, which stimulates growth of shrub and herbaceous plants (Roundy et al. 2014b; Figure 4). On any site that has low perennial grass cover and invasive annuals before treatment, managers should expect to have more annuals after treatment. Fire increases risk of annual grass dominance more than mechanical treatments by increasing soil temperatures, soil organic matter decomposition, available soil nitrogen, and by setting back perennial grasses, which are critical to weed suppression. Site climatic conditions also affect annual grass resistance, as warmer and drier sites are typically less resistant than cooler and moister sites.

Seeding and Weed Control

Project planners should also consider the need for additional effort, including seeding and weed control, after removing trees. Warmer and drier sites, later phase conifer stands, and sites with depleted perennial grasses, are less resilient to disturbance and may be good candidates for post-treatment weed control and seeding. Sites with relatively high cover of perennial grasses and forbs that are treated mechanically do not typically need seeding. Prescribed fire or slash pile burning may increase the likelihood of invasive plant introduction so the need for weed control and seeding of slash piles should be evaluated, especially when fire severity is high. In some instances, it is also desirable to accelerate shrub recovery post-fire. Seeding and transplanting of sagebrush on appropriate sites has proven successful.

Post-Treatment Management

Given the cost of conifer removal, it is only good business to protect that investment. Management treatments are essentially designed to alter the trajectory of the ecosystem in order to produce a desired future condition. What happens immediately post-treatment can determine the structure and function of the site down the road. Since deep-rooted perennial grasses are key to site function, it is especially critical that management after treatment encourage their recovery.

Livestock grazing is one management activity common across the west that can influence perennial grass abundance and should be considered in project planning. Mechanically treated Phase 1 and 2 woodlands with intact understories may not require grazing deferment, assuming proper grazing was being implemented prior to treatment. Mechanically treated Phase 3 woodlands may require rest or deferment if the understory component is depleted. After fire or seeding, at least two years of rest is recommended; warmer and drier sites may require even longer periods of rest or growing season deferment during the critical perennial grass growth period (April-July).

Planning follow-up maintenance after conifer removal can extend the lifespan of the initial treatment. The first time a site is cut, and occasionally after burning, young trees, seed producing trees, and a conifer seed bank may remain on the site. Planning a maintenance cut five years after the initial treatment is a cost-effective approach that will extend the lifespan of projects for many decades.

Finally, it is essential to establish permanent monitoring points prior to treatment to evaluate site recovery over time. Photo points work exceptionally well for highly visual treatments like conifer removal. Additional monitoring of understory vegetation is valuable for determining if a site is still on the desired trajectory or if adjustments to management are needed.

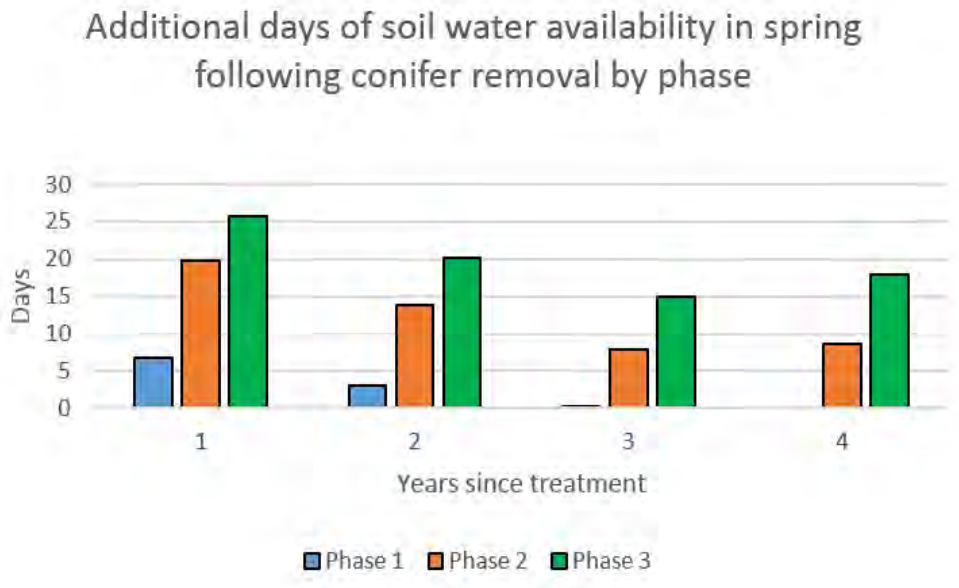

Figure 4. Days of soil water availability following tree removal. Tree removal by fire or cutting decreases canopy interception of precipitation and tree water use, which results in additional days of soil water availability compared to untreated areas (Roundy et al. 2014b). Additional water availability is greatest when trees are reduced at Phase 3. The additional soil water availability increases growth of perennial shrubs and herbs, but can also support cheatgrass growth on warmer sites.

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Fuel Breaks that Work

The Northern Great Basin (NGB) sagebrush steppe has undergone significant transformations in the last few decades. Formerly a shrub-bunchgrass community that was only periodically affected by wildfire, the NGB sagebrush steppe is now one of the most threatened ecosystems in the United States (Noss et al. 1995). Invasive grasses like cheatgrass (*Bromus tectorum*) and medusahead (*Taeniatherum caput-medusae*) are continually increasing, converting native sagebrush steppe plant communities into nonnative annual-dominated grasslands. In lower elevations of the NGB sagebrush steppe (below 4000 ft), the fire return interval has been reduced from 50 to100 years to less than 10 years in some places. These changes are having highly negative effects on sagebrush obligate species, including greater sage-grouse (*Centrocercus urophasianus*), which is being considered for listing under the Endangered Species Act.

Wildfires in the sagebrush steppe expand quickly and can affect hundreds of thousands of acres of sage-grouse habitat in a matter of days. For example the Long Draw (2012) and Buzzard Complex (2014) fires in southeastern Oregon both had multiple hundred-thousand-acre runs in a single burning period with a rate of spread between 10 and 15 miles per hour. To compound the problem, annual grasses that typically invade lower elevation sagebrush communities (below 4000 ft) are now expanding into mid elevations following wildfire. In cases where the perennial grasses and forbs have been depleted, these previously more resistant sagebrush communities have become susceptible to conversion to invasive annual plant dominance (Davies et al. 2011). Scientists and managers struggle with how to protect sagebrush habitat from wildfires that perpetuate the invasive annual/wildfire cycle.

In January 2015, Department of Interior Secretary Sally Jewell implemented Secretarial Order 3336 that builds on the National Cohesive Wildland Fire Management Strategy, and provides for policies and strategies for preventing and suppressing rangeland fire and restoring sagebrush landscapes impacted by fire. One method fire managers are using in the NGB to combat wildfires is the establishment of strategically placed fuel breaks. Fuel breaks are blocks or strips where fuels have been modified or reduced and are placed adjacent to discontinuous or altered fuel beds that are intended to reduce flame lengths and the rate of spread of oncoming wildfires. Fuel breaks can facilitate fire suppression efforts and reduce the loss of key sagebrush habitat.

Purpose: To provide a framework for the placement, use, and effectiveness of established fuel breaks for protecting sagebrush ecosystems.

In Brief:

- Established fuel breaks are a useful tool for managing the size and severity of wildfires.
- Managers recommend a holistic approach that includes education, monitoring, and maintenance to maximize the benefits of fuel breaks.
- Fuel breaks are useful for slowing and sometimes stopping fires, but can't alone be depended on to stop a wind-driven head fire.

Four main criteria for fuel breaks

- Landscape level considerations. Locate breaks in low to mid-elevation ecosystems that have low resistance to invasive annual grasses.

- Strategic level considerations. Locate breaks where necessary for firefighter access and safety.

- Timetable considerations. Plan construction so that breaks are there when you need them.

- Economic considerations. Use breaks as a long-term strategy to reduce the size and severity of wildfires.

BLM Fire Manager Interviews from Idaho, Nevada, and Oregon

Peer-reviewed literature on the effectiveness of fuel breaks in the sagebrush steppe is hard to find. Available research primarily addresses the protection of property, not the protection of habitat. Fire behavior models can't capture the combined effects of fire suppression and fuel breaks. Despite the lack of scientific information, firefighters routinely use (and require) fuel breaks in wildfire operations. Firefighters are able to observe the effectiveness of fuel breaks first hand. Using qualitative interviews, information from the fire line can be captured.

To glean that first-hand experience, fifteen interviews were conducted with fire managers – fuels and fire specialists and fire ecologists – who have worked in the NGB. They were interviewed from district offices across the network of BLM districts in the NGB – Boise and Twin Falls in Idaho, Elko and Winnemucca in Nevada, and Vale and Burns in Oregon. Managers were asked about the function, strategic placement, and effectiveness of different types of fuel breaks that had been used on their districts. Managers who were interviewed averaged 23 years of experience and each contributed substantial operational knowledge that normally goes unrecorded. Themes from the interviews are summarized below.

Function of an Established Fuel Break

Fire managers resoundingly agreed that the purpose of fuel breaks is to allow firefighters to actively engage in fire suppression in a safe, strategic manner without committing exhaustive resources to control or contain the spread of wildfire. The basis for constructing fuel breaks should be the expected fire behavior for a given fuel or vegetation type and the resource objectives that the fuel breaks are designed to protect. Fuel breaks in one form or another are constructed "on the fly" for every fire; these include basic hand lines, dozer lines, and retardant lines. Established fuel breaks apply the same concept as suppression fuel breaks, but are put in place before the fire so that firefighters can use them when wildfires occur.

Proactive fuel breaks (the enhancement of existing roads and vegetation manipulation adjacent to these roads) can constrain fire spread and augment suppression efforts by providing firefighters better access to the fire and safe locations to establish anchor points and engage in suppression.

By reducing the flame intensity (Figure 1) and the rate of spread, a fuel break can work as a fire suppression resource and allow firefighters to focus on areas of greater concern (e.g., key sagebrush habitat). Strategically placed fuel breaks help contain flanking and backing fires using fewer resources and provide safe anchor points to conduct burnout operations for combating head fires.

"*The main function of any fuel break is to break the fuel side of the fire behavior triangle (fuels, weather, and topography). The only leg of that triangle that we can manipulate or control is the fuels*."

–Lance Okeson, Boise District BLM Fuels AFMO

"Changing fire behavior from 12 to 15 foot flame lengths down to a 0 to 4 range gives them a fighting chance."

–Jason Simmons, Vale District BLM AFMO

Backing Fire: Fire spreading, or ignited to spread, against the wind or downslope. A fire spreading on level ground in the absence of wind is a backing fire.

Burnout Operations: Setting fire inside a control line to consume fuel between the edge of the fire and the control line.

Head Fire: Fire spreading or set to spread with the wind.

BEHAVE+: A system of interactive computer programs for modeling fuel and fire behavior, comprised of two systems: BURN and FUEL.

Flame Length Comparison between Mowed and Unmowed Sagebrush

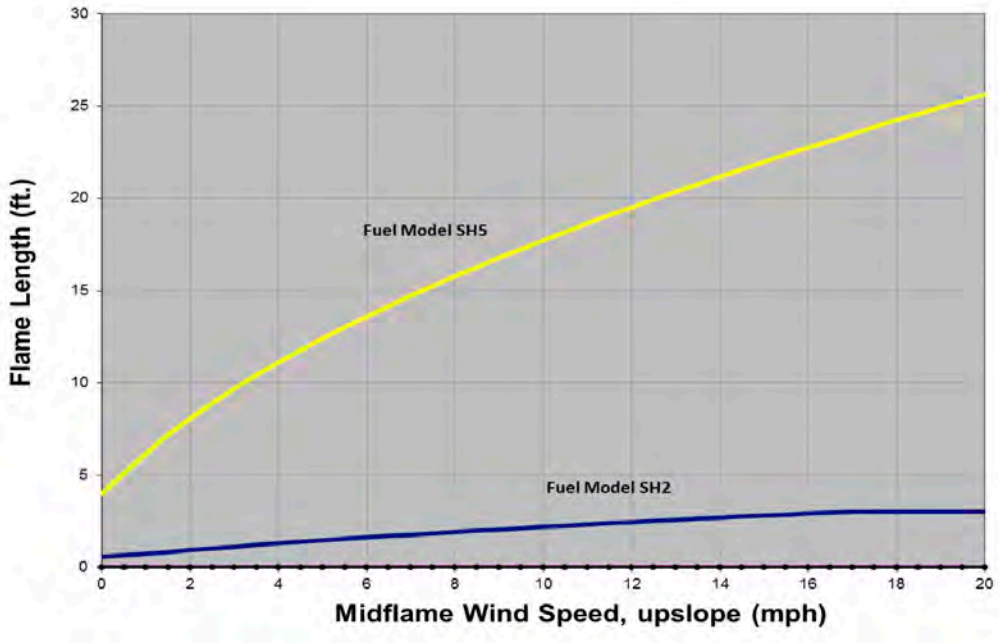

Figure 1. Flame length comparison between the typical sagebrush fuel model (SH5) and a representative model (SH2) for mowed fuel. The graph shows the results of the BEHAVE+ fire behavior model in typical summer conditions with a 20 percent slope.

Fuel Break Treatments and Parameters

Fire managers have used a wide variety of established fuel break types to help suppress wildfires in the NGB. Fuel break treatments and parameters are considered based on location, elevation, climate, values at risk and species of concern. In some cases, several treatments are used in combination to establish and maintain fuel breaks.

Road Maintenance: Roads have been the primary form of control lines and in some cases provide the only source for a fuel break. Clearing roads and adjacent roadbeds can be very effective for preventing and/or controlling rangeland wildfires, and is what firefighters use most of the time to help suppress wildfires. Road improvements alone, however, are not enough to suppress wildfires in heavy brush or during high wind events. All managers recommend combining fuel breaks with roads for better access to the fire and to limit the disturbance footprint.

"But we've had others, I was part of one…right here off the interstate…and we just had one little fuel break that went off I-84 … it tied into an existing road. It wasn't that long of a fuel break but it started in a place where we've had prior fire starts. Right on an interchange used as an exit pull off … All it was is just road improvements where we cleaned and widened the road… We turned a jeep trail into an actual fuel break and the fire was just 30 acres as opposed to the potential for something over 100. So I think they definitely had an advantage."

–Jason Simmons, Vale District BLM AFMO

Brown Strips Devoid of Vegetation: Disk lines are the preferred treatment for preventing wildfire starts along interstates and highways. Disk lines may range from 10 to 20 feet and are taken down to mineral soil. Boise, Winnemucca, and Vale districts all use disk lines adjacent to interstates to prevent human caused starts. Tumbleweed burning along fence lines is another method of creating brown strips. Brown strips were proven to be effective in preventing wildfires, though lack of continual annual maintenance was stated as a significant downfall to their use. But erosion potential is a concern on erodible soils or steeper slopes.

"For example, in 2012 just one of those fuel breaks along Highway 95 aided in the suppression of … I think it's six or eight fires that particular year."

–Mark Williams, Winnemucca District BLM Fire Ecologist

Mowed Fuel Breaks: Mowed Fuel breaks immediately adjacent to roads are the preferred treatment to limit wildfire size in or near intact sagebrush patches. Fire managers recommend mowing strips of at least 100 to 300 feet adjacent to roads on both sides, depending on live fuel loading and resource objectives. Mowed strips must be wide enough to break large-scale, wind-driven fires that can produce 30-foot flame lengths. Managers agreed that "the wider the fuel break, the better." Vegetation should be mowed down to 6 to 12 inches to be effective. Follow-up chemical treatments and drill seeding may be needed to prevent the spread of invasive plants. Selection of species to seed is a local decision based on soils, community potential, invasive species present, and management objectives. The advantages of mowing include maintaining native vegetation and the ability to set back fires if needed.

Winnemucca and Elko Districts use mow lines to protect key sagebrush habitat. Vale District uses a combination of mowing, disking, and chemical treatments.

Back fire: Intentionally setting fire inside the control line to slow or contain a rapidly spreading fire. Provides a wide defense perimeter and makes possible locating control lines where the fire can be fought on the firefighter's terms.

Figure 2. Example of fire behavior in a Wyoming big sagebrush vegetation type (SH5 fuel model).

Mowed fuel breaks adjacent to roads were an integral part in corralling the western flank of the Long Draw Fire in 2014. Mowing treatments require maintenance. Maximizing the control of sagebrush in initial treatments will maintain the integrity of the fuel break for a longer period.

"That same fuel break system stopped another two fires. Jackie's Butte fires, which ended up being about 15,000 acres. When we design those that were just outside that boundary, we were looking at compartmentalization."

–Jason Simmons, Assistant Fire Management Officer Vale District BLM.

Greenstrips: Greenstripping is the concept of strategically establishing fire-resistant vegetation to reduce the rate of spread and the intensity of wildfires. Greenstripping is a preferred method in areas that have undergone conversion to invasive annual grassland or areas highly susceptible to annual grass invasion. Strips 100 to 300 feet wide are recommended. The primary advantage of greenstripping is that once they are established they are long term fuel breaks that require limited maintenance. Another advantage is that properly timed livestock use can reduce cheatgrass thereby decreasing fuel continuity and lowering competition with seeded species, which can lengthen the period that the greenstrip plants remain green (Figure 3). Species selected for greenstripping should be fire and drought tolerant, palatable, and able to compete with annual species (Pellant 1994). Species selection for greenstripping is contingent on local conditions and management objectives. Introduced or native species can be effective depending on site conditions (Monsen 1994). Some introduced species have the potential to escape into native communities (Gray and Muir 2013), and species should be chosen carefully.

"I know the Murphy Complex fire … they actually mowed an existing green strip the year before and the crews used that area to burn out from and catch the north head of that fire. And talking to the IC (Incident Commander) that was out there, it did make a big difference because it had been mowed the year before. They can move a lot faster on their burnout operation."

–Brandon Brown, Fire Management Specialist, Twin Fall District BLM

Strategic placement

Fire managers agreed that access was the number one priority for strategic fuel break placement. By using existing road systems such as known fuel breaks, disturbance can be minimized and the initial response time to wildfires can be reduced. Managers recommended that placement of fuel breaks be tied to weather patterns and wind direction, fire frequency and land protection priority. Fuel breaks can be placed directly next to resources at risk in order to provide point protection. They can also be used to compartmentalize large intact sagebrush communities to minimize losses of landscape-scale vegetation. Fuel breaks should be continuous, well known, and most importantly, accessible.

"*The better bang for your buck is to put fuel breaks on a road system so your ground suppression resources can get there, especially in the sagebrush fuel type. If you have air resources, you could put one in and rely on maybe hand crews and aircraft. But to me that's not as effective."*

–Tom Reid, Elko District BLM Fuels Program Manager

Figure 3. A greenstrip in south-central Idaho grazed by livestock in early spring resulting in reduced cheatgrass and a longer effective period to reduce potential wildfire impacts.

Effectiveness

The main theme fire managers expressed regarding fuel breaks is that they are not show stoppers. "*You still have to show up to the fire,*" said Lance Okeson, Boise District BLM Fuels AFMO. Fuel breaks are designed to work in conjunction with fire resources (e.g., engines, water tankers, etc.) to stop fires. In most situations fuel breaks alone will only reduce the rate of spread and intensity of a wildfire. It won't put it out, but it can greatly increase the chances of containing a fire and can dramatically reduce the size and severity of wildfires. Managers agreed that fuel breaks will not slow down head fires under extreme conditions, but will dramatically reduce the spread rate of a flaming front under normal conditions. They also reported that fuel

breaks are extremely effective in controlling backing and flanking fires. Managers from all six districts gave several accounts of how established fuel breaks on their districts have been effective in reducing the size and severity of wildfires.

"It just takes your success rate from 40 percent to 80 percent and you don't see the bubble paint job and melted lights on the engine. When you don't have those fuel breaks, you're still trying to hold the same roads but it's going to take a dozer, eight engines and a crew to pull this project off and in the end they may or may not be successful, but I can tell you it puts firefighters in a greater exposure of risk."

–Dave Toney, Zone Fire Management Officer, Burns Interagency District.

Issues to consider when constructing fuel breaks

The main issues to consider when constructing fuel breaks include: wildlife concerns, invasive weeds, use of non-native plants, wilderness characteristics, jurisdictional boundaries and resource objectives. The fire managers we interviewed resolved most of these issues by effective scoping during the NEPA process, working with subject matter specialists, and using a science-based approach to maintain key habitat in sagebrush ecosystems. Although managers agreed that it is difficult to completely address all of the social and environmental issues related to fuel break construction, for them the benefits of reducing wildfire size and severity always outweighed the cost of disturbance.

Management implications

Established fuel breaks are a useful tool for managing the size and severity of wildfires. Fuel breaks need to be integrated with other natural resource management practices to maintain and restore sagebrush rangelands in the Northern Great Basin. *"It's not just fuel breaks, this is just one tool,"* said Brandon Brown, Fire Management Specialist, Twin Falls District BLM. Limiting large-scale wildfires helps break the invasive annual/wildfire cycle, and provides opportunities for improving the long-term viability of sagebrush steppe restoration. Managers recommend a holistic approach of education, monitoring, and maintenance to maximize the benefits of established fuel breaks.

Table 1. The BLM is currently using the Fuel Treatment Effectiveness database (FTEM) to track the effectiveness of fuel treatments. The list below is a compilation of fuel treatment effectiveness, including fuel breaks, in Oregon, Idaho, and Nevada and shows the percent of treatments (based on acres) that have been effective in changing fire behavior and controlling wildfires. Fires reported are BLM only.

	Did treatment Change Fire Behavior				Did Treatment Control wildfire?				
Year	No		Yes		No		Yes		Total
	Acres	%	Acres	%	Acres	%	Acres	%	
2006	0	0.0%	70	100.0%	0	0.0%	70	100.0%	70
2007	0	0.0%	8,442	100.0%	0	0.0%	8,442	100.0%	8,442
2008	0	0.0%	17,229	100.0%	150	0.9%	17,079	99.1%	17,229
2009	40	1.7%	2,250	98.3%	40	1.7%	2,250	98.3%	2,290
2010	142	7.1%	1,868	92.9%	142	7.1%	1,868	92.9%	2,010
2011	0	0.0%	10,933	100.0%	0	0.0%	10,933	100.0%	10,933
2012	259	0.3%	78,432	99.7%	3,776	4.8%	74,601	94.8%	78,691
2013	1,077	39.3%	1,666	60.7%	977	35.6%	1,766	64.4%	2,743
2014	2,600	12.7%	17,802	87.3%	1,681	8.2%	18,721	91.8%	20,402
Total acres and average percentage	**4,118**	**2.9%**	**138,692**	**97.1%**	**6,766**	**4.7%**	**135,730**	**95.0%**	**142,810**

Detailed Methods

Interviews were coded in agreement with qualitative grounded theory analysis (Struass and Corbin 2008) using NVIVO qualitative software version 10. Individual interview texts were read sequentially and text segments were inductively assigned open codes (simple words or phrases that summarize the theme of the segment). Texts coded with similarity in the previously mentioned categories (i.e. function, parameters, effectiveness etc.) were assigned themes. Themes common among fire managers are described in text.

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Wind Erosion Following Wildfire in Great Basin Ecosystems

Purpose: Wind erosion is a problem in Great Basin shrublands, particularly following large wildfires or other disturbances that remove the protective cover plants provide to soil. This factsheet aims to introduce the basic patterns, concepts, and terminology of wind erosion and to provide a basic framework for erosion risk assessment and response.

In Brief:

- Although soil stability is a major concern following wildfire, efforts to monitor, report, and evaluate wind erosion are rare. These actions are needed to respond to wind erosion events and to enable adaptive management.
- Wind erosion occurs in a variety of forms and impacts ranging from innocuous to severe, such as removal of topsoil, and degradation of downwind air, water, and land resources.
- A variety of indirect and direct methods can be used to measure soil stability, such as time-lapse photography, erosion bridges or pins, collectors that trap soil from passing air, and soil pedon classifications.
- Managers may reduce erosion impacts by avoiding destabilizing burned areas that are prone to erosion through treatments that further disturb soil or prolong bare soil exposure, and by avoiding putting investments like seedings and plantings where wind erosion may degrade them.

Soil resources and context for wind erosion in the Great Basin

Soil structure and function are important to the resistance, resilience, and overall function of semiarid ecosystems of the Great Basin, and soil erosion can have large ecosystem effects. Much of the Great Basin is flat or gently sloped, so erosion is often wind driven (aeolian or eolian) rather than water driven. Wind erosion occurs semi-regularly in playas, sand dunes, some salt desert sites, and croplands, but shrub and grasslands of the Great Basin usually do not have appreciable wind erosion in their undisturbed state. In fact, soils in sagebrush steppe often have a loam component that is at least partly comprised of loess derived from long-term aeolian deposition. However, very high levels of erosion can occur in sagebrush steppe (and related grass or shrublands) following major disturbances, such as large wildfires or cheatgrass die-off (Sankey et al. 2009).

Episodic erosion and redistribution of soils can have significant impacts on sites where soil is lost or redistributed, and on downwind air, water, and land resources. Wind erosion has led to loss of topsoil from burned sagebrush steppe, reducing critical organic matter, nutrients, and hydrological permeability of eroded sites and polluting downwind airsheds (Hasselquist et al. 2011, Ravi et al. 2011). However, not all sites are "damaged" by erosion. Sites in good ecological condition with higher resilience experienced appreciable post-fire wind erosion, yet had only minimal loss of the desirable perennial species and patterning of plants and soils that are important to ecosystem function (Hoover 2010).

The Bureau of Land Management's Emergency Stabilization and Rehabilitation (ESR) program makes appreciable investments into plant and soil treatments with the stated objective

Episodic erosion in the Great Basin can have significant impact on sites where it occurs, as well as downwind air, water, and land resources.

of stabilizing soils. Many of these treatments are in low-elevation, dry, and flat areas that normally support Wyoming big sagebrush and have low resilience to disturbance. However, awareness and understanding of the magnitude of erosion after large wildfires and post-fire rehabilitation in these and other Great Basin shrublands are still in development. Aside from occasional estimates of potential soil loss, direct monitoring or reporting of soil stability is rare on ESR or other restoration projects. This factsheet describes key points for assessing the risk and occurrence of wind erosion.

Awareness, detection, and measurement of wind erosion

Generally, some wind erosion is inevitable following wildfires, as combustion leaves a layer of lightweight, buoyant char and ash that is easily swept away by wind. Of greater concern to management is severe wind erosion that removes inches of topsoil before vegetation recovers after fire. Identifying the potential for erosion, and evaluating any initial erosion, can help managers plan post-fire treatments and explain treatment outcomes in project reporting. Managers need to measure actual erosion rates to evaluate the stability of soils on a site.

A range of methods for monitoring wind erosion are available to land managers, and they differ considerably in cost, sophistication, and in how directly they measure soil movement (Zobeck et al. 2003). Satellite imagery (MODIS AQUA or TERRA, or LANDSAT) or radar imagery (NOAA National Weather Service) can be used to view dust plumes or haboobs if they are sufficiently dense (Figure 1; Wagenbrenner et al. 2012). Highway cameras or automated game cameras capable of time lapse photography can provide another way to observe dust in particular landscapes and relate it to weather records. Repeated aerial photographs (or imagery such as Geoeye ®) can allow identification of areas where black charring is lost more quickly after wildfire due to relatively greater erosion.

Transport modes in wind erosion

Several different terms are used to explain how soil moves (Figure 1). Creep refers to the rolling of large particles short distances. Saltation refers to the bouncing of sand-sized particles across the landscape – up to about 300 foot (100 m) distances with 3 to 6 foot (1-2 m) heights in each bounce. Suspension refers to lofting of buoyant silt and clay-sized sediment into the air for longer-range transport. These smaller particles comprise dust, or particulate matter. Each saltating particle causes movement or loosening of more sand, silt, and clay particles through momentum and static electrical effects. Saltation is considered central to all modes of erosion, and it imparts a cascading effect in which erosion begets more erosion downwind. The increase in the amount of soil moving downwind has been compared to lateral landslides following large wildfires in the Great Basin.

Suspended particles may move in a diffuse haze, or denser clusters of various forms. Dust devils are most common, but they generally redistribute small amounts of soils within sites, and typically are not indicative of appreciable erosion. Dust plumes are similar in form to smoke moving downwind, and are indicative of more intense erosion and site impacts, often extending hundreds of miles beyond burned areas. Perhaps the most intense short-duration movement of soils are dense walls of lofted soils known as haboobs, which are well known in warmer deserts but have recently been observed in the cold desert of the Northern Great Basin. A haboob traveled with the outflow of a collapsing thunderhead from the 560,000 acre Long Draw fire in southeast Oregon and northwest Nevada and delivered record particulate matter levels to a three-county area including Boise, Idaho (Figure 2).

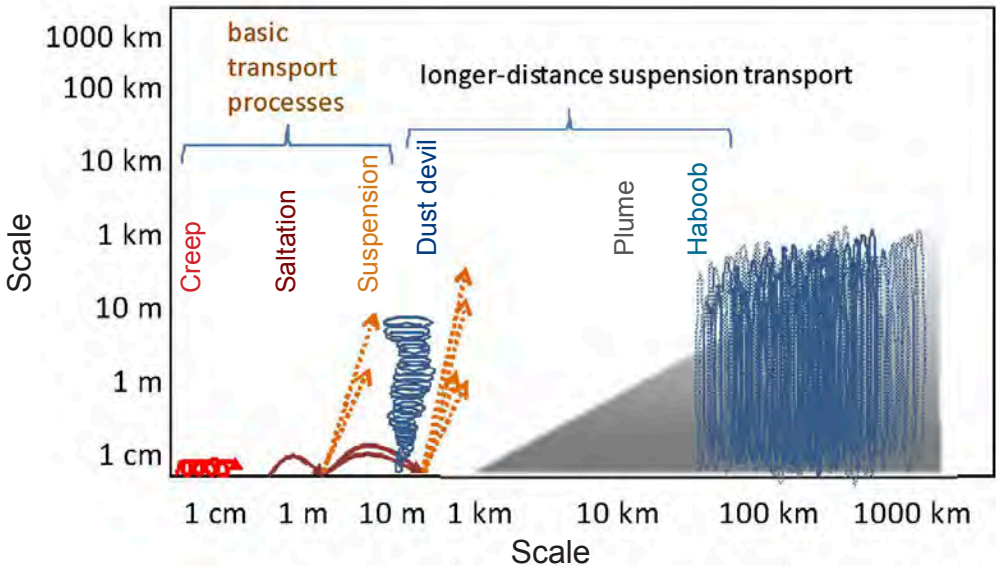

Figure 1. Depiction of the scale of the three modes of sediment transport by wind (creep, saltation, and suspension), and three primary means of medium to long-range transport of suspended sediment (dust devil, plume, and haboob). Scales shown are generalized and refer to height and downwind distance of impact. Colors match terms to specific transport types.

Changes in the amount of soil (lost or gained) over time can be assessed directly using a ruler relative to fixed pins (erosion bridges or nail-and-washer technique, e.g. Sankey et al. 2010). Past erosion can be inferred from soil "pedoderm" classifications and loss of the dark color of soil that is associated with organic matter (Burkett et al. 2015, Hasslequist et al. 2011), or from pedestalling of plants as soil is eroded from around their roots (Figure 2). Also, several direct but more sophisticated measurements of soil movement exist, including measurement of: 1) creep, with simple PVC pipe traps that have openings at the soil surface; 2) saltation, passively over longer times with collectors that trap sediment as air flows through them (e.g., BSNE or MWAC collectors, see Sankey et al. 2009) or actively in real-time with an electric sensor (e.g., Sensit©) connected to datalogger; and 3) suspended dust (particulate matter, usually 2.5 or 10 µm), with standard air-quality sensors (e.g., Met-One Esampler, Wagenbrenner et al. 2012). Erosion bridges and dust collectors (BSNE) have been used by agency field offices (BLM), while the other techniques listed above, as well as advanced remote sensing (Lidar), have been applied to a number of ESR projects by researchers.

Predicting where and when erosion risks are likely after disturbance

Factors to consider in assessing erosion risks include climate and weather/wind forecasts, overall site condition and resilience, upwind saltation sources, and any downwind concerns such as cities and intact vegetation (e.g., Miller et al. 2015). Erosion requires erosivity (wind, lack of plant cover), erodibility (loose, buoyant soil), and a sustained supply of erodible soil to the airstream. High winds are a function of local convection driven by temperature equilibration, thunderstorms, cold fronts or storm fronts, and regional weather patterns.

Vegetation cover protects the soil surface from the shear stresses of wind. Wind erosion usually occurs in the first nine to ten months after a wildfire when the soils are bare and the vegetation has yet to recover. Threshold amounts of plant cover for wind erosion have been determined for sagebrush steppe for only one site (Sankey et al. 2009), and several indicators suggest that the type of vegetation before and after fire is important. Sites where shrubs existed before fire produce the greatest erosion, but intact shrub stands provide significant protection from erosion (Sankey et al. 2012).

Figure 2. Effects of a haboob that occurred after the 560,000 acre Long Draw Fire in southeast Oregon and northwest Nevada in 2012. The top photo shows National Weather Surface RADAR imagery; dust is outlined by an ellipse and arrow shows path of travel and state boundaries are shown for reference. The middle photo is of the same haboob on the ground. The bottom photo shows burned and pedestalled sagebrush after several inches of soil, including all topsoil, were eroded in the month following burning (108,000 acre Jefferson Fire in south central Idaho in 2010).

Perennial grasses or cheatgrass that resprout or germinate in fall can shorten the number of months that soils are bare and exposed to wind after wildfire. High burn severity that results in high plant mortality increases erodibility, but mapping burn severity is challenging in sagebrush sites.

A wide range of soil types can be eroded, regardless of their sand or clay content, degree of particle aggregation (slaking, or aggregate breakdown in water), or "K" value assigned to the soil mapping unit in the USDA Natural Resources Conservation Service, Web Soil Survey and Soil Data Viewer (USDA NRCS 2013). Biotic soil crusts, physical crusts, and gravel or other highly aggregated soil surface conditions inhibit erosion (Ravi et al. 2011). However, sediment supply can increase as a result of factors that loosen soil, such as physical disturbance from hooves, tires, and rain or hail. Saturated soil surfaces have low wind erodibility. However, erodibility has complex responses to sub-saturated soil moisture, and can either increase or decrease following rain (Sankey et al. 2009).

Landscape-scale factors are very important for predicting wind erosion on rangelands. Erosion of sites that are otherwise stable can be induced if the site is bombarded by saltating particles originating upwind. Many rangelands are flat and have long wind fetches that lack hills, gullies, or waterways that disrupt the continuity and cascading of saltation flow. Thus, larger and flatter burned areas can exhibit greater erosion per unit ground area and have appreciable erosion events.

Several quantitative models are available to simulate and predict erosion, but probably are not practical for most field office or district level applications such as ESR projects. The USDA Wind Erosion Equation (WEQ), which crudely predicts erosion based on an index of soil erodibility, surface roughness, fetch, and vegetation cover, has been replaced by the more sophisticated and resolute Wind Erosion Prediction System (USDA NRCS 2014). These and other models require substantial parameterization efforts to validate them in burned sagebrush steppe. In semiarid ecosystems of the Great Basin a better approach may be coarser mapping of erosion risk that excludes non-erodible surfaces (e.g., gravel or firmly crusted soils) and uses topography and weather forecasts to predict high wind exposure and connectivity of wind and saltation flow.

Management actions

If wind erosion becomes appreciable on large burn areas, there is often little that can be done to control it, and so managers are left with focusing on 1) assessing where and when erosion risks are greatest, 2) avoiding actions that worsen the erosion and associated resource losses, and 3) protecting small areas or features from erosion. A primary management concern is often protecting staff and the public from dust storms, which reduces visibility and has caused highway fatalities and respiratory stress. Post-fire management actions to address wind erosion, including deferral of soil-disturbing treatments, may also be rationalized based on protection of human health and safety or loss of seedings. Use of rangeland seed drills, chaining or harrowing can impact the soil surface and influence erodibility, but longer term enhancement of perennial vegetation and reduced fire may offset the initial erosion risks posed by these treatments. Wind erosion may complicate the effectiveness of post-fire treatments, particularly through seed loss or transport of herbicide to non-target areas. Unfortunately, direct monitoring of soil stability and wind erosion is rare for post-fire treatment projects in the Great Basin. Also, few research projects have assessed whether or not soil-disturbing treatments implemented after fires have a net stabilizing effect on soils, and those projects show mixed results (Miller et al. 2012, Germino, in prep).

Based on the available information, several considerations are provided for implementing restoration/rehabilitation projects after wildfire in areas where wind erosion is a threat. Further assessment is needed to test their effectiveness across the Great Basin:

- It is important to consider net risks and benefits of actions that may destabilize soils (e.g., vehicle traffic on burned areas, soil disturbances associated with seeding). If soil disturbances are necessary, they can be guided by developing provisional wind-erosion risk maps.
- If seed drills are necessary, using imprinting or minimum-till drills and avoiding disking (particularly parallel with wind direction) may be advisable depending on site conditions.
- Use of species with larger and heavier seed, combined with seed burial, may result in less seed redistribution by wind after seeding. Also, perennials that tiller or form adventitious roots may be more adapted to shifting soils (e.g., western wheatgrass).
- On sites dominated by invasive annual grasses, a two-step process could be tested in areas with greater than ten inches of precipitation in which a sterile cover crop (e.g., winter wheat) is used to stabilize soils and preempt annual grasses, and then desirable perennials are later seeded into its stubble (Jones et al. 2015).
- In situations where drought may prolong erosion past the first post-fire year, rows of seeded or transplanted shrubs interspersed with bunchgrasses could be tested as semi-natural wind fences to reduce downwind erosion for small areas.
- Undesirable species like cheatgrass may quickly provide a net stabilizing benefit if left untreated after wildfire, although longer-term risks of low plant cover may result from drought, stand failure (die-off), probability of reburning, and fire spread beyond the impacted area.

- Artificial wind protection such as plastic snow fences or rows of straw bales can be cost effective for reducing erosion or drifting onto roads for areas up to a few acres. Fencing that allows plantings to establish may be particularly worthwhile.
- Soils may be stabilized locally through spraying polyacrylamide (FC2712) onto the surface or applying heavy mulches (wood chips), but these approaches are not well tested and are not economical over large areas.

The magnitude of wind erosion after large fires in the recent decade is a significant problem in the Great Basin, and information to help guide risk assessments and treatment plans is becoming available. Due to the lack of previous assessments and dearth of knowledge, most new management actions targeting wind erosion will have an experimental aspect to them. Monitoring and adaptive learning about wind erosion on ESR and related projects, including monitoring of soil movement and changes, are key steps forward.

Any use of trade, product, or firm names is for descriptive purposes only and does not imply endorsement by the U.S. Government.

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Post-fire Grazing Management in the Great Basin

Purpose: To provide guidelines for maintaining productive sagebrush steppe communities in grazed areas after fire. The focus is on plant communities that, prior to fire, were largely intact and had an understory of native perennial herbaceous species or introduced bunchgrass, rather than invasive annual grass.

In Brief:

- Following fire, grazing should not resume until site objectives have been met; at a minimum, surviving perennial grasses must have regained productivity and be producing viable seed at levels equal to grasses on unburned sites.
- During the first years after grazing resumes, grazing should be deferred until later in the season after seed maturity or shatter to promote bunchgrass recovery.
- Once grazing resumes, a rotation system (rest, deferred, or decisional) is recommended for maintaining plant production, cover, and appropriate species composition.
- Careful monitoring and assessment is required to determine when grazing may be resumed, whether post-fire grazing management has been effective, and if changes in grazing management are needed.

Recovery of sagebrush steppe communities after fire

Increasing wildfire size and frequency in the Great Basin call for post-fire grazing management practices that ensure sagebrush steppe communities are productive and resilient to other disturbances, such as drought and plant invasion. Successful post-fire recovery hinges on the growth, reproduction, and recruitment of perennial understory plants, especially bunchgrasses. Perennial grasses provide livestock forage and wildlife habitat, increase resistance to exotic annual grass and broadleaf weed invasion, and assist with soil stability and hydrologic function. Although sites may

Figure 1. Wyoming big sagebrush sites in eastern Oregon (about 11 inches of annual precipitation) with an intact understory of perennial bunchgrasses. Left: A site where management objectives had not yet been met and resting from grazing continued. Right: A site where bunchgrass recovery and soil stability objectives had been met and grazing was resumed.

be managed for a suite of different site-specific objectives, achieving adequate grass production sets the stage for long-term recovery for the rest of the plant community.

Indicators of post-fire recovery:

- Surviving perennial grasses have regained productivity and reproduction
- There is successful recruitment of new perennial plants
- The land has sufficient cover of perennial plants, surface litter accumulation, or cover of biological soil crusts to stabilize soil surfaces

How long should burned areas be rested or deferred from grazing?

Both grazing and clipping studies indicate that it takes bunchgrasses at minimum one to three years to recover to pre-fire conditions and two to three years to produce high quantities of seed in the sagebrush steppe (Bates et al. 2009; Bunting et al. 1998; Jirik and Bunting 1994; Roselle et al. 2010). Grazing rest and deferment schedules should be used to manage the recovery of bunchgrasses and other herbaceous species after fire. Failure to implement a program of grazing rest or deferment may slow recovery (Kerns et al. 2011) and promote undesirable plant species. The rate of perennial grass recovery at a given site will depend on site conditions. In particular, recovery may be slower in lower elevation areas and under low precipitation (Knutson et al. 2014) and may therefore require an extended rest period. Sites with inadequate seedbed conditions, exposed soil, or erosive soils may require an increased post-fire recovery period before resumption of grazing to prevent soil loss.

Rest and deferral recommendations:

- Site conditions, post-burn weather, and the abundance of perennial grasses should always be considered when determining the length of grazing deferment or rest.
- Resting after fire until plants are producing seeds and then resuming grazing only after seed shatter is highly recommended to increase plant production and litter cover. This may require two or more growing seasons following fire.
- Rest or deferment into the third year (or beyond) should be considered if surviving or seeded bunchgrasses have yet to vigorously produce viable seed and biomass. This may be particularly important on relatively warm and dry sites and during drought.

A note about high severity fires:

High severity fires result in excessive mortality of bunchgrasses and increased risk of soil erosion. The goal of a grazing program remains the same – to promote perennial grass recovery, particularly bunchgrasses. High severity fires may require an extension of rest or deferment periods to allow perennial grasses to recover, soils to stabilize, and new seedlings (natural recruits or planted) to establish. Because fire severity will vary within a landscape, grazing deferment should continue until the most severely impacted areas have recovered.

How should burned areas be grazed?

Because site-specific conditions must always be considered, there are no universal rules for managing post-fire plant communities. However, once the decision is made to return livestock to the range, managers must consider how grazing season, intensity, frequency, and duration may affect ecosystem recovery of a burned site.

Season:

Season of use can have long-term effects on relative abundance of perennial grasses, shrubs, and invasive plants and, thus, resilience to fire and resistance to invasive annual plants. Season of use, therefore, should be carefully considered when developing grazing plans for sagebrush steppe communities (Burkhardt and Sanders 1992). Grazing and

Table 1. Useful indicators of post-fire site conditions, which should be compared to reference conditions.

Soils	Plants
• Amount of bare ground • Number of rills and gullies • Presence of pedestals or terraces • Presence of wind-scoured, blowout, and/or depositional areas • Resistance to erosion	• Community composition • Presence of functional/structural groups • Degree of plant mortality/decadence • Annual production • Presence and density of invasive plants • Reproduction by perennial plants • Litter amount

Adapted from: Pellant, M., P. Shaver, D. A. Pyke, and J. E. Herrick. 2005. Interpreting Indicators of Rangeland Health - Version 4: Bureau of Land Management, National Science and Technology Center Technical Reference 1734-6.

defoliation during the active growing season (approximately April through June or July) in the first two or three years post-fire can increase bunchgrass mortality and reduce plant recovery (Bunting et al. 1998; Jirik and Bunting 1994). Once post-fire grazing resumes on a site, use should be **deferred until after seed maturity or shatter** to promote bunchgrass recovery (Bates et al. 2009; Bruce et al. 2007). This is especially important in the first years after grazing resumes.

Intensity:

Once grazing resumes, general grazing recommendations in unburned areas are for no more than 50 percent utilization during active growth, and no more than 60 percent during dormancy (Guinn and Rouse 2009). Under certain conditions (e.g., in warm or dry areas, after high severity fires, or during low precipitation years), even **lower utilization may be required** to allow perennial grasses and soils to recover. In cooler, moister areas, deferred rotation combined with **low to moderate stocking rates** (less than 50 percent utilization) may be as effective as short- and long-term rest (Bates and Davies 2014). Long-term (30 year) studies of post-fire recovery indicate that, even under moderate growing season grazing, sagebrush dominance will increase over time, (Harniss and Murray 1973, Hanna and Fulgham 2015), which ultimately can decrease the resilience of these communities.

Frequency and duration:

Although local conditions will determine the specific deferment schedule required for rangeland recovery, **a rotation system (rest, deferred or decisional)** is recommended for maintaining plant production, cover, and appropriate species composition on sagebrush steppe rangeland (Table 2). General grazing guidelines developed by Guinn and Rouse (2009) for unburned areas recommend that pastures be grazed a) no more than half of the growing season, and b) no more than in one of three years during the growing season for native bunchgrasses and in two of three years for introduced bunchgrasses. **Post-fire grazing after rest or during deferment periods may need to be lighter** than the aforementioned recommendations because **newly seeded and surviving plants are at risk of repeated defoliation** due to animal preference for foraging in burned areas. Options for mitigating livestock distribution problems in large grazing units include fencing, herding, and strategic placement of water, salt, and supplements.

Monitoring

Careful monitoring and assessment will assist managers in determining when grazing can be resumed, evaluating the effectiveness of post-fire grazing management practices, and deciding if adjustments in grazing management are required. Sites should be monitored for utilization levels of perennial grasses and other plants, relative composition of perennial grasses and forbs, invasive annual grasses and forbs, shrubs, as well as species of interest such as those that are threatened and endangered. Sites also should be monitored for indicators of the three main attributes of ecosystem health: soil and site stability, hydrologic function, and biotic integrity.

Regular monitoring and assessment will allow managers and ranchers to adaptively manage grazing as conditions change in the post-fire environment. The effects of post-fire grazing management may not be detectable in the first few years after a fire (Bates and Davies 2014), so it is important that monitoring and adaptive management be carried out over time. Any downward trends in perennial grasses

Table 2. Typical grazing systems used in sagebrush-bunchgrass range of the Great Basin, along with their implementation requirements and suitability. For more information on grazing systems see: Holechek, J. L., R. D. Pieper, and C. H. Herbel. 2007. Range Management: Principles and Practices. Upper Saddle River, NJ: Prentice Hall.

Grazing System	Implementation Requirements	Suitability
Rest Rotation Grazing	*Minimum of three pastures* • One full year of rest on at least one pasture • Plants set seed two out every three years in each pasture	• Sagebrush-bunchgrass range • Rough topography
Deferred Rotation Grazing	*Minimum of two pastures* • Deferment provided during period when plants are most grazing-sensitive on one or more pastures and on a rotating basis	• Sagebrush-bunchgrass range • Rough topography • Riparian
Decisional (Rotation) Grazing (e.g., seasonal suitability)	*Multiple pastures* • Rest or deferment of pastures on a rotating basis - Designed mainly to graze prior to plants' sensitive period - May be incorporated into rest or deferred rotation systems - Stock moved based on seasonal forage production	• Sagebrush-bunchgrass range • Rough topography, especially with strong elevation or precipitation gradients, variable ecological sites or conditions

and forbs, or failure to maintain other recovery objectives, such as limiting invasive plant cover, would indicate that grazing management practices should be modified to promote resilient plant communities.

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Establishing Big Sagebrush and Other Shrubs from Planting Stock

Reestablishment of big sagebrush and associated native shrubs following wildfire or other disturbance is critical to facilitate vegetation recovery and to provide community structure and services. Poor establishment of shrubs from seed can result from several factors, including adverse environmental conditions, herbaceous competition, the use of maladapted seed, and inappropriate seeding strategies (Monsen and Stevens 2004). The use of planting stock can circumvent some of these problems (Shaw 2004, see graphic below).

Planning and Site Preparation

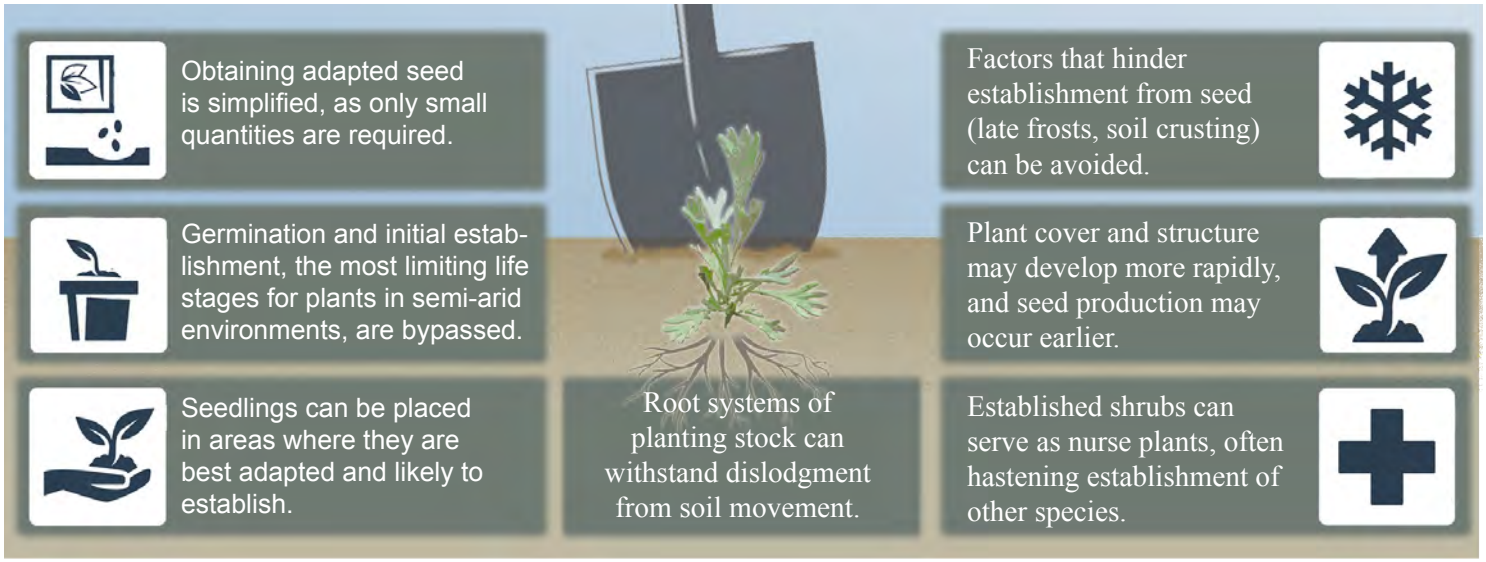
Project planning requires knowledge of site history and of pre- and post-disturbance vegetation composition. This aids in the development of management objectives to address site-specific constraints and revegetation timelines. Plan development should include stratification of the site by relatively homogeneous units based on these and additional factors (e.g., slope, aspect, soil conditions). This will aid in identifying appropriate species and sources of materials, as well as the number and size of plants required. Project areas where planting stock may be considered include post-fire landscapes, cheatgrass (*Bromus tectorum*) and crested wheatgrass (*Agropyron cristatum* complex) monocultures, and mining and energy development sites where rapid soil stabilization is required. Depending on site constraints, budget, and project

Purpose: Bareroot or container seedlings can be used to quickly re-establish big sagebrush and other native shrubs in situations where direct seeding is not feasible or unlikely to succeed. Guidelines are provided for developing a planting plan and timeline, arranging for seedling production, and installing and managing outplantings.

In Brief:

- The use of seedlings can avoid problems like adverse environmental conditions, competition from herbaceous plants, and unsuccessful seedings.
- Knowing your site is key, including information about vegetation composition, slope, aspect, and soil conditions.
- Selecting nurseries based on experience with the target species, type of planting stock required, and location relative to the planting site is essential.
- Proper planting technique and root placement is critical to the long-term survival and growth of bareroot seedlings.

Dodging Plant Demise: Some of the Benefits of Using Sagebrush Seedlings



size, the following recommendations can be implemented to improve planting success (Shaw 2004, Wirth and Pyke 2011, Davidson 2015):

- Use species and populations adapted to site conditions. On severely disturbed sites, early seral species may be more appropriate than late seral or climax species present in pre-disturbance vegetation.
- Use furrows, pits, and mulches to collect and retain water in arid areas.
- Provide supplemental water via remote irrigation methods to establish seedlings on very arid sites or to maintain seedlings during unusually dry seasons.
- Inoculate seedlings with appropriate species of mycorrhizal fungi, if available, to increase initial plant growth and survival.
- Use erosion control structures, such as weed-free straw wattles, to reduce soil and water erosion and to provide protection for seedlings.
- If high soil surface temperatures are expected, select protected microsites and use planting stock with large stem diameter and high root-to-shoot ratios. Temperatures greater than 130 ^{o}F near the soil surface can be lethal to phloem and cambial cells.
- Retain shade (e.g., taller woody and non-woody plants, post-fire standing dead shrubs) during site preparation, but plant seedlings on microsites from which vegetation has been removed.
- Use mechanical or chemical site preparation treatments to reduce competing vegetation.
- Minimize frost heaving by planting larger seedlings, covering the root plug of container seedlings with native soil, and providing a cover of sod, litter, or debris.
- Protect seedlings from late frosts by avoiding frost-prone sites, establishing strips of rock or vegetative mulch to protect developing species, and retaining insulating ground cover material.
- Prevent damage from both above and belowground herbivory (e.g., pocket gophers feeding in the root zone and browsing by jackrabbits, other small mammals, and big game species) (Figure 1).

When designing planting configuration for each project area, consider seed dispersal characteristics, site fragmentation, understory weed cover, and plant survival probabilities. Seedlings can be planted in random patterns or in clusters or islands, using mixtures of species to create natural-appearing stands. Maximal distances between plants or islands should be based on pollination considerations. Logistical and cost considerations should also inform seedling densities and patterns. As an example, the recommended density and distance between individual plants for big sagebrush is 190 plants per acre (16 foot spacing) to 2,700 plants per acre (4 foot spacing) (Wirth and Pyke 2011). In most cases, expect density to increase over time from natural seeding.

Figure 1. Ridged mesh tubes may be used to prevent aboveground seedling herbivory.

Because most shrub seedlings are slow-growing compared to grasses, survival percentages may be reduced and time to maturity may increase substantially if they are planted with seeded grasses or amid competing weedy species. This problem may be alleviated by planting seedlings in microsites from which herbaceous competition has been removed. Organic or plastic mulches may be used to control competition in windbreak or cluster plantings.

Seed Requirements: Quantities, *Sources, and Storage*

Only small quantities of seed are required to produce planting stock for most projects. Seed requirements are calculated based on the number of seeds per pound of pure seed, seed purity, germination, and nursery-specific culling and mortality rates. At the Lucky Peak Forest Service Nursery near Boise, Idaho, a conservative production estimate for big sagebrush, a small-seeded species, is about 100,000 seedlings from 1 pound of cleaned seed (purity > 80 to 90%, germination > 90%, 2.0 to 2.3 million seeds per pound of pure seed, depending on the subspecies). For antelope bitterbrush, a

large-seeded species, the production estimate is about 10,000 seedlings per pound of cleaned seed (purity > 95%, germination > 85%, 15,750 seeds per pound of pure seed, Bonner and Karrfalt 2008, J. Sloan, personal communication). Because production estimates vary among nurseries, it is essential to consult with nursery personnel to determine seed requirements for growing seedlings of individual species.

In or near fire-prone areas or other sites where restoration is anticipated, it makes sense to maintain seed collections from local populations. These collections can be cleaned and tested in advance and kept in storage until needed (Bonner and Karrfalt 2008). Developing a seedbank for seedling production requires little storage space and ensures that seed supplies will be immediately available even during poor seed production years. Planning for collection by provisional seed zone will help to ensure that adapted sources are available for propagation (Bower et al. 2014). If seed is not available, seed collection during the appropriate season for each species must be added to the project planning timeline. In the case of big sagebrush, it is important that the appropriate subspecies be harvested. Geneticists and plant material specialists can aid in selecting appropriate species and populations.

Seed of many Intermountain West shrub species can be stored under ambient conditions in warehouses for two or three years, often longer. A few species (e.g., big sagebrush, winterfat [*Kraschenninikovia lanata*], and rabbitbrush [*Ericameria* spp. and *Chrysothamnus* spp.]), however, are short-lived and require storage in moisture-proof containers at low relative humidity and temperature conditions. Bonner and Karrfalt (2008) provide storage requirements for many shrub species.

Propagating Plant Materials

Nurseries should be selected based on experience with the target species, type of planting stock required, and location relative to the planting site. Private and state nurseries produce seedlings under contract or on a speculation basis for the private and public sector, but there are some restrictions on state nurseries. Federal nurseries produce seedlings under contract for federal and state agencies.

The goal in seedling production is to produce stock that best fits environmental conditions at the planting site. Both container and bareroot seedlings of big sagebrush and other shrubs can be grown and outplanted successfully (Figure 2, Bonner and Karrfalt 2008, Dettweiler-Robinson et al. 2013, McAdoo et al. 2013). There are advantages and disadvantages to the use of each. As examples, container seedlings are generally more costly, though differences vary among species and nurseries. Some species, however, are easier to grow as container stock and the production period may be shorter. Nursery personnel can aid in determining seedling types, sizes, and production specifications to provide suitable high-quality planting stock.

Specifications should be included in contracts to guide grading and culling. Specifications are usually morphological (e.g., height, root length, stem diameter, dry weight, root-to-shoot ratio) because these traits are visible and generally easy to measure (Landis et al. 2010). At the Lucky Peak

Figure 2. Propagation of big sagebrush seedlings at the Lucky Peak Forest Service Nursery near Boise, Idaho: A) bareroot seedlings field seeded in May for fall harvest, and B) greenhouse-grown container seedlings about five months post-planting.

Forest Service Nursery near Boise, Idaho, for example, the standard specifications for Wyoming big sagebrush container seedlings produced in 6.3 in^3 tubes are: 6-inch height, 8-inch root length, and .08 inch stem caliper (C. Fleege, personal communication). Other measurable characteristics are physiological (e.g., dormancy level, measurements of stress resistance such as cold hardiness or root growth potential). Recommendations for use of larger containers or production of larger bareroot stock may be made if plantings are targeted for unstable or dry sites or in situations where more rapid development is essential.

The time requirement for seedling production varies with species, stock type, seedling size, and nursery location. Bareroot stock of many shrub species, including big sagebrush, can be produced in one growing season (Figure 3), but some slower-growing species require two or sometimes three growing seasons (Bonner and Karrfalt 2008). Bareroot seedlings are harvested when they are dormant in late fall and can be fall planted in some areas or held in cold or freezer storage over winter for spring planting. Container stock of many species can be produced in one year or less, with schedules varying among nursery facilities. Seedlings can be hardened off and stored outdoors or kept in cold or freezer storage until planted.

Planting

When to Plant

Selection of planting dates depends upon the species and planting location. Cool, overcast, humid days with light rain or snow provide optimal planting weather. Bareroot and container stock of shrub seedlings have been spring planted throughout the Intermountain West where adequate spring moisture occurs. Seedlings must be held in a dormant or hardened condition and planted before native plants of the same species at the planting site break dormancy. Non-dormant stock must be planted after danger of frost has passed, which may not occur until soils have begun to dry. In spring, drier, low elevation areas see rapid increases in daytime temperatures, which may result in water stress and plant mortality unless seedlings receive supplemental water.

Fall planting can be successful in areas with mild climates if soil temperatures and water availability permit development of new roots before winter (Wirth and Pyke 2011). Supplemental watering is essential if the soil is dry. Seedlings need adequate time for root development before the onset of cold weather. If root development does not occur before the ground freezes, the seedlings are left poorly anchored and vulnerable to frost heaving.

Planting Techniques and Tools

Proper planting technique and root placement is critical to the long-term survival and growth of seedlings. When planting bareroot stock, the roots should be placed vertically in the planting hole and fanned out against its wall. For container stock, careful handling is advised to maintain the integrity of the soil around the root plug. Seedlings should not be planted too high and root plugs should be covered with native soil to prevent desiccation and frost heaving. Soil must be carefully compacted around root systems to eliminate air pockets without crushing the roots (Figure 4, 5). When planting in heavy clay soils, however, avoid compacting soil around the planting hole as this can contribute to frost heaving.

Figure 3. Bareroot big sagebrush seedlings harvested after one growing season at the Lucky Peak Forest Service Nursery near Boise, Idaho. (Scale: each ruler is 12 inches).

The following tools are useful for eliminating competing vegetation and for planting seedlings (Shaw 2004; Landis et al. 2010):

- **MacLeod**: a combination hoe and rake used to remove competition and surface debris.
- **Hoedad or planting hoe**: these are available in many styles and can be used on steep, rocky and compacted sites. The back and side of the blade can be used to remove competition.
- **Planting bar**: a tool with a wedge-shaped blade and foot pedals, which is useful for planting in rocky and sandy soils. It can cause compaction if used in clay soil.

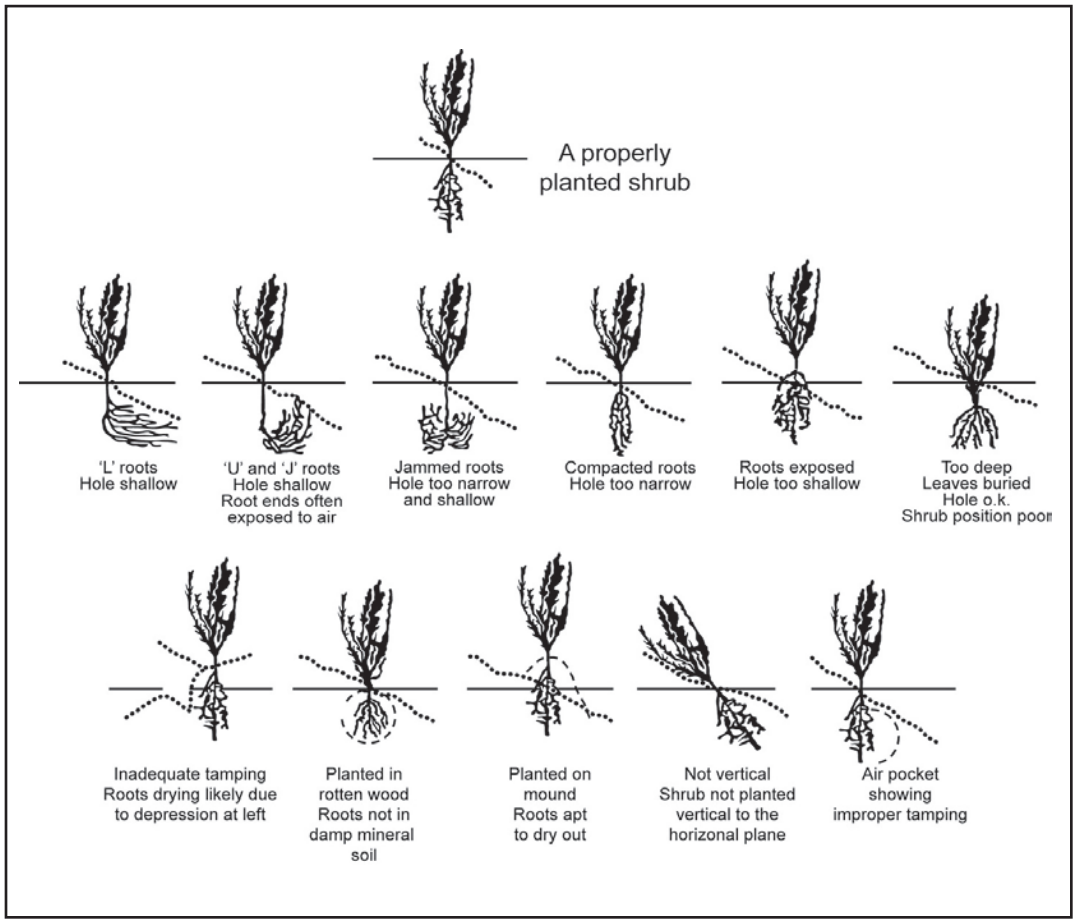
- **Planting shovel**: on this tool the reinforced blade is particularly useful for planting large stock and for planting in deep, loose soils.
- **Dibble**: a tool for planting container stock in light-textured soils. Hollow tips that match specific container sizes are available. These reduce compaction compared to solid tips and extract a core of soil that can be used to cover the top of the root plug.
- **Power auger**: gas-powered augers can be used to prepare planting holes for planting crews. They are most effective on moderate terrain with deep soil free of rocks, roots or excessive surface debris and when larger stock is being planted.
- **Transplanter**: a tractor-drawn mechanical planter that can be used to plant seedlings on flat or rolling topography that is not rocky. Transplanters are most economically used on large projects with good access. Capabilities vary among models.

Monitoring

Post-planting monitoring should be employed to evaluate seedling establishment and inform future restoration practices. Standard methods for monitoring restoration seedings and plantings may be used to assess stand development during the first two to three years. These include such measurements as seedling density, cover and vegetation gaps (e.g. Herrick et al. 2005; Wirth and Pyke 2007). Intermittent monitoring thereafter can aid in evaluating plant community development, selecting or modifying management actions, and planning future projects.

Figure 4. (*Left*) Planting big sagebrush in a microsite from which competing vegetation has been removed. The root plug should be covered with a layer of native soil to prevent wicking and frost heaving. Plants should be watered in if soil is dry.

Figure 5. (*Below*) Proper planting of bareroot seedlings and common planting errors (modified from Weadick 1976).



In addition to the standard methods, additional monitoring might include: 1) causes of mortality or predation; 2) general plant health; 3) growth rates; 4) structural development; 5) time of first seed production; and 6) spread from seed or vegetative structures. Post-planting monitoring can also provide valuable economic information such as cost per surviving seedling.

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Assessing Fuel Loads in Sagebrush Steppe and PJ Woodlands

Purpose: To define wildland fuels and review some of the approaches used to assess fuel loads in Great Basin ecosystems. Assessing wildland fuel loading is important for quantifying potential fire hazards, for monitoring the effectiveness of fuel treatments, and for predicting fire behavior, soil heating, fuel consumption, and emissions.

In Brief:

- Managers have developed several approaches for assessing fuel loads that vary with landscape scale, required data accuracy and precision, and resources available for data collection.
- Understanding and quantifying the different components of wildland fuels, such as total fuel, consumable fuel, and time-lag fuels, is the first step for developing valid estimates of fuel loads.
- Methods vary from those that are rapid and more qualitative to those that are quantitative. They include fire behavior fuel models, photo series, photoload methods, the planar-intersect method, and remote sensing.
- Approaches vary in accuracy and in time and effort required for sampling. Fire behavior fuel models or photo series guides are effective for rapidly assessing fuel loads on multiple sites, but more intensive methods such as the planar intersect method are useful during the personnel-training phase.

What are wildland fuels?

Understanding the different components of wildland fuels is the first step for developing valid estimates of fuel loads. **Total fuel** is all plant material, both living and dead, that can burn in a worst-case situation. **Consumable fuel** is the portion of total fuel that would be consumed by fire under specific conditions and is related to factors like fuel moisture content, season, weather conditions, time of day, and plant growth stage or phenology. **Biomass estimates** differ from **fuel loading estimates**. Above-ground biomass includes all the plant organic material on a site (including litter and duff). Fuel only includes the portion of biomass that may be consumed by fire. Biomass is more than 'fuel' and provides many ecological functions. **Herbaceous fuel** (grasses and forbs) is commonly separated into living and dead, or current and previous years' growth. **Woody fuel** is also separated into living and dead components. Typically, living woody biomass is not readily consumed in a fire, and at times even living herbaceous material will not burn. Dead woody fuels may persist on the landscape for many years and sometimes decades. Large-diameter woody material will not readily burn under most conditions. Thus, these types of organic materials are included in biomass estimates but not usually in fuel loading estimates.

Herbaceous fuels are typically separated into live and dead material because they may burn under different conditions. Dead herbaceous material varies in fuel moisture level depending on the atmospheric conditions. The moisture content of living herbaceous material is dependent upon soil moisture, temperature, and plant phenology. New growth of plant material has a high moisture content, which declines as the plant matures.

Dead woody fuel is often separated into diameter size classes because it has been found that this greatly influences the likelihood of consumption during fire as well as fire intensity, severity, and spread. The diameter size classes include those

Wildland Fuel Terms

Total Fuel		All plant material, both living and dead, that can burn in a worst-case situation.
Consumable Fuel		The portion of total fuel that would burn, depending on fuel moisture, weather, plant stage, and more.
Biomass Estimates		All above-ground plant organic material at a site, including litter and duff.
Fuel Loading Estimates		The portion of the total biomass that may be consumed in case of a fire.
Herbaceous Fuel		Grasses and forbs, commonly separated into living and dead
Woody Fuel		Wood, also separated into living and dead. Living woody biomass is not readily consumed in a fire.

that are: <¼, ¼ to 1, 1 to 3, and >3 inches. They are frequently referred to as 1-hour, 10-hour, 100-hour and 1000-hour **time lag fuels** because of the rate at which they equilibrate with changing atmospheric relative humidity. The diameter of each piece of dead woody fuel greater than 3 inches is usually measured since a small increase in diameter greatly increases the amount of biomass. In mature juniper (*Juniperus* spp.) woodlands, litter and duff beneath the tree canopies may also constitute a significant amount of the site's fuel.

Why assess wildland fuel loading?

Estimates of fuel loading are useful in many applications (Table 1). The initial need for fuel loading estimates resulted from the development of fire behavior prediction systems such as BehavePlus. Knowing levels of fuel loading helped managers predict fire behavior using these systems. More recently developed software programs such as FARSITE and FlamMap are now used to predict broad-scale fire behavior across multiple vegetation types. All require fuel loading data and sometimes other types of data as well. These software programs have proven useful in predicting fire behavior in both wildfire and prescribed fire applications, including strategic planning.

Pre-fire fuel loading can be compared to the estimated reduction in fuel load after fire to interpret burn severity and subsequent fire effects. **Burn severity** is generally defined as the degree of ecological change due to fire. Both field and remotely sensed observations are used to map burn severity. The differenced Normalized Burn Ratio (dNBR) can be used to infer burn severity from remotely-sensed data. The Monitoring Trends in Burn Severity Project (MTBS) is a database of large fires for which dNBR has been mapped within each fire perimeter. Methods based on field observations include the Composite Burn Index (CBI).

Table 1. Commonly used tools and software that utilize fuel load data[1]

Technology or tool	Primary use by land managers
Fire Behavior Fuel Models (FBFMs)	Data from FBFMs are used as inputs for BehavePlus, FOFEM, FARSITE and many other programs for prediction of fire behavior and fire effects such as soil heating and smoke.
BehavePlus	The BehavePlus fire modeling system is an application that involves modeling fire behavior and fire effects. The system is composed of a collection of mathematical models that describe fire behavior, fire effects, and the fire environment. The program simulates rate of fire spread, spotting distance, scorch height, fuel moisture, wind adjustment factor, and many other fire behaviors and effects; so it is commonly used to predict fire behavior in several situations.
FlamMap	The FlamMap fire mapping and analysis system is a PC-based program that describes potential fire behavior for constant environmental conditions (weather and fuel moisture). FlamMap does not calculate fire spread across a landscape or simulate temporal variations in fire behavior caused by weather and diurnal fluctuations.
Fire Area Simulator (FARSITE)	FARSITE is a fire growth simulation modeling system. It uses spatial information on topography and fuels along with weather and wind files. It incorporates existing models for surface fire, crown fire, spotting, post-frontal combustion, and fire acceleration into a two-dimensional fire growth model.
Composite Burn Index Photo Series (CBI)	The CBI photo series uses plot data and photos to illustrate the range of burn severity encountered in ecosystems of the U.S. The series offers a way to calibrate field interpretations, providing a sense of what the CBI represents visually on the ground. It offers insight into the variety and combinations of fire effects that make up the overall post-fire condition on a site.
Fuel Characteristic Classification System (FCCS)	FCCS calculates and classifies fuelbed characteristics and their potential fire behavior.
Monitoring Trends in Burn Severity (MTBS)	MTBS is a program that is designed to map the perimeters and severity of all fires within the United States since 1984 based on satellite images.
LANDFIRE	LANDFIRE provides broad scale geo-spatial products and information related to vegetation, fuel, and disturbance at the national level.

[1] *Descriptive material has primarily been drawn from FRAMES (https://www.frames.gov/) or directly from the software web material.*

Currently many land managers are completing fuel treatments using livestock grazing, prescribed fire, and mechanical methods for achieving numerous objectives. Monitoring can utilize fuel assessment methods to quantify or qualify the short- and long-term effectiveness of the fuel treatments in modifying fuels as well as the effects of fuel treatments on the plant community.

In many regions air quality and smoke production from fires is a major concern. Fuel loading assessment methods used in conjunction with smoke production models such as FOFEM and Consume (FBFMs) can be used to predict fire effects on air quality and can be useful in predicting emissions from both wild and prescribed fires.

Figure 1. Estimating fuel loading on the Snake River Plain in southern Idaho using the photo series method.

What approaches exist for assessing wildland fuels?

The assessment of wildland fuels can vary from rapid visual approaches to more time intensive direct sampling strategies. Methods to predict fuel loading using remotely-sensed data have also been developed. Each method has its advantages and disadvantages as discussed by Keane (2015). The appropriate method depends on the assessment objectives, the required accuracy of the estimate, the spatial scale of the assessment, the urgency of the assessment, and the resources available for collecting data.

Fire Behavior Fuel Models (FBFM). One of the initial methods to estimate fuel load was the use of the Fire Behavior Fuel Models. Originally there were 13 models from FBFM that represented various vegetation types found throughout the United States (Anderson 1982). Through the use of descriptive material and photographs, managers selected the fuel model that best represented their site. Fuel loading information was available in tabular form and was also preloaded into the Behave program. Sagebrush (*Artemisia* spp.) steppe and juniper woodlands were poorly represented in these initial models. Scott and Burgan (2005) described 40 additional fuel models which contained more examples of sagebrush steppe and juniper woodland vegetation commonly found in the Great Basin. Thus, land managers with site specific data have the option of creating their own custom fuel models.

Photo Series. Another method for fuel loading assessment is the photo series, which is the most rapid and least costly approach. These consist of a sequence of photographs illustrating examples of different fuel loading in various vegetation types (Figure 1). Several photo series are available for Great Basin sagebrush steppe and juniper woodland vegetation (Stebleton and Bunting 2009, Bourne and Bunting 2011, Ottmar et al. 2000). This method involves matching as closely as possible the manager's sites with the photographs included in the series. Many authors suggest matching the photos by vegetation layer or fuel strata rather than trying to find a single photograph to fit a site. For example a manager would use one photograph to quantify the herbaceous component and another to predict the overstory fuel. Fuel loading of the site can then be derived from the tabular data associated with the photo. Once the observer is well trained in this method, multiple sites can be assessed quickly, each taking less than five minutes. This allows the observer to sample across the gradient of sites, which helps them gain a measure of the fuel heterogeneity on the landscape.

Photoload Method. A related method, the photoload method, uses photographs of artificial fuels of different types and sizes (large woody, herbaceous, shrub, litter etc.) to represent the site's actual fuel (Keane and Dickinson 2007). The manager matches the site's fuel to photographs of each fuel strata. As with the photo series, fuel load values for the site are derived from tabular data. At this point photoload guides are not available for sagebrush steppe and juniper woodland vegetation.

Planar-intersect Method. A number of field sampling approaches have been developed. Perhaps the most commonly used in land management monitoring for surface woody fuels is the planar-intersect method (Brown 1970, Brown et al. 1982) (Figure 2). This method involves using multiple line transects along which the relevant fuel data are recorded. Usually multiple lines are sampled for a given site (five or more), and multiple sites are sampled within the

area of interest. By sampling multiple sites, this method can also provide a measure of fuel heterogeneity. A more complete description of the planar-intersect method can be found at the FIREMON website (https://www.frames.gov/partner-sites/firemon/firemon-home/). While not part of the planar intersect method, FIREMON also contains suggested methodology for sampling herbaceous and shrub fuel and biomass (most of which include clipping, drying and weighing of samples).

Remote Sensing Methods. Methods to estimate fuel loading using remotely-sensed data are available (Keane et al. 2001). These methods do not measure fuel loading directly, but rather they assess the landscape cover of vegetation and other cover types from remotely sensed data which is then classified into similar groups. The classified groups are then associated with typical fuel loading data. The fuel loading data for the groups have generally been developed through intensive field sampling such as those described previously (Figures 3 and 4). Using these methods, managers can assess large spatial areas quickly. This method may also provide a measure of fuel heterogeneity, but this depends on the pixel size of the remotely-sensed data, the accuracy of the vegetation map, the variability of fuels within the vegetation classes, and other factors.

Figure 2. Sampling fuel loading using the planar intersect method at Lava Beds National Monument in northeastern California.

Figure 3. Composition and fuel loading values of a Wyoming big sagebrush steppe in northern Nevada. Low herbaceous fuel loading and high levels of bare ground reduce the probability of fire under low intensity burning conditions.

Canopy coverage

Shrubs: 35%
Perennial grass: 21%
Bare ground: 34%

Fuel

Total shrub: 18.3 t/ac
Live herbaceous: 311 lb/ac
Dead herbaceous: 350 lb/ac

Figure 4. Composition and fuel loading values of a typical Phase 2 western juniper woodland in southwestern Idaho. Juniper woodlands are characterized by having low fine fuel loading and heterogeneous fuel distribution.

Canopy coverage

Trees: 14% Shrubs: 24%
Perennial grass: 26% Bare ground: 20%

Fuel

Total live tree: 4.9 t/ac Dead tree: 0.5 t/ac
Total shrub: 0.6 t/ac
Live herbaceous: 104 lb/ac
Dead herbaceous: 43 lb/ac

Comparison of methods

Skikink and Keane (2008) compared five field techniques for estimating surface fuel loading in montane forests. The planar-intersect method was determined to be the best method tested. The photoload method compared well with the planar-intersect method. The photo series method tended to result in greater fuel load estimates for the fine wood debris and coarse woody material. However, ponderosa pine-dominated sites (*Pinus ponderosa*) were primarily sampled in this study, and no shrub or herbaceous-dominated sites were included.

Fuel loading varies greatly at all spatial scales, fine to broad. This variation can influence fire behavior and thus fire effects on the ecosystem. The non-spatially explicit fire behavior models, such as BehavePlus, generally assume that the fuel load is homogeneously distributed within the area modeled. The spatially explicit models, such as FARSITE, assume that there are varying fuel loads within the area of concern but that fuel is homogeneous with the smallest pixel represented in the data. Consequently, depending on the pixel size and the heterogeneity, fuel loading may or may not be well represented. Representing fuel load heterogeneity across all the relevant scales is still challenging (Figure 5).

Figure 5. Fuel loading varies at all scales within the landscape. Fuel heterogeneity can dramatically influence fire spread and behavior, particularly with respect to moderate and low intensity fires. Top: Fine scale [mountain big sagebrush steppe (L), western juniper woodland (R)]; Middle: community scale [Wyoming big sagebrush steppe (L), western juniper woodland (R)]; Bottom: Landscape scale [mountain big sagebrush and low sagebrush steppe, and aspen woodland (L); western juniper woodland and mountain big sagebrush steppe (R)].

Summary

The different methods developed to assess fuel loads in sagebrush steppe and juniper woodland vegetation vary in accuracy, and in time and effort required for sampling. Many sagebrush steppe and woodland areas have heterogeneous fuels across a treatment area. Identifying areas of high and low fuel loading helps during the planning and implementation phases of a project. Different actions may be required to hold a prescribed fire in areas of a unit with high fuel loading. Also, variable fire intensity and burn severity is attributed to variable fuel loading. Thus, it is important to obtain multiple estimates that are representative of the variety of fuel loading amounts within a heterogeneous landscape, particularly the low fuel loading sites. FBFMs or photo series guides are effective methods to rapidly assess the fuel loads on multiple sites. However, more intensive sampling methods such as the planar intersect method are useful during the personnel-training phase.

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Fire Research and Management System (FRAMES)
https://www.frames.gov/

FIREMON:
Fire Effects Monitoring and Inventory System
www.frames.gov/partner-sites/firemon/firemon-home/

Monitoring trends in burn severity (MTBS)
http://www.mtbs.gov/methods.html

National Wildfire Coordinating Group (NWCG)
Glossary of Wildland Fire Terminology
http://www.nwcg.gov/?q=glossary

Great Basin Factsheet Series
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Seeding Big Sagebrush Successfully on Intermountain Rangelands

Purpose: To provide land managers with state-of-the-art information on the establishment of big sagebrush through direct seeding.

In Brief:

- Big sagebrush can be seeded successfully on climatically suitable sites in the Great Basin using the proper seeding guidelines.
- These guidelines include using sufficient quantities of high-quality seed of the correct subspecies and ecotype, seeding in late fall to mid-winter, making sure that the seed is not planted too deeply, and seeding into an environment with reduced competition.
- Reducing the seeding rates of highly competitive grasses will increase the chances of sagebrush establishment.
- Aerial seeding the first winter after a burn following drilling of larger-seeded species at reasonable rates is one approach for large scale-post-fire restoration projects that has been successful.

Introduction

Big sagebrush (*Artemisia tridentata*) is the dominant shrub species on over 60 million acres of Intermountain rangeland. For much of the first half of the 20th century, big sagebrush tended to increase in cover on rangelands where understory grasses were depleted by overgrazing, prompting efforts to reduce or even eradicate this species as part of efforts to increase forage production. Its value for wildlife was eventually recognized, however, and efforts to direct-seed it as part of seed mixes for winter game range rehabilitation date from the 1960s.

More recently, devastating large-scale fires, in part a consequence of annual grass invasion, have impacted a sizeable portion of the sagebrush steppe ecosystem, especially in the Great Basin. Post-wildfire seeding of big sagebrush has been undertaken as part of reseeding efforts on large acreages. Sagebrush does not need to recruit from seed every year in order to persist on a site, so it is not too surprising that some years are not suitable for establishment from seed even on favorable sites. Poor weather for establishment can render even the most artful seeding effort ineffective. Here we discuss some of the many factors that can increase the likelihood of successful sagebrush establishment from direct seeding. By following the guidelines below, we have found that big sagebrush can be established successfully from seeding in many years, even on Wyoming big sagebrush sites, as long as they are in climatically suitable areas.

The effects of rapid climate change add a new and challenging dimension to the problem of sagebrush restoration. Bioclimate envelope modeling predicts that many drier, lower-elevation areas historically occupied by Wyoming big sagebrush will probably become climatically unsuitable for sagebrush within fifty years (Still and Richardson 2015). It is likely that we are already seeing the effects of climate change on sagebrush seedling establishment in these areas, as years with weather suitable for successful establishment occur

2005 Esmeralda Fire, Emergency Stabilization and Rehabilitation (ESR) sagebrush and yarrow seeding on Willow Creek Ridge, 14 miles east of Midas, Nevada. Photo taken October, 2014.

increasingly less often. Adult stands may be able to persist in areas where seeding establishment has become unlikely. This means that traditional sagebrush seeding prescriptions that worked well in most years even in marginal areas in the past now have a much reduced probability of success in these areas. After such stands are lost to wildfire, it becomes very difficult or impossible to reestablish sagebrush from seed, or even to ensure long-term persistence using transplant stock on a local scale. Seeding decisions in the face of issues associated with climate change should be based on the best science available, with close coordination between scientists and managers on the ground.

The Right Seed Lot

Big sagebrush is a complex species with a very wide ecological range, so it is not surprising that not all sagebrush seed lots are 'created equal'. The three principal subspecies occupy different habitats, with mountain big sagebrush (ssp. *vaseyana*) on higher elevation sites, basin big sagebrush (ssp. *tridentata*) on deep soils in the valleys, and Wyoming big sagebrush (ssp. *wyomingensis*) on drier upland sites at low elevation. It is important to know which subspecies is appropriate for the site to be seeded, and to make sure that purchased seed belongs to the correct subspecies. Even seeding the right subspecies does not necessarily guarantee a good fit ecologically, as each subspecies contains numerous ecotypes whose establishment and growth characteristics are fine-tuned to specific environments. Guidelines based on provisional seed zones are a good place to start (Bower et al. 2014), and purchase of certified seed collected from sites verified by inspection (www.utahcrop.org/certified-wildland) is another step closer.

A recent study examining big sagebrush seed size differences suggests that even the above precautions may not be enough to ensure that seed collections labeled Wyoming big sagebrush (larger seeds) are true to subspecies rather than mixtures that also include basin big sagebrush (smaller seeds; Richardson et al. 2015). Many sagebrush seeding failures are undoubtedly due to the planting of poorly adapted seed lots. There may soon be seed size criteria employed as part of the seed testing and certification procedure, which will increase the chances of obtaining site-adapted seed lots. Mountain big sagebrush seed is intermediate in size, but the easy test for leaf fluorescence in water under black light is a reliable subspecies indicator. When sagebrush seed is in limited supply after a poor production year and especially after a particularly severe fire season, managers have sometimes been tempted to use less well-adapted lots from distant areas. This approach is rarely successful, especially on more marginal sites.

Sagebrush Seeds – Not Built to Last

Big sagebrush is a relatively long-lived plant that can produce many millions of seeds in its lifetime. The seeds are programmed to germinate in very early spring, soon after dispersal in the late fall or winter. Seeds can sometimes persist at very low densities in the soil seed bank for a year or two, but recovery from the seed bank after disturbance is rare (Young and Evans 1975, Meyer 1990). The seeds have a correspondingly short shelf life in storage, making it difficult to maintain quality. Extremely small seed size (1-2 million seeds per pound; Meyer 2008) combined with low initial purity makes cleaning to high purity generally cost-prohibitive, as it doubles the cost of the seed.

Consequently, commercially available sagebrush seed lots typically contain a large fraction of 'trashy' non-seed material. Seed cleaned to high purity has a longer shelf life and may become more widely available. Seed lot quality is usually defined on a pure live seed (PLS) basis. Percent purity multiplied by percent viability divided by 100 equals percent pure live seed (e.g., 15% purity x 90% viability/100 =13.5% PLS).

Key components of maintaining high viability are controlling seed moisture content and storage at cold temperatures. The take-home for managers is to: (1) use a current-year seed lot if possible, (2) purchase seed that has been cold-stored, and (3) have a seed lot that is a year or more old retested for viability immediately prior to purchase. Use of current-year seed lots can often be practical even though seed is produced late in the season. Taking precautions to assure that the seed lot used is of high quality is essential, as poor quality seed is a common cause of seeding failure.

Sage grouse in the 2011 Indian Creek Fire native grass/forb drill seeding project area, which was overseeded with Wyoming big sagebrush. Photo taken September 2013, two growing seasons after the treatments were completed. Establishing juvenile sagebrush plants (circled) can be found throughout the stand.

Let It Snow! Weather and Timing

Because sagebrush seed requires only a short chill following dispersal to be ready to germinate (Meyer 1994), the best time to seed is when sagebrush would naturally be dispersed, namely from late fall into winter. January is generally the best month to aerial-seed. Snow cover seems to be essential for seeding success, whether the snow falls before or after the seeding. The seeds can even germinate beneath the snow and be ready for action in very early spring right after snowmelt (Meyer 1994). Seeding earlier in the fall places the seed at risk for a longer period prior to germination and could potentially cause premature fall germination, which is not the norm for this species because of its late fall dispersal, and likely would result in winterkill. Spring seedings are almost universally unsuccessful, especially on Wyoming big sagebrush sites, because the soil dries too rapidly for the tiny seedlings to get their roots established.

Seeding Methods: To Fly or Not To Fly

Sagebrush seeds must be planted on or very close to the soil surface because of their very small size. There are basically two methods--aerial seeding and surface seeding. Aerial seeding is by definition broadcast seeding. On large-scale seedings, the sagebrush seed is usually applied by helicopter or fixed wing aircraft, either in a mix or following the drilling of larger-seeded species. Important components of successful aerial seeding (in addition to those already mentioned) include the correct seeding rate (commonly expressed as PLS or pure live seed per unit area) of sagebrush relative to other species in the seeding, mixing the seed onsite and during application, and hiring an operator who has experience applying relatively small quantities of very small seeds at a consistent rate. Some form of seed bed preparation can also improve sagebrush establishment, though it is not essential in the post-burn environment. Often drill seeding of other perennials creates microsites for sagebrush establishment from aerial seeding, though this type of seed bed can be quite rough. Other alternatives are chaining or harrowing either before or after seeding.

If the cost of sagebrush seed is limiting, it is better to seed at the correct rate in swaths alternating with unseeded areas than to seed the whole area at a suboptimal rate. This is because the success of the seeding will depend on a sufficiently high ratio of sagebrush seeds to the seeds of other species, particularly highly competitive grass species. Sagebrush seed can be mixed and planted directly with other small-seeded native species that are not too competitive, such as yarrow or Sandberg bluegrass. Mixed sagebrush-yarrow seedings have been particularly successful in northeast Nevada which is a climatically suitable area.

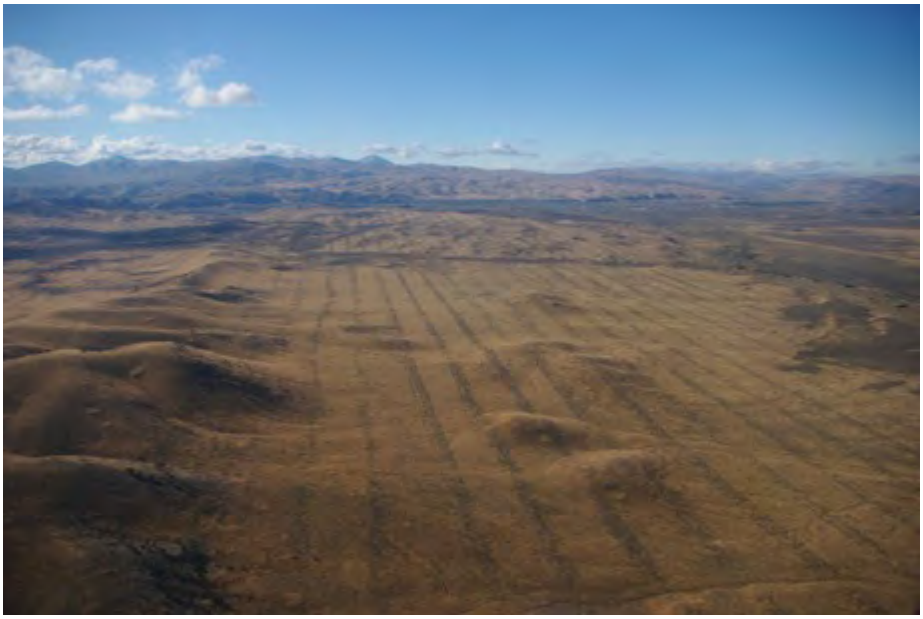
For more intensive restoration activities on a smaller spatial scale and even in large scale seedings, sagebrush can also be surface-seeded. This can include broadcast seeding or

(Top) sagebrush and forb seeding on the 2013 Willow Fire with helicopter and bucket used for aerial seeding. Photo taken January 16, 2013. (Below) Fixed wing aerial application used for sagebrush seeding.

planting with an implement such as Truax or no-till drill (Monsen and Meyer 1990, Monsen et al. 2004). Because the seeds are so tiny, they are best not drilled at the same depth as larger-seeded species. One approach is to place sagebrush seed with seeds of other small-seeded species in a separate box on the drill and use a technique such as pulling the hose, so that that the seeds are dribbled on the surface, ideally using a roller type imprinter or press wheel to firm the seed bed and press the seed into the surface. This also has the advantage of separating the seed from larger-seeded species on a small spatial scale. However, drilling can sometimes be successful even without separating the seed, especially with adequate seed bed preparation. If the seed bed is loose and sloughing, sagebrush seed can become buried too deeply even if not drilled. Conversely, seeding onto a hard, crusted seed bed is also not ideal. Pipe-harrowing following broadcast seeding can improve success, especially if the seed bed is hard or rocky.

Seeding rates that result in an average of 40 to 80 seeds per m^2 (4 to 7 per ft2) usually result in adequate stands of sagebrush. This corresponds to a rate of 0.08 to 0.2 lb per acre on a PLS basis for a lot that averages 1.8 million seeds per pound.

Seed at PLS lbs per acre rates between 0.16 and 0.2 for Wyoming big sagebrush, between 0.08 and 0.10 for basin big sagebrush, and between 0.10 and 0.12 for mountain big sagebrush. These rate differences correspond to subspecies differences in seed size. To determine the bulk seeding rate equivalent to a PLS pound, take the reciprocal of the desired PLS rate expressed as a proportion (e.g., 1 pound PLS per acre at 10% PLS=1/0.10 = 10 pounds bulk seed). As sagebrush seed is usually sold at ca. 10-15% purity, this corresponds to approximately 1-2 pounds per acre of bulk seed. The bulk seeding rate should always be adjusted according to the PLS of the lot.



(Top) Fixed wing aerial ESR sagebrush seeding on the 2006 Susie Fire north of Carlin, NV. Seeding was done every third swath in crucial big game winter range and sage grouse habitat. Photo looking south toward Carlin taken October, 2011. (Below) 2006 Susie Fire aerial sagebrush seeding seven years after treatment. Area was seeded in stripes with a fixed wing aircraft.

Competition, Nurse Plant Effects, and Seeding in Mixes

The success of a sagebrush seeding is strongly dependent on the level of competition both from species already present on the site and species in the seed mix. Planting into a dense stand of annual grass weeds like cheatgrass or medusahead almost always results in failure. This is one reason that planting the first winter after a fire in sagebrush is highly recommended—the hotter fires generated by woody fuels are more effective at destroying the annual grass seed bank and creating a window of opportunity for shrub seedlings. If a seeding fails the first year due to unfavorable weather, it is possible to seed again in a later year, but this is much more difficult due to increased competition from weeds or other seeded species. Usually such follow-up seedings require some seed bed preparation to be successful and are carried out using mechanical equipment on the ground.

Sagebrush is also subject to the negative effects of competition from seeded grasses, especially from more competitive introduced forage grasses or when any perennial grasses are seeded at high rates. It is sometimes possible to successfully establish big sagebrush in seedings that include introduced perennial forage grasses, but a reasonable balance must be maintained. Adding a token amount of sagebrush seed that fails to establish does not demonstrate that mixed seedings always fail. Reducing the seeding rates for perennial grasses and seeding less competitive native grass species are both tactics that increase the chances for sagebrush establishment.

Seeding into established perennial grass stands can be a good way to create more structurally complex vegetation, and natural sagebrush encroachment into pasture plantings was long viewed as a problem (Meyer 1994). If the herbaceous perennial vegetation is grazed by livestock or wildlife, there are often openings that permit shrubs to establish over time. Seeding sagebrush into small-scale mechanical scalps or after low-impact tillage in perennial vegetation can also work well (Meyer 1994).

Perennial or even weedy annual vegetation can also sometimes have a positive effect on sagebrush establishment, largely because of its reliance on snow cover for successful establishment. On barren, windswept sites or in years with little snowfall, existing vegetation can act to trap snow on a small scale and provide microsites for sagebrush recruitment. One predicted effect of climate change is that years with adequate snowfall will become less frequent, making sagebrush establishment more difficult. Research has shown that local redistribution of snow cover with snow fencing can enhance sagebrush establishment under conditions of inadequate snowfall (Monsen et al. 1992). This means that if sagebrush can be established on even part of the landscape, it will act as a seed source as well as a nurse plant to provide a microenvironment for continued recruitment. Planting early seral shrubs like rubber rabbitbrush (*Ericameria nauseosa*) with sagebrush can also facilitate continued sagebrush recruitment by trapping snow and otherwise improving seed bed conditions. Perennial grass stands can also fulfill this function if they are not too dense. Even Russian thistle has been observed to act as a nurse plant for big sagebrush on mine disturbances. Another approach has been to seed sterile wheat or rye the first year, then seed sagebrush and other species the following year, so that the standing litter from the cereal seeding creates favorable microsites for sagebrush recruitment. This approach has mostly been applied on severe disturbances.

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Assessing Impacts of Fire and Post-fire Mitigation on Runoff and Erosion from Rangelands

Fire Impacts on Infiltration, Runoff Generation, and Erosion

Wildfires are a natural component of rangeland ecosystems, but fires can pose hydrologic hazards for ecological resources, infrastructure, property, and human life. There has been considerable research conducted on the effects of fire on hydrologic processes and sediment movement over the point (<20 ft^2) to patch or hillslope (100 to 320 ft^2) spatial scales in shrublands and woodlands of the western United States (Pierson et al. 2011; Williams et al. 2014a). Nearly all of this work has been conducted using rainfall simulation and overland flow experiments.

Sagebrush rangeland burned by the Soda Fire (2015) within the Reynolds Creek Experimental Watershed, southwestern Idaho. The photo shows extensive bare ground associated with high rates of surface runoff and formation of high velocity concentrated flows.
Photo credit: USDA Agricultural Research Service.

Purpose: To provide an overview of the immediate and short-term hydrologic impacts of fire on infiltration, runoff, and erosion by water, and of the effectiveness of various mitigation treatments in the reduction of runoff and erosion in the years following the fire.

In Brief:

- ***Amplified runoff and erosion responses*** are most likely where fire increases bare ground to 50 to 60 percent and slopes exceed 15 percent. Extensive bare ground promotes accumulation of runoff and formation of high velocity concentrated flow, capable of entraining and transporting a high sediment load.
- ***Runoff and erosion responses*** are likely enhanced on steep slopes and under high rainfall intensity. Rainfall intensity and bare ground are strong predictors of post-fire responses. The hydrologic and erosion recovery period for rangelands will vary with precipitation and ground cover in the years following burning and is influenced by ecological site and pre-fire conditions.
- ***Risk assessment tools are available*** to assist in evaluation of post-fire conditions and their effects on runoff and erosion.
- ***Effectiveness of post-fire stabilization treatments*** depends on magnitude, intensity, and duration of the rainfall events following fire; ability of the treatment to increase surface cover or trap sediment; persistence of the treatment; and interaction of the treatment with vegetation and ground cover reestablishment.

Table 1. Site characteristics, runoff, and sediment yield from rainfall simulations (60 min except where noted) on unburned and high, moderate, and low-severity burned shrublands (Pierson et al. 2002, 2008, 2009) and woodlands (Pierson et al. 2013; Williams et al. 2014b, Pierson et al. 2015).

Ecosystem	Microsite	Burn severity	Plot size (ft^2)	Slope (%)	Time post-fire (month)	Rainfall intensity ($in\ h^{-1}$)	WDPT[A] (s)	Bare soil (%)	Canopy cover (%)	Ground cover (%)	Runoff coef.[B] (%)	Sediment yield ($lb\ ac^{-2}$)
Sagebrush rangeland	Coppice	Unburned	5	35–60	12	2.6	–	7	88	93	11	20
		Moderate	5	35–60	12	2.6	–	97	11	3	34	270
		High	5	35–60	12	2.6	–	98	13	2	37	195
	Interspace	Unburned	5	35–60	12	2.6	–	89	18	12	24	35
		Moderate	5	35–60	12	2.6	–	95	16	5	26	105
		High	5	35–60	12	2.6	–	99	5	1	49	1320
Sagebrush rangeland	Coppice	Unburned	5	30–40	1	3.3	200	1	100	99	30	110
		High	5	30–40	1	3.3	102	99	1	1	37	365
	Interspace	Unburned	5	30–40	1	3.3	220	6	74	94	49	215
		High	5	30–40	1	3.3	97	99	4	1	30	190
Sagebrush rangeland	Coppice	Unburned	5	35–50	1	3.3	286	2	84	98	39	150
		Moderate–High	5	35–50	1	3.3	261	42	10	58	76	1630
	Interspace	Unburned	5	35–50	1	3.3	110	25	31	75	63	1740
		Moderate–High	5	35–50	1	3.3	117	84	0	16	55	6290
	–	Unburned	350	35–50	1	3.3	–	24	57	76	4	70
	–	Moderate–High	350	35–50	1	3.3	208	76	0	24	27	8810
Juniper woodland	Tree Coppice	Unburned	5	10–25	12	4[D]	42	0[E]	17	100	23	475
		High	5	10–25	12	4[D]	54	88[E]	5	12	58	1840
	Shrub Coppice	Unburned	5	10–25	12	4[D]	3	41[E]	117	59	20	55
		High	5	10–25	12	4[D]	11	94[E]	21	6	23	1280
	Interspace	Unburned	5	10–25	12	4[D]	3	88[E]	20	12	63	320
		High	5	10–25	12	4[D]	3	93[E]	21	7	51	1200
Juniper woodland	Tree Coppice	Unburned	140	10–25	12	4[D]	–	18[E]	26	82	13	430
		High	140	10–25	12	4[D]	–	73[E]	15	27	58	9660
	Inter–canopy	Unburned	140	10–25	12	4[D]	–	89[E]	18	11	50	2430
		High	140	10–25	12	4[D]	–	88[E]	32	12	50	5100
Pinyon-juniper woodland	Tree Coppice	Unburned	140	10-15	12	4[D]	–	6[E]	27	94	5	320
		Moderate	140	10-15	12	4[D]	–	27[E]	6	73	14	700
	Inter–canopy	Unburned	140	10-15	12	4[D]	–	64[E]	39	36	47	1980
		Moderate	140	10-15	12	4[D]	–	86[E]	23	14	43	3090
Utah juniper woodland	Tree Coppice	Unburned	140	15–20	12	4[D]	–	15[E]	21	85	10	590
		Moderate	140	15–20	12	4[D]	–	68[E]	3	32	51	16885
	Inter–canopy	Unburned	140	15–20	12	4[D]	–	79[E]	19	21	45	2640
		Moderate	140	15–20	12	4[D]	–	81[E]	17	19	42	4380

[A]Water drop penetration time (WDPT) is an indicator of strength of soil water repellency as follows: <5 s wettable, 5-60 s slightly repellent, 60-600 s strongly repellent.

[B]Runoff coefficient is equal to cumulative runoff divided by cumulative rainfall applied. Value is multiplied by 100 to obtain percent.

[C]Data presented from south-facing slopes only.

[D]Simulated storm applied immediately following 45 min simulation of 64 mm h^{-1} rainfall.

[E]Includes rock cover and ash; bare areas of rock and bare soil were extensive due to woodland encroachment.

Studies indicate runoff and erosion by water may increase 2- to 40-fold immediately post-fire over scales of <20 ft^2, and 6-fold and 125-fold respectively at the hillslope scale (Table 1). Few rangeland studies have evaluated the impacts of fire on hydrologic and erosion processes at hillslope to landscape or watershed scales (e.g., paired watersheds). Studies from mountainous forested settings indicate hillslope erosion can approach 24 to 40 tons per acre annually the first few years following burning, and recovery to pre-fire erosion rates may take four to seven years (Robichaud 2009). Numerous anecdotal reports have documented large-scale flash flooding and debris flow events following intense rainfall on burned rangelands. Reports of flooding and debris flow events commonly document that these landscape-scale processes are initiated by increased plot-scale to hillslope runoff and soil loss following fire.

Fire primarily alters hydrology and erosion processes by consumption of the protective ground cover and organic matter. The exposed bare soil becomes susceptible to increased runoff generation and sediment detachment and transport (Figure 1). The first order effect is increased water availability for runoff generation. Fire-removal of plants and litter reduces rainfall interception and surface water storage, promotes rapid runoff, and decreases ground surface protection against raindrop impact and soil detachment by overland flow. Fire effects on infiltration and runoff generation are increased where soil water repellency persists post-fire or is enhanced by burning. Soil water repellency is commonly found within the first few inches of soil underneath unburned sagebrush, and pinyon and juniper litter on rangelands and its strength may increase or decrease with burning (Pierson et al. 2008, 2009, 2013).

Coarse-textured soils are thought to be prone to water repellency, but water repellent soil conditions have also been documented for fine-textured soils. Fire-induced increases in runoff and soil loss are typically greater from areas underneath shrubs and trees than interspaces between woody plant canopies. Canopy locations commonly have greater post-fire sediment availability and stronger soil water repellency than interspaces between canopies.

Increased post-fire runoff generally facilitates formation of highly erosive concentrated flow and increased soil erosion on hillslopes. Homogenous bare soil conditions (bare ground >50 to 60 percent) in the immediate post-fire period allow overland flow to concentrate into high velocity flows with greater erosive energy and transport capacity than processes occurring at the point scale (Figure 1). Concentrated flow moves soil detached by rainsplash and sheetflow downslope while also eroding sediment from within the flow path. Concentrated flow is the dominant water-based erosion process in the first one or two years post-fire and is accentuated by steep, bare hillslopes coming together. Accumulation of water and sediment on hillslopes can result in resource-, property-, and life-threatening erosion events. For example, a nine minute convective rainstorm on burned rangeland hillslopes along the Boise Front Range, Idaho, generated flooding and mud-flows in the City of Boise. The flooding was driven by intense rainfall and formation of concentrated flow on bare, strongly water repellent soils with reduced water storage capacity and low surface roughness. Similar hydrologic and erosion responses to convective storms have been reported for burned cheatgrass sites and woodlands in Utah and Colorado. The likelihood or risk of such large-scale flooding events is related to the spatial connectivity of susceptible surface conditions and the occurrence of runoff generating rainfall. Great Basin plant community conversions to invasive annual grass (e.g., cheatgrass and red brome) and climate trends that promote wildfire activity increase the likelihood that rangelands will be exposed to runoff and erosion generating storms and thereby likely enhance long-term soil loss associated with frequent re-burning.

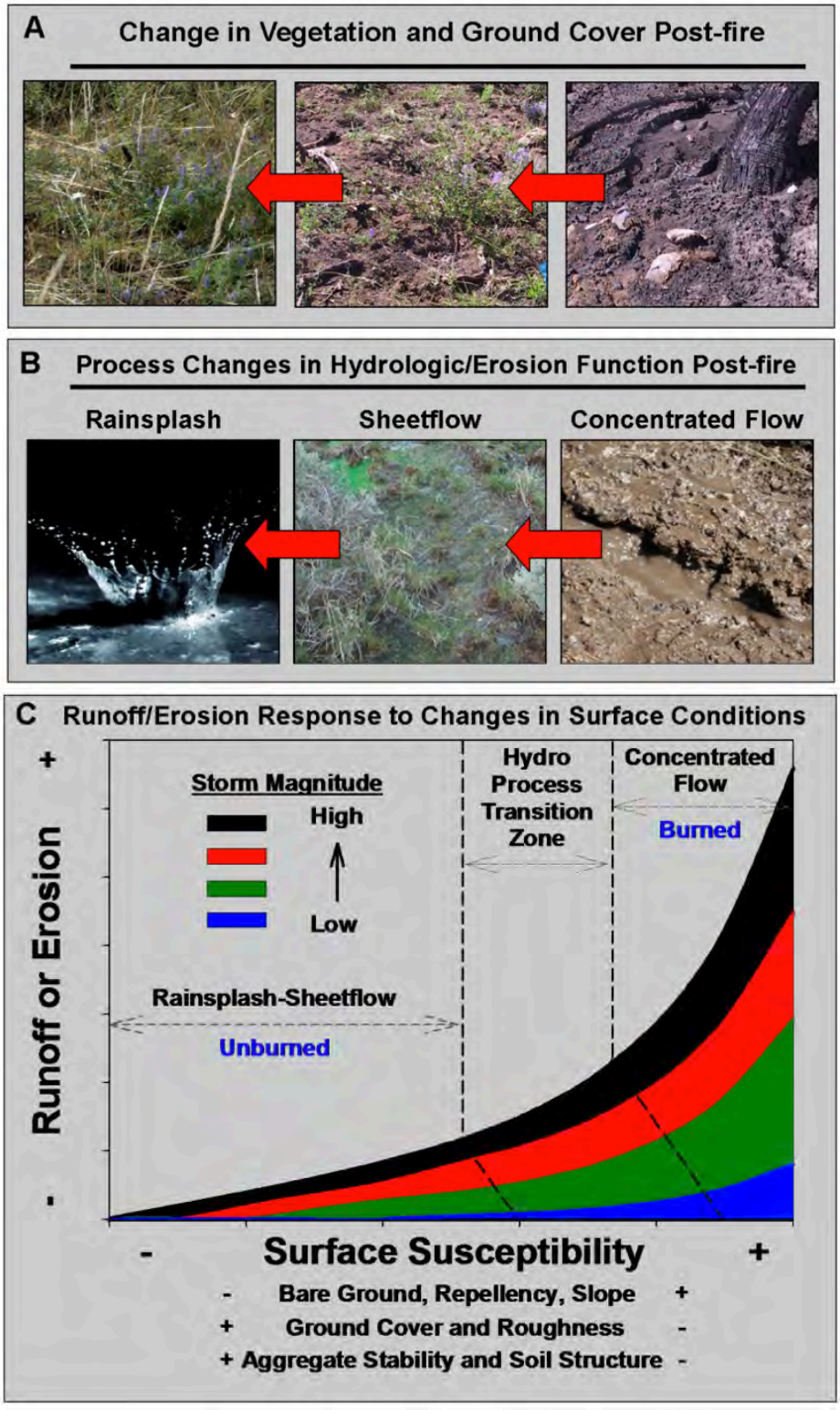

Figure 1. A) Change (recovery) in vegetation and ground surface conditions following burning; B) the shift in hydrologic processes from concentrated flow-dominated to rainsplash-dominated; and C) the decline in runoff or erosion response and shift in dominant erosion processes with decreasing surface susceptibility. Bare water repellent soil conditions in the immediate post-fire period facilitate runoff generation and promote formation of high-velocity concentrated flow. The decline in runoff or erosion response with time post-fire is strongly related to changes in ground surface conditions that trap and store water and sediment and inhibit concentrated flow. Modified from Williams et al. (2014a, b) and Miller et al. (2013).

Post-fire Hydrologic Recovery

The relative hydrologic recovery of burned rangelands is primarily influenced by the pre-fire vegetation and ground cover characteristics, fire severity, and post-fire weather and land use that affect vegetation recovery. Pre-fire vegetation and ground cover influence variability in burn severity and post-fire plant recruitment (Miller et al. 2013). Burn severity relates to the degree of impact of fire on vegetation and soil. High severity burns on productive shrublands may consume nearly 100 percent of the plants and litter, but runoff and erosion can return to pre-fire levels within a few years post-fire (Pierson et al. 2011). Rainfall simulation studies of burned mountain sagebrush communities have found that runoff post-fire returns to pre-fire levels within one growing season and that post-fire soil erosion returns to near pre-fire levels once bare ground declines to near 60 percent, usually within two to three growing seasons depending on post-fire precipitation. Other rangeland studies in the Great Basin indicate bare ground commonly returns to pre-fire levels within two to four years. Burning a Phase II to III woodland on a mountain big sagebrush ecological site increased hillslope scale runoff and erosion 4- and 20-fold from areas underneath tree canopies the first year post-fire (Williams et al. 2014b). Erosion remained elevated underneath burned junipers two years post-fire due to delayed plant establishment and bare ground persistence. Burning had no effect on hillslope-scale runoff and erosion in intercanopy areas (areas between tree canopies) the first year post-fire. Two years post-fire less erosion occurred from burned than unburned intercanopy areas probably due to well-distributed intercanopy herbaceous reestablishment post-fire.

Although relative hydrologic recovery of rangelands appears to occur within one to three years post-fire, rangelands likely remain susceptible to runoff and erosion during extreme events until overall site characteristics (e.g., live plant and litter biomass) are similar to pre-fire conditions. Rangeland ecosystems with warm/dry soil temperature/moisture regimes may require longer periods to recover hydrologically than cool/moist sites and may be vulnerable to cheatgrass invasion and subsequent re-burning. Hydrologic recovery and resilience of woodland-encroached sagebrush sites have received only minor attention in the literature. Burning may represent a potential restoration pathway for pinyon and/or juniper expansion in sagebrush steppe on cool/moist ecological sites. However, less productive sites or sites with minimal pre-fire herbaceous cover may exhibit less hydrologic resilience post-fire with respect to Phase II woodlands and intact sagebrush communities. Regardless of the soil temperature/moisture regime and pre-fire state, short-term post-fire hydrologic recovery is likely delayed by land use activities and/or drought conditions that inhibit vegetation and ground cover establishment.

Assessing Post-fire Risk

Numerous tools have been developed in recent years to aid in the assessment and prediction of post-fire hydrologic and erosion risk, including literature, sampling methods and devices, and predictive technologies to aid or guide post-fire assessments, response forecasting, and decision making. This factsheet does not allow for detailed descriptions of the numerous available tools, but provides references to some of the most widely used resources.

- ***A synthesis of fire effects on vegetation and soils*** for rangelands in the context of ecological site characteristics is in Miller et al. (2013).
- ***Field methodology for assessing soil burn severity*** and suggestions for integration of soil burn severity mapping with other predictive technologies is provided by Parsons et al. (2010).
- ***Use of mini-disk infiltrometers*** for rapid assessment of infiltration and hydrologic effects of soil water repellency (Robichaud and Ashmun 2013).
- ***The Rangeland Hydrology and Erosion Model (RHEM***) provides simultaneous comparisons of runoff and erosion predictions across multiple sites with varied conditions and has recently been enhanced for application to disturbed rangelands (Al-Hamdan et al. 2015). The model requires relatively minimal user input of commonly obtained site characteristics (e.g., slope angle, distance, and shape; soil texture; and canopy and ground cover) and delivers runoff and erosion predictions at the annual time scale and for various return-interval runoff events.
- ***The Erosion Risk Management Tool (ERMiT***) is a post-fire erosion prediction tool that estimates hillslope response based on user input for climate, soil texture, dominant vegetation type, slope gradient and length, and soil burn severity (Robichaud et al. 2007). ERMiT predicts the probability of a given hillslope sediment yield for an individual storm in each of five years following burning and provides assessment of the effectiveness of various mitigation treatments.

Many of the tools noted above are described in more detail in a recent review by Robichaud and Ashmun (2013). Additionally, recent journal articles by Pierson et al. (2011) and Williams et al. (2014a) provide reviews of fire impacts on rangeland hydrologic response and assessing post-fire hydrologic vulnerability and risk.

Mitigation of Post-fire Runoff and Erosion

The mitigation of post-fire runoff and erosion from rangelands has not been extensively studied. Therefore, much of what we know regarding effects of post-fire mitigation strategies comes from studies in forests (Robichaud et al. 2010). Post-fire runoff and erosion stabilization treatments generally

are from one of the following categories: 1) erosion barriers, 2) mulches, or 3) chemical soil surface treatments. Post-fire seeding is addressed in several Great Basin Factsheets and therefore is not discussed here. The effectiveness of each of these types of treatments depends on many factors, including: 1) burn severity conditions, 2) magnitude of storm events (that is, storm intensity/duration), 3) type and quality of installation or treatment, 4) persistence of the treatment, and 5) interaction of the treatment with vegetation and ground cover recruitment.

- ***Erosion barriers*** can be constructed of downed logs, straw wattles, or lines of straw bales and are commonly used to trap runoff and promote sediment deposition immediately upslope. Erosion barriers can be effective at trapping runoff and sediment from low intensity storm events, but are often overtopped by runoff during moderate to extreme events. Sediment storage capacity behind erosion barriers can also be filled by the first few sediment producing events, minimizing the beneficial effect for subsequent storms. Proper installation is paramount to the effectiveness of erosion barriers, as improper barrier installation can amplify erosion. Robichaud et al. (2010) provides a review of erosion barrier effectiveness in reducing post-fire runoff and erosion and provides methods for estimating erosion barrier performance.
- ***Mulch treatments*** are increasingly applied to mitigate post-fire erosion. Mulch is applied to increase ground cover and thereby protect the soil surface from raindrop impact, increase infiltration, and reduce overland flow volume, velocity, and sediment movement. Mulch treatments may consist of aerially or manually distributed agricultural straw (wheat, barley, rice), wood-based mulch (shreds or strands) or wet application of a hydromulch, made up of organic fibers and seeds bonded by a tackifier. On burned forested sites application of more than 50 percent ground cover of wood, strand mulch resulted in persistence of some mulch on sites four and seven years post-treatment, limited negative impact on vegetation, and substantially reduced annual sediment yield (by 79 to 96 percent) the first year post-fire. Wheat straw mulch application increased ground cover by 56 to 87 percent across all sites, but reduced first year sediment yield (by 97 to 99 percent) at only two of four sites where it was applied partly due to site-specific differences in straw distribution and vegetation recovery. Hydromulch treatment generally persists for weeks to months and had limited beneficial effect on post-fire runoff and erosion especially with high rainfall intensity events. Better hydromulch treatment effectiveness has been observed in Southern California with low intensity rainfall and rapid vegetation establishment.
- ***Chemical Surface Treatments*** are made from various soil binding agents which are sprayed or applied dry with pellets. When the wet binding solution dries, it forms a web of polymers that coats the surface soil particles. The treatment degrades within months after application. In a southern California post-fire study, little benefit was observed from this treatment on reducing soil erosion (Robichaud et al. 2010).

Overall, beneficial effects of treatments over the first four years are typically associated with the initial effect on ground cover, the persistence of the treatment, and vegetation recovery. Wood strands and agricultural straw mulch both may reduced sediment yield, but the wood strands show greater persistence against the effects of wind and water over time. Needle cast from low to moderate severity fires on burned pinyon and juniper woodlands may provide a natural mulch-type surface protection against runoff and erosion in the first year post-fire by limiting bare ground exposure to rainfall and aiding infiltration into water repellent soils.

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Websites

The Rangeland Hydrology and Erosion Model, RHEM:
http://dss.tucson.ars.ag.gov/rhem/

The Erosion Risk Management Tool, ERMiT:
http://forest.moscowfsl.wsu.edu/fswepp/

Burned Area Emergency Response Tools:
http://forest.moscowfsl.wsu.edu/BAERTOOLS

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Management of Aspen in a Changing Environment

Purpose: To provide land managers with information that can help them identify different aspen types, assess the condition of aspen stands, and prioritize stands for restoration using appropriate treatments.

In Brief:

- Aspen communities are biologically rich and ecologically valuable, yet they face myriad threats, including changing climate, altered fire regimes, and excessive browsing by domestic and wild ungulates.
- Recognizing the different types of aspen communities that occur in the Great Basin, and being able to distinguish between seral and stable aspen stands, can help managers better identify restoration needs and objectives.
- Identifying key threats to aspen regeneration and persistence in a given stand or landscape is important to designing restoration plans, and to selecting appropriate treatment types.
- Although some aspen stands will need intensive treatment (e.g., use of fire) to persist or remain healthy, other stands may only require the modification of current management practices (e.g., reducing livestock browsing) or may not require any action at all (e.g., self-replacing stable aspen communities).

Background and Ecology

Quaking aspen (*Populus tremuloides*) is an economically and ecologically valuable tree species that is considered to be in decline across much of the western United States due to fire suppression, severe drought, herbivory, conifer competition, and mortality from disease and insects (Campbell and Bartos 2001). Both gradual aspen decline and sudden aspen dieback (SAD) events have been recorded throughout the western U.S. in recent decades. Aspen communities are often biological hotspots in the Great Basin, because they provide critical habitat for many plant, mammal, bird, and insect species. Thus, continued aspen decline could result in cascading losses of animal and plant species.

The potential for aspen habitat loss may be particularly pronounced in the Great Basin. Aspen is the only broad-leaved, deciduous tree species of significant areal extent here, but it occupies only about one percent of this generally arid ecoregion. Aspen communities are found in higher-elevation mountain ranges in much of the northern and central portions of the Great Basin, but become less common in the southern part of the region. Aspen are typically found in montane and subalpine zones, where soil moisture is adequate during the growing season. These are typically areas with winter snowfall that subsidizes soil moisture content during drier summer months. Riparian aspen communities occur along streams and other water features, and may extend into lower elevations with generally drier conditions.

Although aspen is often considered an early successional species, aspen forms both seral (transitional) and stable (persistent or "pure") communities. In seral communities, especially those in landscapes with longer-lived conifer species, disturbance plays an important role in the persistence of aspen. Fire, in particular, is critical for aspen renewal in many seral stands, and it can create mosaics of aspen- and conifer-dominated communities that are dynamic across landscapes and over time. After fire, aspen typically resprouts prolifically and can dominate in post-fire landscapes for decades. Without a return of fire, conifer species gradually increase and form late successional communities, potentially eliminating aspen over time (Strand et al. 2009a). However, in pure aspen, or even in mixed stands with an absence of strong conifer competitors, fire may not be necessary for aspen persistence. Stable aspen communities persist via steady rates of tree recruitment, or with episodic regeneration stimulated by overstory mortality events caused by drought, pathogens, or age (Shinneman et al. 2013). In the Great Basin, both pure aspen and mixed aspen-conifer stands occur, with some mountain ranges (e.g., Ruby Mountains, Santa Rosa Range, Steens Mountain) dominated by pure aspen communities in montane and subalpine zones.

Aspen communities in the western U.S. are often dominated by long-lived clones of genetically identical individuals (ramets) that can comprise entire stands of trees and that persist through asexual reproduction (suckering). However, recent research has shown that sexual reproduction (through seed production and seedling establishment) in aspen of the Mountain West is more important than previously understood. Sexual reproduction is most common after disturbance, can provide greater genetic diversity at both stand and landscape scales, and may allow better adaptation to changing environmental and climate conditions (Long and Mock 2012).

Prioritizing stands for restoration treatments

It can be difficult to identify and then prioritize aspen stands most in need of restoration, let alone determine effective treatments. However, a key consideration is to recognize that aspen communities in the Great Basin are influenced by diverse biophysical settings, disturbance regimes, and climate conditions that have shaped the successional, compositional, and structural characteristics of the stands. Determining the stand type can help managers evaluate how current stand conditions compare to historical ranges of variability and develop appropriate management strategies. What follows are four classifications of aspen stand types that have been developed based on relationships among stand conditions, disturbance regimes, and environmental settings.

- At the continental scale, aspen communities of North America have been classified into seven subtypes (e.g., montane aspen), each nested within seral or stable functional types (Rogers et al. 2014).
- At the regional scale of the Intermountain West, aspen communities have been classified into 56 types based primarily on plant composition and structural characteristics, and further characterized by seral versus stable stand dynamics (Mueggler 1988).
- Within the Intermountain West aspen have also been classified into five fire-regime types, delineated along gradients of fire frequency and severity, defined as fire-dependent (seral) or fire-independent (stable), and associated with specific environmental conditions (Shinneman et al. 2013).
- At a local scale, aspen in the Sierra Nevada were classified based on growing conditions and relative dependence on fire for persistence (Table 1; Shepperd et al. 2006).

In addition to stand type, other important considerations for prioritizing sites for treatment include land use history, landscape context, and ongoing or future threats (e.g., climate change). For instance, a stable aspen stand with an old and senescent overstory might not be a concern, especially if wild or domestic ungulate browsing has not limited recruitment and if multi-cohort aspen stands exist elsewhere on the landscape.

Table 1. Prioritization of treatment sites and methods in aspen communities is based on an understanding of different aspen functional/stand types. Several aspen classifications exist, including this one developed for the Sierra Nevada. By using stand types, resource managers can better assess management options to achieve desired outcomes, including restoring stand composition and age structures, promoting recruitment, and influencing successional trajectories beneficial to aspen (adapted from Sheppard et al. 2006).

Aspen Stand Type	Successional Type	Characteristics
Meadow Fringe	Seral	Aspen restricted to less saturated soils on meadow edges (fringe). They typically have diverse herbaceous understories and are often seral to conifers.
Riparian	Seral	Aspen occurring along water sources (streams, seeps) that may or may not contain a woody understory (e.g., alders or willows).
Upland Aspen/Conifer	Seral	Aspen co-occurring with conifers, located away from obvious surface water sources.
Lithic	lava, boulder, talus	Aspen occurring in association with lithic features, such as glacial moraines, talus, or lava flows. May serve as refugia from browsing, fire or other disturbance.
Snowpocket	Stable	Aspen occurring where topography causes greater snow accumulation.
Upland Pure	Stable	Aspen occurring outside riparian zones, but not typically containing conifers.
Krummholz	Stable	Aspen with a low shrub-like stature that is often associated with high-elevation, wind-swept topographic features (e.g., rocky ridgelines).

In contrast, a conifer-dominated mixed aspen stand might need restoration treatment, especially if natural fire regimes have been altered by suppression activities at landscape scales and/or browsing has impacted recruitment rates.

Once assessments of stand history and stand type have been made, additional site-specific criteria are needed to further prioritize stand treatment. Various ecosystem attributes can be used to evaluate aspen stand stability, conditions, and trends such as proportion of conifer in the overstory, aspen age, and density of regenerating aspen trees (Table 2). Also, various protocols have been developed to quantify risk factors and prioritize aspen stands for treatment, based on these ecosystem attributes (see review in Shepperd et al. 2006).

Restoration Strategies and Treatment Types

Once a stand has been assessed and restoration objectives established, various treatments can be implemented to achieve those objectives (Figure 1). Regardless of treatment type, chances for successful aspen asexual reproduction depend on the factors in the "Aspen Regeneration Triangle."

Table 2. Ecosystems attributes that can be evaluated to determine aspen stand stability, conditions, and trends. The attributes and the criteria used to determine the type of management action, if any, will vary depending on stand type, stand history, and restoration objectives. Other attributes that may be monitored include soil temperature, distance to water, and wildlife habitat structure. Assessment and monitoring protocols are available in Sheppard et al. 2006 and Strand et al. 2009b.

Category	Key Attributes to Evaluate and Monitor
Forest overstory	• Absolute tree cover, canopy closure • Proportion aspen vs. conifer species • Tree density • Stem diameter / basal area • Stand age / tree age class distribution • Tree height • Live / dead crown ratio
Understory plant community	• Total understory cover • % cover by functional type (native forbs, native grasses, shrubs, and suckers/saplings) • Plant species richness
Ground cover	• Cover of litter, basal vegetation, downed wood, moss, fungi, decomposing organic matter, bare ground
Regeneration	• Number of aspen suckers/seedlings/saplings per area • Recruitment rate (to height adequate to avoid excessive herbivory)
Non-native, noxious, or invasive species	• % cover (by invasive species type)
Fragmentation	• % of landscape fragmented by roads, trails, powerlines, structures, campsites, mines, ponds, or reservoirs
Disturbance agents	• Estimates of fire history (e.g., frequency) from maps, fire-scars, soil charcoal • Uncharacteristic plant type conversion (due to excessive or inadequate rates of disturbance) • Ratio of trees affected by disease, insects, drought, sun-scald, etc.
Herbivory	• % terminal leaders browsed • % of biomass removed from branches • Trampling, amount/type of animal scat

Figure 1. An aspen stand located in an urban interface that has experienced 80 to 100 years of fire suppression, 50 years of moderate to high recreation use, over 100 years of cattle and sheep grazing, and 40 years of elk use. Sites such as this often need active or passive restoration. Even with a good understanding of stand type and history to help determine appropriate restoration strategies, there are many challenging management considerations, including determining if fire is a socially acceptable option, how to best control wild ungulate and domestic livestock use, how to manage human recreation use, and whether or not understory plants will need to be re-introduced.

These include: 1) hormonal stimulation (by interruption of the flow of auxin from shoots to roots); 2) protection from herbivory; and 3) a growth environment with ample solar radiation, soil moisture, and nutrients (Shepperd et al. 2006). In addition, to assess the effects of different management practices, it is necessary to monitor stand attributes that indicate treatment success (e.g., sucker density and recruitment) (Table 2, Figure 2).

Silvicultural treatments

Because aspen are often poor competitors, a commonly used silvicultural treatment is hand or mechanical removal of competing vegetation, typically conifers. Such treatments have been effective in restoring aspen sprout density (e.g., Jones et al. 2005), especially when residual aspen trees still have vigor and when sprouts or suckers are protected from ungulate browsing. However, success after conifer removal can also depend on other site, disturbance, and climate factors. For instance, in the eastern Sierra Nevada, competing lodgepole pine were removed from a seral aspen stand, but over the next three years little sprouting occurred and many residual older (>130 years) aspen trees died due to sunscald (Krasnow et al. 2012). Clearfell-coppice (complete stand removal) has also been used in the past to harvest aspen wood and return stands to early successional conditions. Although clearfell-coppice techniques can stimulate dense reproduction in vigorous seral stands, potential drawbacks may occur.

Figure 2. Visual indicators of aspen health:

a) An aspen stand in good condition with adequate canopy cover, multiple layers of vegetation, and multiple ages of aspen. The view through the stand is often limited by aspen stems, saplings and suckers, and native species of tall forbs, mountain shrubs and shade tolerant grasses.

b) An aspen stand in poor condition with visible, bare soil. The aspen stems are primarily all one age class (mature) and show significant signs of damage and disease. Suckers and saplings are rare or absent. Native mountain shrubs, tall forbs, and grasses are rare.

c) White fir is expanding outward from the center of this aspen stand, possibly due to lack of fire or because livestock or wild ungulate browsing has eliminated understory aspen recruitment. If restoration treatments (e.g., prescribed fire) are required, they are unlikely to be successful if ungulate browsing is not controlled. Reintroduction of native understory plant species may also be necessary.

These include soil compaction, lack of diverse age classes, and altered nutrient cycling. Modifying these traditional coppice methods to retain groups of aspen trees as seed sources can promote sexual reproduction and increase genetic diversity (Long and Mock 2012), as well as decrease site disturbance.

Mechanical root stimulation (root ripping)

Preliminary studies indicate that lateral roots will produce sprouts when severed from the parent tree (thus interrupting the flow of auxin). A dozer-mounted ripper was used successfully to regenerate aspen by severing lateral roots on the periphery of a stand, producing sprouts up to 42 feet (13 meters) away from the existing aspen clone. This technique has not been rigorously tested, but may hold promise as a viable method of regenerating an existing clone without top-killing mature stems (Shepperd et al. 2006).

Prescribed fire

Prescribed fire can be an effective treatment to rejuvenate aspen because top-killing aspen can provide hormonal stimulation, release a pulse of nutrients to the soil, reduce vegetative competition, and increase solar radiation to the forest floor. This technique might be most effective in mixed aspen-conifer, as pure aspen stands may not have the necessary fuel loads or moisture to easily carry fire, and there is little evidence that fire played an historical role in these communities (Shinneman et al. 2013). In the Coconino National Forest in Arizona, the logging slash of removed conifers was scattered to fuel a subsequent prescribed fire that resulted in significantly higher sprout densities compared to conifer removal only (Shepperd et al. 2006). However, prescribed fires can be problematic if they do not burn intensely enough to kill aspen or competing species, if heavy coarse woody debris heat-kills underground lateral roots, or if post-fire aspen sprouts are unprotected from native or domestic browsers.

Wildfire use

Wildfire has historically been and will likely continue to be a primary disturbance agent for regenerating seral aspen. When socially acceptable and ecologically advantageous, allowing wildfires to burn and create early successional conditions favorable for aspen regeneration has many advantages. Wildfires often burn at higher severity and cover larger areas than prescribed fires, which favors aspen regeneration (Figure 3). Moreover, wildfires open the limited spatial and temporal window for successful aspen seedling establishment, which is increasingly recognized as important for aspen reproduction and genetic diversity (Long and Mock 2012, Krasnow and Stephens 2015).

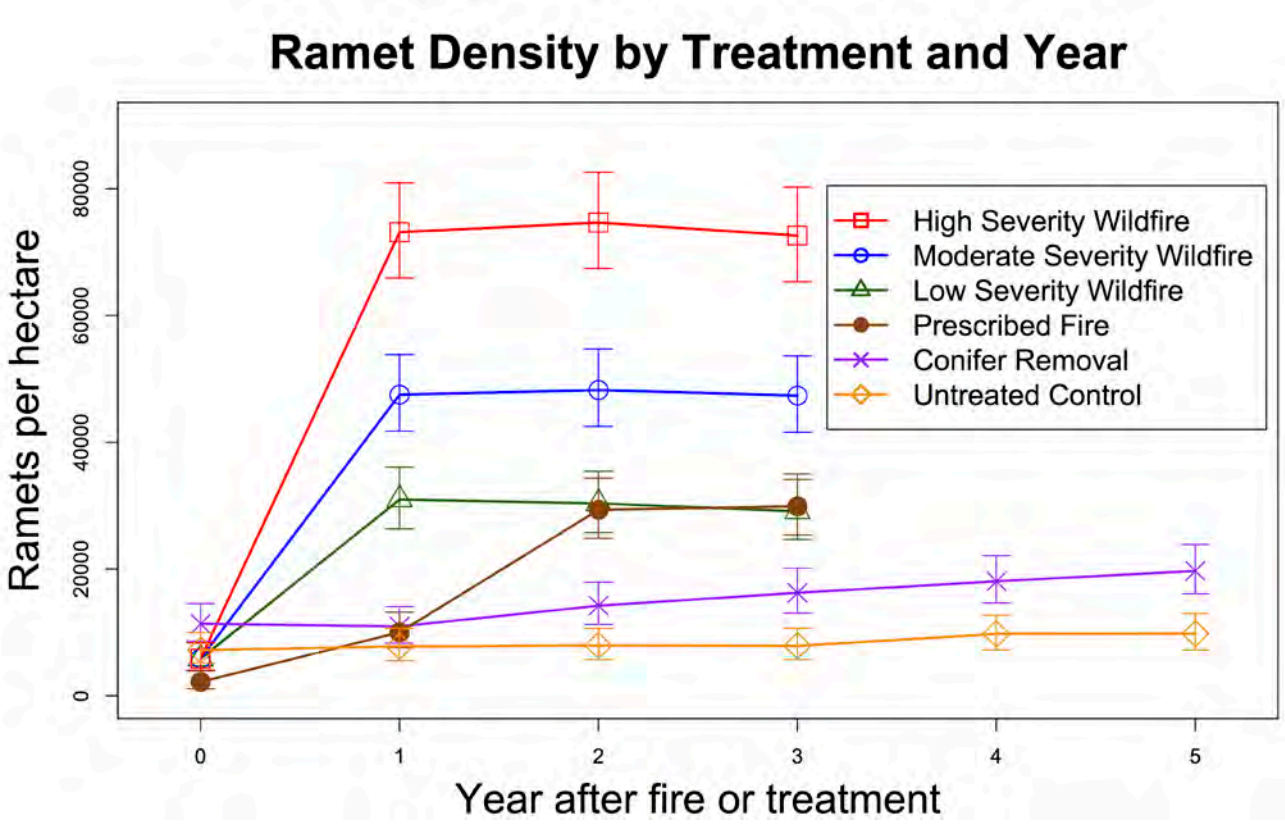

Figure 3. Individual tree (ramet) density over time following prescribed fire, conifer removal and low, moderate, and high severity wildfire in comparison to an untreated control. Points indicate the mean ramet density among plots and whiskers represent the 95% Poisson confidence intervals (from Krasnow and Stephens 2015).

Livestock and Wildlife Management

It is important to assess the effects of livestock and wild ungulates (deer and elk) in a restoration project area and to develop mitigation measures to minimize possible impacts to aspen regeneration (Figure 4). Season-long and intensive browsing by livestock and wild ungulates in aspen stands will reduce aspen establishment and recruitment, suppress understory shrub and tall forb density, and may create openings for non-native plants. To escape heat and find succulent vegetation, cattle often gather in and heavily use aspen stands. Small, low-elevation stands are often at greatest risk to damage from livestock browsing pressure, especially when combined with other factors, such as drought and wildlife herbivory. Post-disturbance aspen stands are also often susceptible to ungulate browsing pressure that can inhibit recruitment and seedling establishment.

Several management options may be effective to reduce the negative impacts of browsing on aspen regeneration, including removing or selectively controlling ungulates to allow aspen ramets to grow above browse height. Effective herding or removal of livestock in late summer can reduce many negative grazing impacts. In some cases, conifer and aspen trees can be cut and felled horizontally and layered to create a barrier to browsing by livestock and deer (Kota and Bartos 2010). Elk are not as easily deterred, and successful recovery of small and isolated aspen stands may require taller ungulate-proof fencing. Recovery of aspen will likely be more successful if browsing is eliminated or reduced for eight to ten years, with effective duration depending on browsing species and pressure, and the time required for suckers to grow above browse-height (Shepperd et al. 2006).

Figure 4. Long-term grazing and associated effects on aspen health:

a) This aspen stand has been grazed by sheep for more than 80 years. The understory is primarily grass with few forbs and no shrubs. Aspen regeneration is poor. Changes in grazing management have improved the understory cover, but forbs and shrubs may need to be introduced and timing of grazing altered to allow for aspen regeneration.

b) This aspen stand has been grazed by cattle for more than 80 years. The understory has some forbs, but grasses and shrubs are missing. Aspen regeneration is occurring due to a shorter grazing season. Shade tolerant grasses from nearby areas may move into the stand over time, but tall forb species are limited and may need to be seeded.

c) Although the fire return interval was appropriate, a degraded understory before fire combined with heavy ungulate browsing after fire resulted in a loss of this aspen stand. This site was fenced with an eight foot wildlife enclosure three years post-fire, but snow and ungulate pressure allowed openings in the fence, and grazing by elk and cattle over 10 years resulted in a loss of tall forbs and prevented successful aspen suckering.

Long-term Management Considerations Under Climate Change

Earth's climate is becoming warmer, and the amount of snow and ice is decreasing. In the Great Basin, temperatures are increasing, relative humidity is decreasing, and seasonal precipitation is becoming more variable. Recent, drought-induced aspen dieback events have occurred throughout the western U.S and Canada, and more extreme and prolonged drought events may become more common under future climate (Anderegg et al. 2013). Great Basin aspen located at low elevation and south or west facing aspects may be particularly susceptible to drought-induced mortality, as documented in other western U.S. regions. In addition, shorter and warmer winters are leading to reduced snowfall or snowpack persistence in the Great Basin (Chambers 2008), thereby reducing snow-water subsidies that support aspen, especially at lower elevations. Unlike in many other ecoregions, Great Basin aspen communities have little opportunity to migrate under climate change, because they are surrounded by low elevation sagebrush steppe and semi-desert.

In addition, recent fire-climate trends and predictive models suggest an increase in average annual area burned by wildfire under climate change (Dennison et al. 2014). Although it seems likely aspen will decline due to a warmer and drier climate, increased fire activity could benefit aspen in locations with sufficient growing season moisture. Recent modeling suggested that, although the range of aspen in the northern Great Basin would be restricted under future climate change, fire could facilitate aspen movement into higher elevations that are currently dominated by subalpine fir (Yang et al. 2015). Thus, allowing desirable wildfires to burn in some high elevation locations may create suitable conditions for the establishment of new aspen stands.

Many current management strategies presume that the past is a good predictor of the future; however, in times of climate change there is no single solution that fits all cases. Managers are encouraged to be flexible, innovative, and implement experimental approaches at small scales to explore which options result in the desired outcome. A range of management options may need to be considered, including managing some ecosystems for resistance to undesirable change, promoting ecosystem resiliency after disturbance, and facilitating inevitable ecosystem change to result in acceptable rather than catastrophic conditions (Millar et al. 2007). Indeed, it may become necessary to manage for different plant communities in areas that are not likely to support aspen into the future, while simultaneously implementing management practices that promote aspen in areas most likely to remain or become suitable for future regeneration and growth. We also suggest implementation of monitoring programs for detecting changes in regeneration, growth, and mortality in a variety of management situations (i.e., no action; active and passive management regimes).

If lack of regeneration and growth is observed in a stand, it is important to attempt to identify stressors (e.g. herbivores, conifer succession, drought). Finally, realistic management goals are important because loss of aspen may reflect ongoing successional or climate-induced trends, and future losses are likely in certain biophysical settings (e.g., low-elevation, southwest-facing slopes).

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Woody Fuels Reduction in Wyoming Big Sagebrush Communities

Purpose: To discuss consequences and options for woody plant fuel reduction in Wyoming big sagebrush plant communities of the Intermountain West.

In Brief:

- Loss of understory herbaceous species, an increase in annual weed cover, and in many cases an increase in shrub cover have resulted in more fine fuels, greater fuel continuity, and more frequent fires in Wyoming big sagebrush communities.
- Fuel treatments can decrease woody fuels and fire severity and help restore the plant community, but the possibility of negative versus positive effects must be carefully evaluated.
- Thinking through a series of key questions that determine treatment response helps in deciding whether to proceed with woody fuels reductions and, if so, which treatment methods to use.
- Herbicides or mechanical treatments may be used, depending on impacts of treatment on the desirable herbaceous species and the degree of surface disturbance. Prescribed fire in Wyoming big sagebrush is extremely risky and, in general, is not recommended.

Wyoming big sagebrush (*Artemisia tridentata* Nutt. ssp. *wyomingensis* Beetle & Young) ecosystems historically have been subject to disturbances that reduce or remove shrubs primarily by fire, but occassionally due to insect outbreaks and disease. Depending on site productivity, fire return intervals occurred every 60-110 years. Following fire, perennial grass-dominated plant communities slowly underwent succession to return to a community co-dominated by sagebrush and perennial grasses. Due to historical and (in some cases) recent overgrazing, many Wyoming big sagebrush communities have undergone changes in plant community composition – primarily a decrease in the density and cover of native perennial grasses and forbs.

The consequences of this loss of understory herbaceous species have been an increase in annual weed cover and, in many cases, shrub cover. Increases in annual weeds such as cheatgrass (*Bromus tectorum* L.) result in more fine fuels, greater fuel continuity, and more frequent fires. These changes have led to more severe and larger fires during periods of extreme fire weather.

Management to address these changes in fuels and fire behavior is challenging in Wyoming big sagebrush communities because warm and dry conditions coupled with low productivity result in (1) low resilience and thus slow recovery following both wildfire and management treatments, and (2) low resistance to annual weeds.

Why Reduce Woody Fuels in Wyoming Big Sagebrush Communities?

Objectives for fuel management in Wyoming big sagebrush communities typically include both decreasing woody fuels and fire severity, and restoring ecosystem structure and function. Reducing woody plant cover has the potential to increase production of perennial grasses and forbs, improve habitat for some wildlife species, reduce intensity and severity of wildfires, increase fire suppression options, and reduce smoke particulate production harmful to human health (Pyke et al. 2014). In most cases shrub thinning is the most appropriate goal, but complete shrub removal may be appropriate for highly specific goals. For example, fuel breaks along roads can reduce the likelihood of wildfire spreading into adjacent sagebrush communities and provide a safer environment for fire suppression. (See "Fuel Breaks that Work" in the Great Basin Factsheet series.)

Potential Positive and Negative Consequences

Woody fuel treatments in Wyoming big sagebrush communities may have both positive and negative consequences. The likelihood of a positive response depends on the management goals, overall environmental context, pre-treatment condition of the community, and methods used.

A primary objective of thinning of sagebrush fuels is to release desirable perennial herbaceous vegetation from competition with sagebrush and promote increases in its density and cover (Pyke et al. 2014).

Increases in perennial herbaceous vegetation can increase resistance to weed invasion and resilience to future disturbances (e.g., wildfire), decrease the abundance of dry fine fuels produced by exotic annuals, decrease wind and water erosion, and increase water infiltration, soil organic matter, and soil carbon sequestration. However, perennial grass response to shrub removal or reduction depends on both the method used and the initial cover of native perennial grasses, and is not always positive (Davies et al. 2011). Shrub thinning can increase soil water and nutrient resources which can be used by desirable herbaceous perennials. However, the extra resources also can be monopolized by exotic weeds, especially if the treatment results in soil surface disturbance, increasing the likelihood of fire and habitat degradation. Shrub removal, even in the absence of ground disturbance, may decrease long-term resistance of plant communities to exotic annual grass invasion (Blumenthal et al. 2006).

The effect of Wyoming big sagebrush reduction on wildlife habitat depends on the species of wildlife and the method and amount of reduction. Although treatment results are variable, it has been suggested that sagebrush reduction can stimulate production of forbs important to brooding sage-grouse, wild ungulates, and pollinators. Sagebrush reduction by mowing has been found to increase Wyoming big sagebrush nutritional quality (Davies et al. 2009). Small patches of reduced sagebrush cover within sagebrush landscapes have improved sage-grouse brooding habitat in mountain big sagebrush, but these relationships have not been tested in Wyoming big sagebrush (Beck et al. 2012).

In contrast to the potentially beneficial effects, loss of structural habitat complexity with shrub reduction or removal may negatively impact shrub-dependent wildlife species and impair screening cover in sage-grouse breeding habitat (Beck et al. 2012). The degree of impact varies with treatment spatial scale. Small-scale reductions within a largely intact sagebrush landscape may have little negative impact and can even benefit birds whose habitat requirements are associated with spatial and seasonal availability of grass- and forb-dominated plant communities. However, if sagebrush reduction leads to reduced forb abundance, seasonal habitat for sage-grouse, wild ungulates, small mammals, and pollinators can be compromised. Habitat for both shrub and herbaceous-associated wildlife species is compromised if shrub reductions result in exotic annual grass increases. Loss of, or dramatic reduction in sagebrush cover can have negative impacts on the winter habitat of sage-grouse, pronghorn, mule deer, and elk. Also, reduction in sagebrush cover may reduce nesting cover for sage-grouse and nesting habitat availability for twig-nesting native bees, which are important pollinators.

Increasing the Chances of a Positive Outcome

Whether the response to fuels treatment is positive or negative depends on many factors, some of which can be controlled and some not. While responses are complex, thinking through a series of key questions that determine plant successional trajectories following treatment will help to determine whether to proceed with woody fuels reductions and, if so, which treatment methods to use (Table 1; Miller et al. 2014).

Table 1. The primary components that determine successional trajectories following fuels treatments, and the key questions used to evaluate those successional trajectories and consequently, management outcomes (adapted from Miller et al. 2014).

Primary Components	Key Questions
Ecological Site Characteristics	• Temperature regime? • Moisture regime? • Potential vegetation?
Current Vegetation	• Reference state & phase (seral state)? • Invaded state or phase-at-risk? • Invasive species seed source? • Need to seed? • Old-growth or woodland phase?
Disturbance History	• Types? • Past effects? • Current impacts?
Treatment Type & Severity	• Intensity and duration? • Crown or surface fire? • Size and complexity? • Time of year? • Surface disturbance?
Pre & Post Weather	• Fuel loads and moisture? • Seed banks? • Post treatment establishment? • Recent drought?
Post-Fire Grazing	• Deferment period? • Active management?
Monitoring & Adaptive Management	• Were the objectives met? • If not, what adjustments or follow-up management is required?

What is the ecological site type?
Ecological site descriptions provide information on climate, topography, and soils and can be used to help predict treatment outcomes. Favorable herbaceous responses are more likely on sites with relatively high productivity and cool (frigid) and moist (ustic or xeric) soil temperature and moisture regimes than on sites with warm (mesic) and moist or dry (aridic) regimes (Chambers et al. 2014; Miller et al. 2014).

What is the pre-treatment composition of the plant community?
The pre-treatment cover of perennial grasses and forbs is a primary determinant of the site's response to treatment. In general, the greater the cover of perennial grasses and forbs prior to treatment, the greater the likelihood of a favorable response. In Wyoming big sagebrush communities, about 15 to 20 percent pre-treatment cover of herbaceous perennial species appears necessary to prevent post-treatment increases in exotic annuals (Davies et al. 2008, Chambers et al. 2014).

What is the overall condition of the community as determined by its disturbance history?
If interspaces between perennial plants are predominantly covered by exotic annual grasses (as opposed to bare ground), or, if perennial bunchgrasses are located predominantly under shrub canopies, the apparent trend is downward and the site could be at high risk of annual grass increases following treatment or disturbances such as wildfire.

How will the treatment affect the recovery potential of the site and the likelihood of increasing exotic annuals like cheatgrass?
Treatments that reduce cover or density of herbaceous perennials or biotic crusts can threaten post-treatment recovery. Surface disturbance and associated biotic crust damage often favor cheatgrass and other exotic annuals. Also, herbicide treatments that reduce sagebrush or perennial grasses and forbs can increase resource availability and may favor annual invaders if post treatment cover of perennial herbaceous species is insufficient for recovery.

How will pre- and post-treatment weather influence treatment outcomes?
Weather conditions prior to, during, and following the treatment year can affect recovery of native perennials and the response of cheatgrass and other annual invaders. Consequently, weather can influence both the decision to treat and post-management actions such as length of grazing deferment.

Is a post-treatment management plan in place?
If perennial grass cover is limited prior to treatment, grazing should be deferred after treatment to allow perennial grasses to recover. The length of deferment depends on the productivity and soil temperature and moisture regime of the site, the pre-treatment cover of perennial grasses, treatment severity, and the post-treatment weather. Warm and dry sites with low productivity and sites with lower cover of perennial grasses and forbs will require longer periods of deferment, especially during drought periods.

Is a monitoring plan in place?
Post-treatment monitoring provides information on treatment outcomes that can be used to adjust future treatment prescriptions as well as post-treatment management.

What will the impacts be on other important resources?
Interdisciplinary teams including state agency wildlife biologist should be used to plan woody fuels reduction treatments (amount of removal, spatial pattern of treatments, etc.). This ensures that wildlife species of concern and other issues such as archaeological resources, threatened and endangered plant species, etc., are considered.

Methods of Woody Fuels Management

Managers must consider both the effects of shrub reductions and the particular methods used to achieve that reduction (Monsen et al. 2004). Methods should be evaluated in the context of the questions posed above and the guidance in Miller et al. (2014). For example, what are the impacts of treatment on the desirable herbaceous species and the degree of surface disturbance? Table 2 summarizes the relative effects of different shrub reduction techniques on factors of interest.

Herbicides – Areas treated with herbicides maintain some vertical plant structure due to dead shrubs that can persist for years, which benefits some wildlife. However, these areas also retain woody fuel vertical structure so fuel reductions occur over the long term, not short the term. Aerial application of herbicides minimizes surface disturbance from wheel tracks of the spray rig during ground application. Tebuthiuron is the herbicide most commonly used for reducing Wyoming big sagebrush cover.

Tebuthiuron is applied as dry pellets that dissolve and leach into the soil where it is absorbed by plant roots, inhibiting photosynthesis. It can be applied any time the soil is not frozen or covered by snow. Although it is non-selective, big sagebrush is particularly sensitive to its effects, so it can be applied at rates that selectively kill sagebrush with minimal impact on other plants in the community. Sagebrush usually begins to exhibit senescence and defoliation about one year following application. Leaves may grow back and die again before eventual death, usually by the third year. The half-life of tebuthiuron is 360 days, but it will remain active in the soil for up to seven years following treatment (depending on the initial application rates), inhibiting recruitment of sagebrush seedlings. (See the manufacture's instructions and Olson and Whitson 2002 for application information.)

Mechanical – Mechanical means are a commonly used option for Wyoming big sagebrush reduction (see rtec.rangelands.org/). The amount of surface disturbance can vary greatly depending on the technique. Incorporating seeding

Table 2. Summary of relative effects of the different shrub reduction techniques on factors of interest when making decisions about treatments. VH = very high, H = high, M = medium, L = low, VL = very low, EV = extremely variable.

Factors	Herbicide	Mow	Crush				Drag				Fire	Biological
	Tebuthiuron	Mower	Roller Chopper	Aerator	Discing	Imprinter	Smooth Chain	Ely Chain	Rail	Dixie Harrow	Prescribed Burn	Targeted Grazing
Undisturbed surface %	VH	H	L	M	L	M	M	L	L	L	H	M
Flexibility in % removal	H	H	L	M	M	L	L	L	L	L	VL	H
Seeding compatibility	VL	VL	H	H	VH	VH	M	H	H	H	M	M
Cost effectiveness	H	M	M	M	M	M	M	M	M	M	EV	L
Structure modification	L	VH	H	H	H	H	M	H	H	H	H	M
Treatment lifespan	VH	L	M	M	M	M	VL	L	L	L	EV	M
Ability to manage within patch diversity	H	VH	H	H	M	H	H	M	M	M	L	M
Ability to manage among patch diversity	H	VH	VH	VH	VH	VH	H	H	VH	VH	M	H
Certainty of woody fuels reductions	H	VH	H	H	H	H	H	H	H	H	EV	M

with a mechanical treatment is possible if the understory lacks perennial plants and does not have a cheatgrass understory. Seed must be incorporated into the soil and applied at the appropriate time for successful establishment (Monsen et al. 2004). All of the mechanical methods can modify plant community structure as well as change species composition. One limitation of all mechanical techniques is inaccessibility on steep slopes (over 30 percent with the exception of chains which can be used on slopes up to 50 percent).

Mowing with a large rotary mower (brush hog, rotary cutter) cuts off plants at the stem (Figure 1). Because sagebrush does not re-sprout, this can reduce plant density and cover, depending on the blade height which can be adjusted to obtain the desired level of sagebrush reduction. Herbaceous and some shrub components re-sprout and may increase or be unaffected. Increases in the rest of the community may be desirable (e.g., perennial grasses) or undesirable (e.g., rabbitbrush). Mowing is the least ground-disturbing of the mechanical methods, but it is difficult to combine with a seeding practice because of the lack of a way to ensure good seed-to-soil contact (Davies et al. 2011).

Crushing or cutting with land imprinters, aerators, roller choppers, and discs removes or reduces Wyoming big sagebrush by breaking and cutting stems, reducing cover, and causing varying levels of mortality. Herbaceous and some shrub species typically re-sprout and are minimally affected, depending on equipment settings. Aerators are less ground disturbing than other crushing or dragging mechanical methods.

Figure 1. Mowing treatment in Wyoming big sagebrush at Onaqui, Utah, with blade height set to thin sagebrush canopy cover approximately 50 percent. Photo: Summer Olsen.

All of these crushing methods are very compatible with seeding because of the abundance of seed-to-soil contact microsites created. Seed can be applied either before or after the treatment, depending on the seeding technique.

Dragging of chains, rails, or a 'Dixie Harrow' removes Wyoming big sagebrush through scraping and crushing. Brittle sagebrush stems are severed or broken while the rest of the plant species remain relatively intact. Sagebrush mortality is typically higher with summer treatment compared to a spring treatment. Degree of surface disturbance depends on the type of equipment, but they are all suited to combine with seeding. Smooth chains are the least surface disturbing, but also the least effective (30 percent reductions in Wyoming big sagebrush). Ely chain, rail, and Dixie Harrow result in greater sagebrush removal (50 to 75 percent) and greater surface disturbance. On sites with more than 25 percent pre-treatment sagebrush cover, using the rail and Dixie Harrow is difficult due to the tendency of sagebrush plants to accumulate and clog equipment.

Figure 2. Fire burning up to a mowed line in a Wyoming big sagebrush plant community in southeast Oregon. Mowing alters the structure of woody fuels, reduces fire behavior, and increases the success of suppression efforts.

Prescribed fire – Prescribed fire (Figure 2) can reduce woody fuels in Wyoming big sagebrush if there are sufficient fine fuels to carry the fire. However, prescribed fire in the warm and dry sites characteristic of Wyoming big sagebrush is extremely risky. Following fire, these sites exhibit (1) limited or slow recovery, (2) low resistance to invasive annual grasses, and (3) decreased habitat suitability for many wildlife species. Fire escape can consume excessive amounts of the landscape and increase cheatgrass invasion, both of which have detrimental effects on wildlife habitat. Prescribed burns should only be conducted if perennial grasses are adequate to compete with invasive annuals. Fire can still be risky if perennial grasses are predominantly located under shrub canopies, as shrubs generate high heat loads when burning, which can kill perennial grasses and reduce resistance to exotic annual grasses. Cool burning conditions (lower temperatures and higher humidity) and small burn patch sizes can help to reduce perennial grass mortality. The risk of an undesirable outcome decreases on cooler and moister sites with a greater herbaceous perennial plant component, but prescribed fire should still be used with extreme caution (Rhodes et al. 2010).

Targeted Grazing – Targeted grazing is the application of a specific kind of livestock at a determined season, duration, and intensity to accomplish defined vegetation or landscape goals. Wyoming big sagebrush reduction with targeted grazing can range from 10-70 percent. It is manageable and scalable.

The effect on other plant community components is minimized when applied in the dormant season, preferably after a hard freeze, and when adequate rest during the growing season follows treatment. Targeted grazing to reduce sagebrush cover requires a higher level of management, supervision, labor, and knowledge compared to typical grazing practices. It is a deliberate and focused effort rather than a byproduct or side effect of existing grazing practices.

Sheep and goats are natural browsers and can be encouraged to increase use of sagebrush in the fall or winter with supplemental feed. Cattle forage selection can be shifted to include a significant amount of sagebrush through conditioning. Logistics such as assembling an adequate number of animals in the right place at the right time under the right conditions typically limit the applicability and magnitude of this technique.

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Seeding Techniques for Sagebrush Community Restoration After Fire

Introduction

Great Basin sagebrush communities are experiencing widespread degradation due to the introduction of invasive annual weeds and disturbances that promote weed expansion, including inappropriate grazing and fire. Many sites previously occupied by diverse communities of perennial grasses, forbs, and shrubs have been reduced to depauperate sagebrush stands that readily become dominated by invasive annuals following fire. Post-fire seeding may be necessary to prevent these areas from converting to annual grasslands.

For many years, post-fire seedings on public lands have followed a rehabilitation model where rapid establishment of perennial cover is the primary objective. To achieve this objective, managers have relied heavily on rangeland seeding techniques and plant materials originally developed for forage production. The use of rangeland drills to seed crested wheatgrass (Young and McKenzie 1982, Vallentine 1989) exemplifies this approach. The rehabilitation model is increasingly being replaced by a restoration model that includes plant community diversity and wildlife habitat as desired outcomes of post-fire seeding (PCA 2015, USDOI 2015). The shift towards restoration has led to an increased use of native plants and development of new or modified seeding techniques to accommodate multiple seed types (Monsen and McArthur 1995, Monsen et al. 2004, Benson et al. 2011). This factsheet presents information on seeding strategies and techniques that can be used to restore diverse sagebrush communities following fire. Other factsheets in this series provide complementary information on seeding big sagebrush and establishing shrubs from planting stock.

Purpose: To outline important considerations and options for post-fire seeding, including the selection of seed mixes and seeding equipment for restoring sagebrush communities following fire. The emphasis is on lower-elevation communities where restoration needs are greatest. References and resources are offered for greater detail and guidance on specific topics.

In Brief:

- Post-fire seeding increasingly emphasizes restoration of plant community diversity and wildlife habitat, requiring seeding techniques for a variety of seed types.
- Low-elevation sagebrush communities are often priority areas for post-fire seeding, but they require careful planning and sometimes multiple treatments to ensure seeding success.
- Information is available to assist in making decisions regarding seed sources, seeding rates, and species compatibility when formulating seed mixes for post-fire seedings.
- Seeding equipment should be selected based on terrain, seedbed and burial depth requirements of seeded species, and potential impacts to residual plants and biological soil crusts.
- Rangeland drills can be modified to place seeds of different sizes in different rows allowing smaller seeds to be placed on the surface rather than in furrows, thus increasing the probability of establishment.

Deciding Whether to Seed

Post-fire seeding with limited resources requires a triage approach to prioritizing treatments. One approach is to focus on areas that have the greatest chance of successful seedling establishment, typically higher elevation areas with more favorable soil moisture and less competitive pressure from invasive annuals. The drawback of this approach is that these sites are less likely to require seeding due to inherent resilience. Careful attention should be paid to whether a site is likely to recover without seeding, because seeding may actually disrupt site recovery (Miller et al. 2015). Low- to mid-elevation sites may not need to be seeded if fire-resilient perennials are present and weed control measures (e.g. herbicides, biocontrols) are applied. Pre-emergent herbicides can be applied in the fall to reduce invasive annuals and thereby assist perennial plant growth and reproduction (see Great Basin Factsheet 3 for further discussion).

Another approach is to focus on areas with the most critical need for restoration following fire (e.g., crucial wildlife habitat corridors) or areas that are least likely to recover on their own (Miller et al. 2015). Lower-elevation Wyoming big sagebrush sites commonly fall into this category, although even in this case, sites in good condition may recover without seeding. The decision to seed a poor-condition, low-elevation sagebrush site is complicated by the fact that these sites are more difficult to seed and success is not guaranteed with a single treatment. Multiple attempts at seeding may be necessary in combination with weed control measures.

Seeding is commonly implemented within the year following a fire in an effort to take advantage of reduced annual weed abundance immediately post-fire, and to quickly establish perennial cover. However, delaying seeding until a later year may be sensible if drought conditions are predicted for the upcoming winter and spring. The best season to seed is usually late fall or winter. If seeded too early in the fall, seeds lacking a stratification requirement may germinate prematurely and be killed by winter frosts. High soil moisture in the spring may limit the timely use and effectiveness of ground equipment.

Seed Mixes and Seeding Rates

Seed mixes should be formulated to incorporate species that are native and adapted to the site, have known potential to establish through seeding, and are available from commercial vendors or other sources including agency seed warehouses. Soil surveys, ecological site descriptions (NRCS Web Soil Survey 2015), and vegetation map products (e.g., LANDFIRE 2015) can be useful for identifying characteristic native species for a given site. Information on species suitability for seeding can be obtained from guides developed by land management agencies (see Resources List: Monsen et al. 2004, Lambert 2005a, Ogle et al. 2012, USDA PLANTS 2015). These guides contain recommendations regarding seeding rates, depth of seeding, and seeding technique for many ecologically important plant species. Information on seed vendors can be obtained from online databases provided by the Native Seed Network and RNGR National Nursery and Seed Directory. Seeds purchased or collected for seeding projects should ideally be obtained from within the same provisional seed zone, or if available, empirical seed zone (Bower et al. 2014) as the site to be seeded. Table 1 lists some of the species that have been recommended for low-elevation sagebrush zones.

Differences in competitive ability should be taken into consideration when selecting seed mixes, seeding rates, and seeding strategies (Monsen et al. 2004, p. 140-145). Many forbs and shrubs (as well as some grasses) compete poorly with rapidly-growing perennial grasses that usually dominate post-fire seed mixes. Species with different competitive abilities should be spatially segregated, e.g., by placement in separate drill rows (see examples of compatible combinations in Table 1). As an alternative to spatial segregation, seeding rates of competitive species can be reduced to provide more space for less-competitive species within the seeded matrix, but this may be undesirable on sites where weed suppression is desired. Higher rates are generally necessary with broadcast seeding compared to drill seeding and with small seeds compared to larger seeds.

Seed mixes for low-elevation sagebrush communities should be dominated by grasses, with forbs and shrubs included in proportions appropriate for desired establishment densities. Seed number per unit weight and percentage pure live seed will affect bulk seeding rates. Examples of generic seed mixes and seeding rates for low-elevation big sagebrush sites are shown in Table 2.

Seeding Techniques

Different seeding techniques are necessary for different types of terrain (Monsen et al. 2004, Chapter 4). Techniques that apply seed directly from equipment onto the ground, such as rangeland drills, spreader seeders, cultipackers and imprinters, are generally the best choice for seeding wherever terrain permits. Sites that are too steep, rocky, or debris-covered for these techniques can be aerially seeded, although establishment from aerial seedings may be low on low-moisture sites.

Mechanical soil disturbance should be kept to a minimum on sites with residual biological soil crusts and native perennials capable of resprouting after fire. Minimum-till drills offer lower-impact alternatives to conventional rangeland drills (Monsen et al. 2004, Chapter 4).

Seeding techniques should also be selected based on seed size and depth requirements (Table 1). Drill-seeding is most suitable for species with relatively large seeds that can tolerate burial depths of 1/4 inch or more. Smaller seeds are likely to fare better when spread on the soil surface and pressed into the soil with cultipackers or other imprinter-type devices. Some rangeland drills can be configured to place seeds of different sizes at appropriate depths in separate rows, or can be modified for this purpose (Figure 1). Seed boxes on such drills must have separate compartments for each seed type and row. Triple seed boxes have been developed to accommodate three types of seed: small seed, cool season/grain (large seed), and fluffy/chaffy seed. Common species of each seed type are listed in Table 1. The Truax Roughrider drill by Truax Co., Inc. comes with the option of substituting drill disks with imprinter wheels on rows designated for smaller seeds.

An informative video on rangeland drill calibration is available from the Rangeland Technology and Equipment Council (Outka-Perkins 2010). St. John (2008) provided similar guidance specific to the Truax Roughrider drill. See also Monsen et al. (2004), Wiedemann (2007), Benson et al. (2011) and St. John et al. (2012) for descriptions of seeding techniques and equipment options.

Table 1. Common species suitable for seeding at low-elevation sagebrush sites (derived from Monsen et al. 2004, Lambert 2005a, Ogle et al. 2012, USDA PLANTS 2015). This list is not exhaustive, and not all species are suitable for all sites. Species and seed sources should be selected based on adaptation to planting site conditions.

Common Name	Latin Name	Community[1]	Seed Box[2]	Depth[3]	Group[4]
Grasses					
Bluegrass, Sandberg	*Poa secunda*	BA, BL, WY	SS, LS	≤ ¼-¾"	ABJK
Dropseed, sand	*Sporobolus cryptandrus*	BA, WY	SS	≤ ¼"	AK
Fescue, Idaho	*Festuca idahoensis*	BA, WY	LS	¼-¾"	BJ
Fescue, six-weeks	*Vulpia octoflora*	BA, WY	SS	≤ ¼"	AK
Needle-and-thread	*Hesperostipa comata*	BA, BL, WY	LS	¼-1"	BJ
Needlegrass, Thurber's	*Achnatherum thurberianum*	BA, WY	LS	¼-½"	BJ
Ricegrass, Indian	*Achnatherum hymenoides*	BA, BL, WY	LS	½-4"	CD
Squirreltail, bottlebrush	*Elymus elymoides*	BA, BL, WY	LS	¼-½"	C
Wheatgrass, bluebunch	*Pseudoroegneria spicata*	BA, WY	LS	¼-1½"	C
Wheatgrass, Snake River	*Elymus wawawaiensis*	WY	LS	¼-¾"	C
Wheatgrass, thickspike	*Elymus lanceolatus*	BA, WY	LS	¼-1"	C
Wheatgrass, western	*Pascopyrum smithii*	BA, BL, WY	LS	¼-1"	BJ
Wildrye, basin	*Leymus cinereus*	BA, WY	LS	¼-1"	BJ
Shrubs					
Bitterbrush, antelope	*Purshia tridentata*	BA	LS	½-1½"	EJ
Ephedra, green	*Ephedra viridis*	BA, BL, WY	LS	¼-¾"	EJ
Ephedra, Nevada	*Ephedra nevadensis*	BA, BL, WY	LS	¼-¾"	EJ
Hopsage, spiny	*Grayia spinosa*	BA, WY	FC, SS[5]	≤ ¼"	FGK
Peachbrush, desert	*Prunus fasciculata*	WY	LS	½-1"	EJ
Rabbitbrush, low	*Chrysothamnus viscidiflorus*	BA, BL, WY	FC, SS[5]	≤ ¼"	FGK
Rabbitbrush, rubber	*Ericameria nauseosa*	BA, WY	FC, SS[5]	≤ ¼"	FGK
Sagebrush, basin big	*Artemisia tridentata* ssp. *tridentata*	BA, BL	SS	≤ ¼"	GK
Sagebrush, black	*Artemisia nova*	BL	SS	≤ ¼"	GK
Sagebrush, low	*Artemisia arbuscula*	BA, BL,	SS	≤ ¼"	GK
Sagebrush, Wyoming big	*Artemisia tridentata* ssp. *wyomingensis*	BA, WY	SS	≤ ¼"	GK
Saltbush, fourwing	*Atriplex canescens*	BA, WY	LS	¼-¾"	EJ
Winterfat	*Krascheninnikovia lanata*	BA, BL, WY	FC	≤ ¼"	F
Forbs					
Agoseris, pale	*Agoseris glauca*	BA, WY	SS	≤ ¼"	HK
Aster, Pacific	*Symphyotrichum chilense*	BA	FC, SS[5]	≤ ¼"	HK
Balsamroot, arrowleaf	*Balsamorhiza sagittata*	BA	LS	¼-½"	IJ
Biscuitroot, nineleaf	*Lomatium triternatum*	BA, WY	SS	≤ ¼"	HK
Buckwheat, sulphur-flower	*Eriogonum umbellatum*	BA, BL, WY	SS	≤ ¼"	HK
Dusty-maiden, Douglas'	*Chaenactis douglasii*	BA, BL, WY	SS	≤ ¼"	HK
Flax, Lewis	*Linum lewisii*	BA, WY	SS	≤ ¼"	HK
Fleabane, shaggy	*Erigeron pumilus*	BA, BL, WY	SS	≤ ¼"	HK
Globemallow, gooseberryleaf	*Sphaeralcea grossulariifolia*	BA, BL, WY	SS	≤ ¼"	HK
Globemallow, Munro's	*Sphaeralcea munroana*	BA, BL, WY	SS	≤ ¼"	HK
Globemallow, scarlet	*Sphaeralcea coccinea*	BA, BL, WY	SS	≤ ¼"	HK
Goldeneye, Nevada showy	*Heliomeris multiflora* var. *nevadensis*	BA, WY	SS	≤ ¼"	HK
Hawksbeard, tapertip	*Crepis acuminata*	BA, WY	LS	¼-½"	IJ
Milkvetch, basalt	*Astragalus filipes*	BA, WY	LS	¼-½"	IJ
Penstemon, firecracker	*Penstemon eatonii*	BA	SS	≤ ¼"	HK
Penstemon, scabland	*Penstemon deustus*	WY	SS	≤ ¼"	HK
Penstemon, low	*Penstemon humilis*	BA	SS	≤ ¼"	HK
Penstemon, Palmer's	*Penstemon palmeri*	BA, BL, WY	SS	≤ ¼"	HK
Penstemon, royal	*Penstemon speciosus*	WY	SS	≤ ¼"	HK
Sweetvetch, Utah	*Hedysarum boreale*	BA	LS	¼-¾"	IJ
Tansyaster, hoary	*Machaeranthera canescens*	BA, BL, WY	SS	≤ ¼"	HK
Yarrow, western	*Achillea millefolium* var. *occidentalis*	BA, WY	SS	≤ ¼"	HK

[1]Low elevation sagebrush community: BA=Basin Big Sagebrush, BL=Black Sagebrush, WY=Wyoming Big Sagebrush

[2]Appropriate compartment of a triple seed box: FC=fluffy/chaffy, LS=large seed (cool-season/grain), SS=small seed

[3]Optimal seeding depths vary by soil type, will generally be near the lower end of listed depth range in fine-textured soil, near the upper end of listed depth range in coarse-textured soil

[4]Groups of compatible species for seeding together (e.g. in the same drill row):

A=surface-seeded grass
B=drill-seeded grass (low-competitiveness)
C=drill-seeded grass (high-competitiveness)
D=deep drill-seeded grass
E=drill-seeded shrubs
F=surface-seeded chaffy/fluffy seeds
G=surface-seeded shrubs
H=surface-seeded forbs
I=drill-seeded forbs
J=drill-seeded grass, forbs and shrubs
K=surface-seeded grass, forbs and shrubs

[5]If cleaned of appendages, seeds of these species may be placed in small seed box rather than fluffy/chaffy seed box

Table 2. Examples of seed mixes for restoration of low-elevation sagebrush communities, showing possible species combinations and seeding rates in lbs/acre, devised for a rangeland drill with ten rows, triple seed boxes and depth settings that can be adjusted individually by row.

Example 1: lower diversity mix

Drill Rows	Seed Box[1]	Depth	Species	Lbs/acre
1,3,5,7,9,10	LS	1/2"	Bluebunch wheatgrass	2.0
			Bottlebrush squirreltail	1.0
			Indian ricegrass	1.0
2,6	LS	1/4"	Needle-and-thread	0.5
			Thurber's needlegrass	0.5
			Sandberg's bluegrass	0.5
			Basalt milkvetch	0.5
4,8	SS	surface[2]	Munro's globemallow	0.5
			Scabland penstemon	0.5
			Western yarrow	0.2
			Wyoming big sagebrush	0.5
			Rubber rabbitbrush	0.5
			Total	**8.2**

Example 2: higher diversity mix

Drill Rows	Seed Box[1]	Depth	Species	Lbs/acre
1,3,5,7,9	LS	1/2"	Bluebunch wheatgrass	2.0
			Bottlebrush squirreltail	1.0
10	LS	2"	Indian ricegrass	1.0
2	LS	1/2"	Needle-and-thread	0.5
			Thurber's needlegrass	0.5
			Western wheatgrass	0.5
4	SS	surface[2]	Sandberg's bluegrass	0.5
			Munro's globemallow	0.5
			Scabland penstemon	0.5
			Western yarrow	0.2
			Pale agoseris	0.2
			Threadstalk milkvetch	0.2
			Nineleaf biscuitroot	0.2
6	SS & FC[3]	surface[2]	Wyoming big sagebrush	0.8
			Rubber rabbitbrush	0.5
			Winterfat	0.5
8	LS	1/2"	Antelope bitterbrush	0.5
			Green ephedra	0.5
			Basalt milkvetch	0.5
			Arrowleaf balsamroot	0.2
			Tapertip hawksbeard	0.2
			Total	**11.5**

[1]Appropriate compartment of a triple seed box: FC=fluffy/chaffy, LS=large seed (cool-season/grain), SS=small seed

[2]Disks should be lifted or removed for surface seeding and ideally substituted with imprinter wheels

[3]Seeds dispensed from different seed boxes on the same row

Figure 1. Rangeland drill (P & F Services manufacturer, Kemmerer model) modified to allow for different sizes of seeds in alternate rows. Note triple seed boxes and aluminum pipes installed to dispense seed from small seeds onto soil surface. On rows designated for small seeds, disks are raised above ground level to preclude furrow formation.

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