6. APPLICATION OF NATIONAL SEED STRATEGY CONCEPTS

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Introduction

Native plant species are the foundation of sagebrush ecosystems and provide essential habitat for wildlife species, such as Greater sage-grouse (*Centrocercus urophasianus*; hereafter, GRSG). The National Seed Strategy for Rehabilitation and Restoration (hereafter, Seed Strategy) (PCA 2015) strives to provide all land managers—Federal, tribal, State, county, private, and nongovernmental organization—the tools they need to address ecological restoration across the United States. The Seed Strategy provides a coordinated approach to improving the use of native seed, building Federal and private capacity, and increasing the supply of genetically appropriate native seed (PCA 2015). The Seed Strategy recognizes the value of existing native plants and soil seedbanks and acknowledges that not all disturbances or management treatments require active seeding to restore habitat. The Seed Strategy also recognizes that although many nonnative species have been seeded successfully and economically to provide forage and soil stabilization, their ability to support diversity and provide functioning ecosystems to meet multiple use and sustained yield mandates is limited (PCA 2015). Successful rehabilitation and restoration must always take into consideration compatibility of species in a seed mix, planting season, and appropriate seeding rates, techniques, technologies, and practices; that information is available elsewhere (e.g., Madsen et al. 2012, 2014; Monsen et al. 2004a,b,c; Ott et al. 2016; Pyke et al. 2015a,b, 2017).

Genetically appropriate native plant materials have been historically underdeveloped within the sagebrush biome. This section focuses on the logistics, challenges, opportunities, and considerations for procuring and using native seed in sagebrush ecosystems at broad (sagebrush biome), mid- (level III ecoregions), and local (project to site) scales. It also discusses local scale tradeoffs that should be considered when managers decide to use nonnative seeds within the sagebrush biome. It does not address restoration practices and techniques.

Top left: Bee on a native fiddleneck flower in Nevada (photo: USDOI Fish and Wildlife Service). Top center: Intern collecting Indian ricegrass seed (photo: Sophia Heston, USDOI Fish and Wildlife Service). Top right: Owen Baughman and Lauren Porensky preparing to fill the drill seeder (photo: Beth Leger, University of Nevada, Reno). Middle left: Native forbs in a seed increase field (photo by Anne Halford, USDOI Bureau of Land Management). Middle center: Sagebrush seedlings being grown for bare root stock at USDA Forest Service, Lucky Peak Nursery (photo: USDA Forest Service). Middle right: Western hawksbeard (photo: USDA Forest Service). Bottom left: Drill seeding in the snow (photo: Susan Fritts, USDOI Bureau of Land Management). Bottom right: Successful postfire seeding in a sagebrush ecosystem (photo: USDA Forest Service).

Conceptual Basis

Most gardeners and growers are familiar with the 2012 USDA Plant Hardiness Zone map (https://planthardiness.ars.usda.gov/PHZMWeb/) that is found on the back of almost every seed pack sold in the United States. This is the standard by which gardeners and growers can determine which plants are most likely to thrive at a location based on average annual minimum winter temperature, divided into 10-degree Fahrenheit zones. In this context, seed transfer guidelines, which include mapped seed zones (fig. 6.1), are just a more sophisticated and accurate way to understand what seeds and plants thrive best at a location. Seed transfer guidelines are management tools that define acceptable distances seed can be moved from the point of origin, while considering genetic adaptation (Bower et al. 2014; Kilkenny 2015; St. Clair et al. 2013). For more detail, see Part 1, Appendix 11 of the Science Framework (Chambers et al. 2017; hereafter, Part 1).

Variations in biotic and abiotic factors cause plants to experience natural selection across their range. When adaptive evolution occurs in response to local selective pressures, populations are considered to be locally adapted (Leimu and Fischer 2008; McKay et al. 2005). Common garden studies and reciprocal transplant studies have shown that plant populations are often adapted to local environmental conditions (e.g., Clausen et al. 1941; Hiesey et al. 1942; Joshi et al. 2001; Turesson 1922). For restoration projects, this means locally adapted plants can generally outperform nonlocal plants (e.g., Bischoff et al. 2006; Humphrey and Schupp 2002; Leimu and Fischer 2008; Rice and Knapp 2008; Rowe and Leger 2012).

Ecosystem resilience to disturbance and resistance to invasive annual grasses can be increased by considering both seed source and genetic diversity, in combination with other factors, when selecting seeds and plant materials. Besides project failure, poor seed mix choices may have long-term consequences including genetic degradation of the surrounding plant population, loss of fitness, and loss of evolutionary potential and, consequently, reduction of future

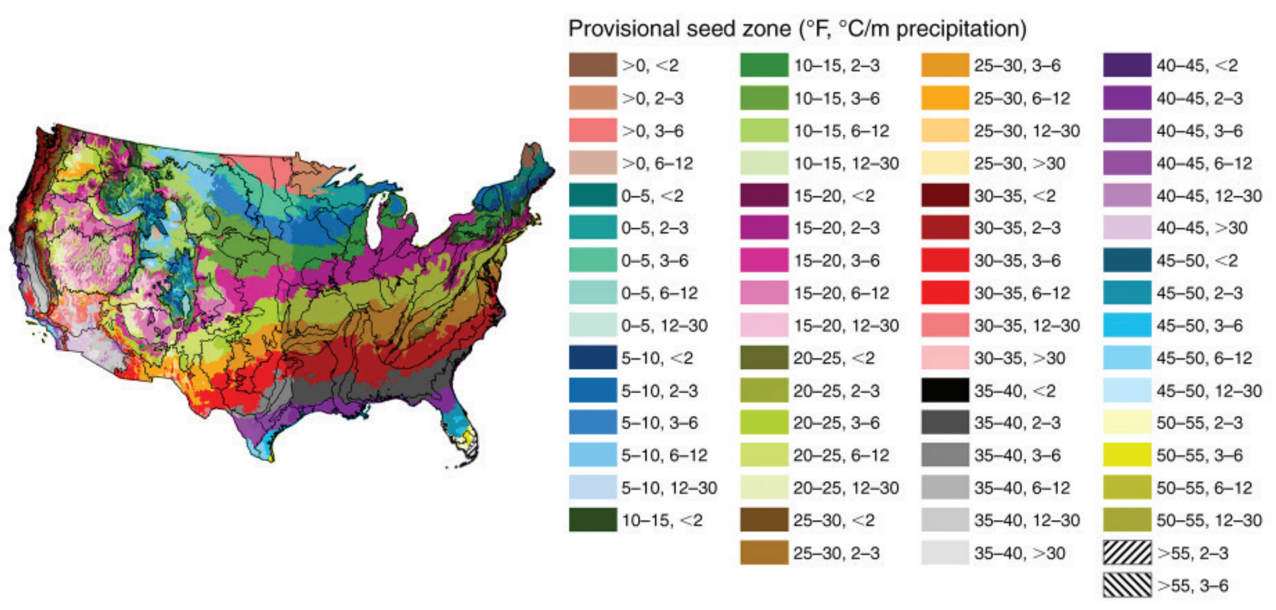


Figure 6.1—Provisional seed zones for native plants (color polygons) overlain with Omernik's (1987) level III ecoregion boundaries (black lines). Provisional seed zones are the first step in defining seed transfer guidelines. Level III ecoregions can be used to refine seed movement within a provisional seed zone. In the legend, the first range of numbers is the temperature class band (°F) and the second range of numbers is the annual heat:moisture (AH:M) index class bands (°C/m precipitation; from Bower et al. 2014) (Chambers et al. 2017, Appendix 11 fig. A.11.2).

plant community resilience and resistance to invasive annual grasses (Crémieux et al. 2010; McKay et al. 2005; Mijnsbruggea et al. 2010; Schröder and Prasse 2013). The Seed Strategy provides a path forward for developing and procuring genetically appropriate native seed sources that have the best genetic fit for individual restoration and vegetation management projects by identifying the research, technology, and monitoring needs for integrating and managing genetic diversity across the sagebrush biome.

Considerations for Enhancing Resilience and Resistance Using Seed Strategy Concepts

Broad- to Mid-Scale Considerations

Prioritizing Native Seed Development

The geospatial data layers and analyses described in Part 1, sections 8.1 and 8.2 of the Science Framework can help prioritize sagebrush ecosystems for native plant materials development, postfire rehabilitation, and restoration. Analyses are conducted at the ecoregion scale because similarities in ecoregional climate, soil properties, resilience to disturbance, and resistance to invasive annual grasses can provide economies of scale compatible with seed development. Collectively, the sagebrush biome includes most of 14 different Omernik (1987) level III ecoregions: Eastern Cascades Slopes and Foothills, Columbia Plateau, Blue Mountains, Idaho Batholith, Snake River Plain, Northern Basin and Range, Central Basin and Range, Wasatch and Uinta Mountains, Middle Rockies, Wyoming Basin, Colorado Plateaus, Southern Rockies, Northwestern Great Plains, and Northwestern Glaciated Plains. Omerick's level III ecoregions served as the basis for the U.S. Environmental Protection Agency (EPA) level III ecoregions described in Part 1 and are synonymous with EPA level III ecoregions (fig. 1.1). For example, warmer and drier areas with low resilience and resistance to invasive annual grasses might require additional seeding after a disturbance to supplement natural recovery. Therefore, ecoregions with predominantly warm and dry soil temperature and moisture regimes, such as the Columbia Plateau, Northern Basin and Range, Central Basin and Range, Snake River Plain, and Colorado Plateaus, may be a higher priority for the development of native plant materials.

Key data layers for prioritizing areas for native plant materials development include: (1) resilience and resistance to invasive annual grasses as indicated by soil temperature and moisture regimes, (2) GRSG breeding habitat probabilities and densities or habitats of other sagebrush obligate habitats, (3) the primary threats for the ecoregion (see Part 1, section 8), and (4) generalized or provisional seed zones (fig. 6.1) (Bower et al. 2014; Part 1, Appendix 11). For example, in the Great Basin, Jensen and Stettler (2012) reported that over the last 30 years, 90 percent of fire rehabilitation projects on Federal land occurred in three major generalized or provisional seed zones. In the eastern range 78 percent of oil and gas development occurs in six major generalized or provisional seed zones (see Part 1, Appendix 8 for data sources). Thus, initial seed development efforts should focus on developing native plant materials for the most appropriate species (most likely native perennial grasses) for these provisional seed zones.

Primary considerations in prioritizing areas for native plant materials development based on resilience and resistance to invasive annual grasses follow (see tables 1.3 and 1.4, especially the sections on postfire rehabilitation and climate change).

- In general, areas with moderate and, especially, high resilience and resistance often recover without seeding following wildfire and vegetation management. Shrubs, particularly sagebrush, may or may not require seeding or transplanting. These areas are relatively low priority for development of native plant materials (table 1.3: cells 1B, 1C, 2B, 2C).
- Priority increases as resilience and resistance decrease and habitat probability for GRSG increases. High priorities include ecological types with low to moderate resilience and resistance that (1) may lack sufficient native perennial grasses and forbs to recover on their own, but (2) have nearby areas still supporting GRSG habitat (table 1.3: cells 2B, 2C, 3B, 3C).
- Areas of low habitat probability for GRSG (table 1.3: cells 1A, 2A, 3A) are generally lower priority, but may become higher priority if they support other species or resources at risk or can be used to increase connectivity among areas with intact sagebrush.
- Areas may be considered for prioritization regardless of resilience and resistance if repeated large fires or other habitat disturbances are causing habitat fragmentation and seeding or transplanting of sagebrush is needed to maintain habitat connectivity.

Because resilience and resistance to invasive annual grasses increase along soil temperature and moisture gradients, an understanding of the relationship of major sagebrush taxa to soil temperature and moisture regimes can help in prioritizing sagebrush and their associated species for seed development by using seed zones and seed transfer guidelines. Within the big sagebrush complex in the western portion of the range, mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*) occurs on cold to cool moist sites, while in the eastern portion of the range it occurs on cold and cool wet, summer moist, or winter moist sites. In the western portion of the range, Wyoming big sagebrush (*A. tridentata* ssp. *wyomingensis*) and basin big sagebrush (*A. tridentata* ssp. *tridentata*) typically occur on relatively warm and dry sites, whereas in the eastern portion of the range, these species occur on a spectrum of sites, ranging from cool and summer moist to warm and dry. Thus, Wyoming big sagebrush and basin big sagebrush may be considered a higher priority for native plant materials development in the western portion of the range based on low resilience and resistance to invasive annual grasses on the sites where they grow.

Some dwarf sagebrush species, such as warm springs low sagebrush (*Artemisia arbuscula* ssp. *thermopola*), alkali sagebrush (*A. longiloba*), and Wyoming threetip sagebrush (*A. tripartita* ssp. *rupicola*) occur on relatively cold to cool sites with high resistance and resilience to invasive annual grasses (Miller et al. 2014) and, therefore, are a lower priority for native plant materials development and restoration. However, other Dwarf sagebrush species—black sagebrush (*A. nova*), pygmy sagebrush (*A. pygmaea*), low sagebrush (*A. arbuscula* ssp. a*rbuscula*), and alkali sagebrush (*A. arbuscula* ssp. *longiloba*)—grow on relatively warm and dry sites (Miller et al. 2014). Although this appears to indicate that the ecosystems where these species are most abundant have low resilience and resistance to invasive annual grasses, soil and vegetation community characteristics need to be taken into account. For example, black sagebrush grows on shallow, stony, calcareous soils which are sparsely vegetated, and thus has a low fuel load and low likelihood of needing restoration. Therefore, black sagebrush is typically a lower priority for native plant materials development and restoration. However, monitoring of all sagebrush ecological types is needed to determine whether declines are occurring due to climate, wildfire, improper grazing, disease, or other perturbations.

Developing the Mechanism for Seed Increase

Vegetation community lists from the available ecological site descriptions for Natural Resources Conservation Service (NRCS) Major Land Resource Areas can be used to identify the native shrub, grass, and forb species needed to restore ecosystem function. Development of lists can be prioritized based on resilience and resistance concepts and the considerations just described. Vegetation community lists can also be used to prioritize species for native plant materials development and regional procurement objectives. One caveat is that ecological site descriptions tend to be dominated by later successional species. In some cases earlier successional species may need to be included in a seed mix to help establish initial site resistance to invasive annual grasses. To achieve this, local expertise and herbarium records coupled with ecological site descriptions should be used to develop the most comprehensive vegetation community lists.

Intact sagebrush communities with low and moderate resilience and resistance to invasive annual grasses can be identified for wildland seed collection or the establishment of commercial seed collection areas. These sagebrush communities can provide reliable, source-identified sagebrush seed for restoration projects. Alternatively, where local seed sources have been depleted or are not available for seed collection (such as Wilderness areas), the development of seed orchards based on seed transfer guidelines and seed zones may be useful.

Potential Tradeoffs and Management Challenges at the Broad and Mid-Scale

Changes in precipitation and temperature regimes are projected to have large consequences for species distributions across the sagebrush biome (see Part 1, section 4.2). This is a challenge for management because the vegetation communities we currently manage may or may not be the same in the future. Developing native plant materials that include the genetic diversity of a species by seed zones can help species seeded onto a site adapt to future changes in climate. Predictive models of changes in climate can be used to assess threats to important restoration species and identify opportunities for targeting, prioritizing, and implementing restoration projects that consider potential changes in species distribution and plant community composition. Modeling changes in species distributions and seed zone boundaries will help identify potential refugia areas and bottlenecks to species' movement and select appropriate plant populations for inclusion in restoration projects to reduce the risk of future maladaptation.

At the broad scale, prioritizing ecoregions and sagebrush ecological types within them (for example, Wyoming big sagebrush ecological types in the Columbia Plateau), may mean that seed needed for restoration within areas that have high and moderate resilience and resistance to invasive annual grasses may not always be as readily available as seed for areas with low resilience and resistance to invasive annual grasses. Therefore, when making seeding decisions, it is important not to waste seed, and seed only when necessary. In areas with high resilience and resistance to invasive annual grasses, not seeding or other passive restoration treatments may be more practical (Pyke et al. 2015a). In areas with lower resilience and resistance to invasive annual grasses that require seeding, individual project planning can help mitigate the need for seed. By building reasonable timelines within individual projects, local seed collection and seed increase can be conducted to ensure that sufficient genetically appropriate native seed is available.

Land managers may want to rehabilitate and restore rangelands that have low GRSG habitat value or other resource management value, but are currently dominated by cheatgrass (*Bromus tectorum*), crested wheatgrass (*Agropyron cristatum*), or some other undesirable plant species, because these rangelands are prevalent at the mid-scale. Under these circumstances, where other range management objectives have a higher priority than GRSG management objectives, the financial costs to procure genetically appropriate native seed, the size and scale of the project, or adverse impacts to remaining local native seed sources (e.g., improper grazing) may preclude the use of native seed. Nonnative species and native cultivars that originate from sites with similar temperature and precipitation regimes may provide an acceptable management tradeoff. However, if native ecosystem restoration is the goal, seed of genetically appropriate native grasses is relatively inexpensive and can be the first step of a "staged planting" approach, whereby grasses and forbs are planted in successive years or forbs are added to a limited number of favorable areas (i.e., forb islands) (Benson et al. 2011) (see section on local-scale tradeoff).

Local Scale Considerations

In this section, local scale refers to individually funded vegetation management activities within a district or field office. At this scale, managers need to carefully consider seed mixes and seed sources because of the critical role they play in managing for resilience and resistance to invasive annual grasses. The importance of deciding when seeding is or is not needed cannot be overstated. Such decisions should be tied to site-specific assessments of current conditions, past management, and the potential for a site to recover without management intervention. Local monitoring data can be used to provide information on seed mixes and seed sources, as well as the need to seed (text box 6.1). Monitoring treatment effectiveness can provide the necessary information on species performance to adjust seed sources over time.

Planning for and initiating collection, seed increase, and long-term storage of native seed are important components of the management and development of native plant materials. Forward planning for the use of genetically appropriate

Text Box 6.1—Monitoring to Inform Selection of Species and Seed Sources and to Evaluate Seed Source Performance

Monitoring data play an important role in selecting species and seed sources and evaluating species performance. First, monitoring data from a project area or site prior to treatment can provide the necessary information on the species composition to select the most appropriate restoration species. Such data can also provide information on suitable areas for seed collection. Second, information about the seed source is essential for selecting plant materials that are genetically adapted to the site conditions. Selecting appropriate seed sources can ensure that the desired species establish and persist and is necessary for achieving successful and effective restoration projects.

Information on the seed sources used in a restoration project should be recorded and tracked in a systematic manner. Relating data on seed sources to seedling establishment as a part of effectiveness monitoring provides critical information on species and seed source performance that can be used to inform future restoration efforts. When only anecdotal data are available, project managers can draw or perpetuate erroneous conclusions regarding the effectiveness of seeding outcomes. Data on seed sources, along with other treatment information, could be recorded in the Land Treatment Digital Library, a catalog of information about land treatments on Federal lands in the western United States (https://ltdl.wr.usgs.gov/). This need is identified and described in the Seed Strategy under Action Item 2.4.1, "Analyze new and existing monitoring methodologies to evaluate restoration outcomes" (PCA 2015).

native seed based on quantities requested annually, number of acres seeded annually, fire projections, or some other metric is critical. Forward planning when seeding with cultivars or nonnatives is generally not crucial because of their widespread availability.

For the western range, Miller et al. (2014, 2015) provide a framework for evaluating postwildfire resilience and resistance to invasive annual grasses, potential successional pathways, and the need to seed at the local scale. A similar framework can be developed for the eastern range. Additionally, the Seedlot Selection Tool (https://seedlotselectiontool.org/sst/) can help with seed source decisionmaking based on climate information. General seeding strategies by resilience and resistance category are:

- **High Resilience and Resistance**. The potential for native shrubs, grasses, and forbs to recover after disturbance without seeding is typically high. Shrubs, particularly sagebrush, may or may not require seeding or transplanting. If sites require seeding, the use of locally sourced or source-identified seed from the same seed zone will improve project success while maintaining genetic adaptation and diversity.
- **Moderate Resilience and Resistance**. The potential for native shrubs, grasses, and forbs to recover after disturbance is usually moderately high, especially on cooler and moister sites. Seeding following disturbance or treatment may be needed in areas with depleted native perennial grasses and forbs. Including perennial grasses in seed mixes that can compete with and provide resistance to invasive annual grasses is recommended. Including locally sourced or source-identified forbs from the same seed zone may be necessary to meet habitat management objectives, but their seeding depends on the degree of site preparation, capabilities of the seeding equipment, and expectation of weed invasion.
- **Low Resilience and Resistance**. Recovery potential after overlapping disturbances (e.g., wildfire, improper grazing) is usually low and seeding is needed in areas with depleted native shrubs, grasses, and forbs. The use of perennial grasses in seed mixes is recommended to provide competition with invasive annual grasses. Decisions on the use of native (locally sourced or source identified from the same seed zone), grasses, native cultivars, or nonnative grasses depends on the availability of seed sources and degree of invasion by nonnative annual grasses. On degraded sites, forbs may be absent. Including locally sourced or source-identified forbs from the same seed zones may be necessary to meet habitat management objectives. However, to successfully seed forbs it is necessary to consider the degree of site preparation, capabilities of the seeding equipment, and expectation of weed invasion.

Good species selections and seed source choices can strengthen community resilience and resistance to invasive annual grasses, whereas poor species selections and seed source decisions can erode long-term community resilience and resistance. Management considerations for resilience and resistance at the local scale include:

- **Incorporating native perennial grasses in all seed mixes used on sites with moderate and low resilience and resistance to invasive annual grasses**. Native perennial grasses compete directly with cheatgrass and other introduced annual grasses for space, water, and nutrients (Blank and Morgan 2012; Chambers et al. 2007; Leger 2008). Including genetically appropriate native perennial grasses adapted to site-specific temperature and precipitation regimes increases resilience and resistance as well as site diversity. Empirical seed zones are available for many of the common native perennial grasses used in rehabilitation and restoration of sagebrush ecosystems.

- **Designing a diverse seed mix of native shrubs, grasses, and forbs for all project seed mixes.** Species diversity is the hallmark of a healthy ecosystem; diverse seed mixes of native shrubs, grasses, and forbs can increase site resistance by filling ecological niches and competing with nonnative invasive annual grasses. Seed mixes should integrate information about ecological site conditions and successional stage for best success. For example, if forbs are included in a seed mix, site preparation and management should prevent cheatgrass invasion, such as through the "staged planting" approach (Benson et al. 2011). Temperature and precipitation conditions that favor seed germination and seedling establishment vary from year to year, so seeding a diverse mix of early and late successional stage native shrubs, grasses, and forbs may increase resilience by providing a range of species capable of germinating and establishing in response to a variety of environmental conditions.
- **Using the right sagebrush in the right place.** With 27 sagebrush species and subspecies across the sagebrush biome, using the correct sagebrush species or subspecies source identified to the same seed zone in restoration projects is essential to creating sagebrush communities that are resilient and resistant to invasive annual grasses. Variations in biotic and abiotic factors cause plants to undergo natural selection and adaptive evolution; thus, individual sagebrush species and subspecies have evolved to grow best under different soil environments, temperature, and precipitation regimes (Dumroese et al. 2015; Miller et al. 2011). Consequently, sagebrush species and subspecies are not interchangeable in a restoration seed mix. For example, Richardson et al. (2015) found that Wyoming big sagebrush has a significantly greater seed weight than basin big sagebrush and determined that 83 percent of certified seed lots used in 2013 and 2014 were labeled as Wyoming big sagebrush but were actually basin big sagebrush. Furthermore, data indicate that local adaptation in sagebrush plays an important role in long-term survivorship. In an Idaho Department of Fish and Game study, Sands and Moser (2012) found locally sourced Wyoming sagebrush seed had 100 percent survivorship after 20 years, while non-locally sourced seed had less than 50 percent survivorship.
- **Including native forbs to create healthier food webs.** Complex and diverse food webs are a hallmark of intact ecosystems with high resilience and resistance to invasive annual grasses. Native forbs are a major component of sage-grouse chick diets (Dumroese et al. 2015), are critical to native pollinators (Pollinator Health Task Force 2015), and can be abundant in sagebrush communities (Humphrey and Schupp 2001; James et al. 2014). In healthy sagebrush ecosystems, native forbs have continuous and overlapping flowering and seed production throughout the growing season—meaning that a variety of ecological niches are filled by a diversity of species. On degraded sites, land managers can attempt to create or repair flowering phenology and reproduction through carefully planned seed mixes. Restoring the native plant community, especially the native forb component, is likely to result in a cascading response in which other native species increase. Thus, native forbs are an important component of sagebrush ecosystem restoration and should be included in seed mixes.

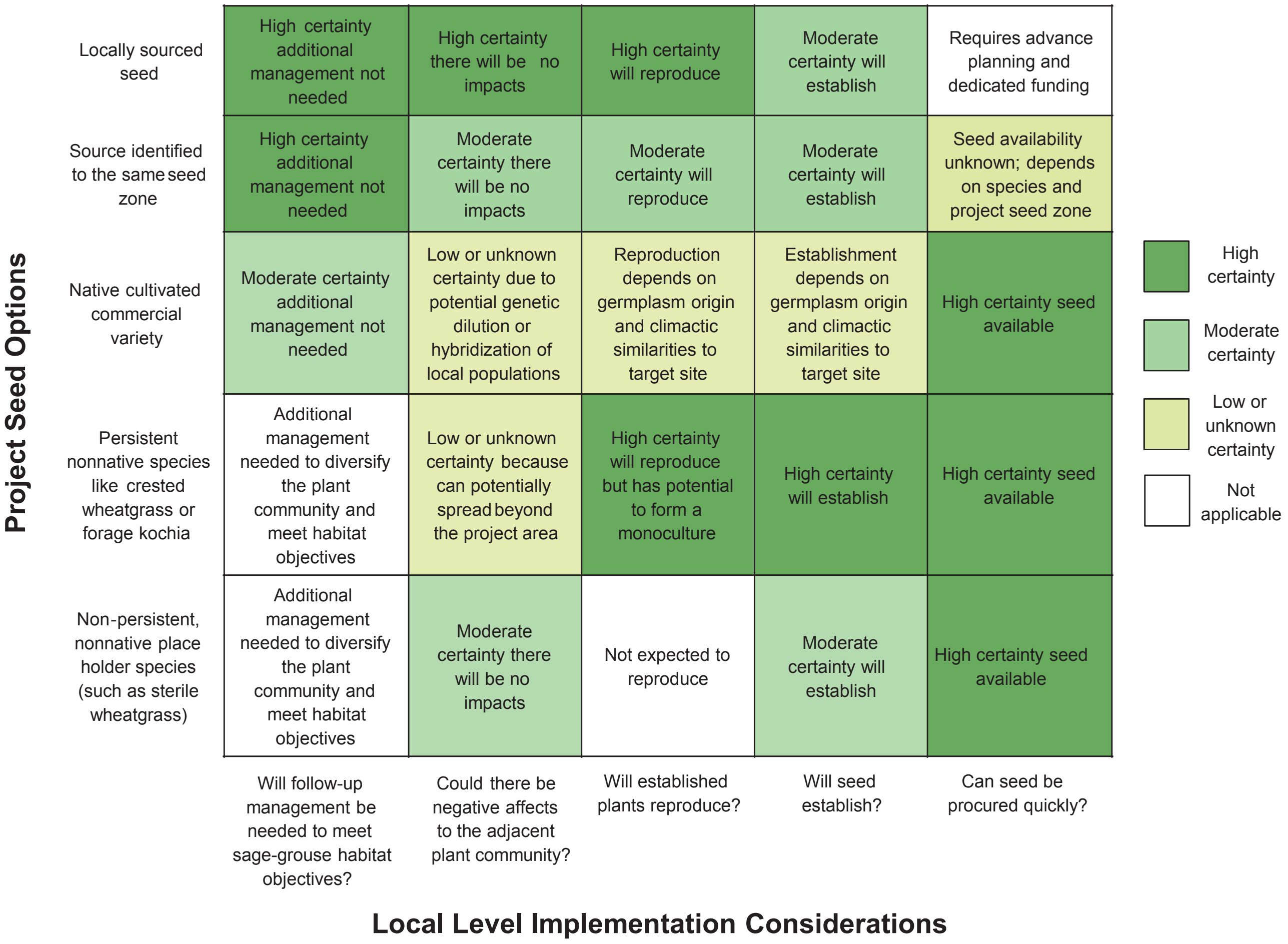
- **Considering use of ruderal or annual native forbs in project seed mixes to increase resistance to cheatgrass where they are naturally abundant and seed sources have been developed.** Some native annual species (such as bristly fiddleneck [*Amsinckia tesselata*]) have been shown to compete well and suppress nonnative invasive annual species due to phenological similarities (Leger et al. 2014; Uselman et al. 2014). Developing competitive, native annual species for use in future seed mixes may improve seeding outcomes in some disturbed rangeland ecosystems. However, the potential amount of seed required, availability, and costs of including native annuals should be carefully considered during project planning.
- **Considering long-term planning at the local scale to preserve seed sources from low resilience and resistance sites that are at high risk of cheatgrass invasion or wildfire.** In these cases, long-term planning can provide seed sources adapted at the seed zone level which will be adapted to site conditions within a seed zone.

Potential Tradeoffs and Management Challenges at the Local Scale

If a decision is made to seed, there are five major tradeoffs related to resilience and resistance concepts and implementation of Seed Strategy concepts. Tradeoffs should not be considered individually, but rather in the context of meeting project objectives while maintaining site resilience and resistance to invasive annual grasses. Local tradeoffs in the context of seed source choices (fig. 6.2) are discussed briefly.

The Tradeoff between Seed Source and the Need for Follow-up Management to Meet GRSG Habitat Objectives. Nonnative species, such as crested wheatgrass and forage kochia (*Bassia substrata*), are widely seeded for rangeland revegetation, postfire rehabilitation, invasive plant control, and green stripping, because they germinate and establish quickly, are readily available for purchase, are cheaper than native species, provide good livestock forage, and compete with nonnative invasive species (Brooks and Pyke 2001; Harrison et al. 2000; Monaco et al. 2003; Pellant 1994; Richards et al. 1998). These nonnative species are used as placeholder or bridge species to convert annual invasive grass-dominated rangelands into native perennial-dominated plant communities (Monaco et al. 2003); however, follow-up restoration rarely happens. Putting this concept into practice has not been widely realized and some of the positively perceived attributes of these species, such as competitive ability, can negatively impact native plant community structure and function.

The wide use of nonnative species in some circumstances represents a tradeoff for achieving diverse ecosystem and habitat management objectives for GRSG, pollinators, and other sagebrush dependent species. For example, crested wheatgrass can be highly competitive with native sagebrush and perennial grass species (Asay et al. 2001; Bakker and Wilson 2001; Hull and Klomp 1967; Marlette and Anderson 1986). Crested wheatgrass can dominate the soil seedbank (Marlette and Anderson 1986) and limit the growth and establishment of native plants (Gunnell et al. 2010; Heidinga and Wilson 2002; Hendersen and Naeth 2005). Attempts to reintroduce native species into crested wheatgrass monocultures suggest that costly and time-intensive repeated treatments are required because this species recovers rapidly from mechanical and chemical control treatments (Davies et al. 2013; Fansler and Mangold 2011; Hulet et al. 2010; McAdoo et al. 2016). Short and long-term (13 years) studies suggest that even if seeded at low rates in a seed mix, crested wheatgrass may ultimately



Project Seed Options	Will follow-up management be needed to meet sage-grouse habitat objectives?	Could there be negative affects to the adjacent plant community?	Will established plants reproduce?	Will seed establish?	Can seed be procured quickly?
Locally sourced seed	High certainty additional management not needed	High certainty there will be no impacts	High certainty will reproduce	Moderate certainty will establish	Requires advance planning and dedicated funding
Source identified to the same seed zone	High certainty additional management not needed	Moderate certainty there will be no impacts	Moderate certainty will reproduce	Moderate certainty will establish	Seed availability unknown; depends on species and project seed zone
Native cultivated commercial variety	Moderate certainty additional management not needed	Low or unknown certainty due to potential genetic dilution or hybridization of local populations	Reproduction depends on germplasm origin and climactic similarities to target site	Establishment depends on germplasm origin and climactic similarities to target site	High certainty seed available
Persistent nonnative species like crested wheatgrass or forage kochia	Additional management needed to diversify the plant community and meet habitat objectives	Low or unknown certainty because can potentially spread beyond the project area	High certainty will reproduce but has potential to form a monoculture	High certainty will establish	High certainty seed available
Non-persistent, nonnative place holder species (such as sterile wheatgrass)	Additional management needed to diversify the plant community and meet habitat objectives	Moderate certainty there will be no impacts	Not expected to reproduce	Moderate certainty will establish	High certainty seed available

- 🟩 High certainty
- ▩ Moderate certainty
- 🟨 Low or unknown certainty
- ☐ Not applicable

Figure 6.2—Seed source and local-level considerations for selecting seed sources and types.

become the most abundant grass in a mixed bunchgrass community (Bakker and Wilson 2004; Nafus et al. 2015).

The Tradeoff between Seed Source and Potential Impacts to the Adjacent Plant Community. Plants established as part of a seeding project interact with the surrounding environment and interbreed with native, resident (local) plant populations. Local seeds or seed sources identified by seed zone are advantageous because they are unlikely to be invasive or overly competitive with other native plants. Local seeds or seed sources identified by seed zone should be most genetically similar to the existing native plant populations and have the lowest potential for adverse genetic impacts.

Seeding with nonnatives may represent an ecological tradeoff because they have the potential to invade and spread beyond a project boundary. For example, Gray and Muir (2013) found that on sites seeded 3 to 24 years earlier, forage kochia spread as much as 710 meters (2,330 feet) into both intact and disturbed plant communities for an estimated rate of 25 meters (82 feet) per year.

Just as individual plants may spread, genes are also capable of spreading into adjacent, resident plant populations. Seeding with native cultivars may represent a genetic tradeoff because of potential adverse impacts to local population genetics through hybridization, potentially affecting overall species fitness

(Hereford 2009; Leimu and Fischer 2008). Seed source is often not a criterion for developing native cultivars. Native cultivars have been developed over many years in an agronomic setting and are often selected for specific traits (see next paragraph), which may or may not align with restoration success (Johnson et al. 2010; Jones and Larson 2005; Leger and Baughman 2015). Introduced seed has the potential to hybridize with native populations and result in maladaptation or negative long-term impacts that could affect a plant community's ability to adapt to changing environmental conditions.

The Tradeoff between Seed Sources and Seed Germination, Establishment, and Reproduction. Traits selected for and often prioritized in native cultivars are: forage quality and yield, seed yield, seedling vigor, ability to establish and persist, and drought tolerance across a range of environmental conditions (Leger and Baughman 2015). Nonnative species are selected for traits similar to those selected in native cultivars. For example, the crested wheatgrass germplasm 'Ephraim' was selected for forage quality and yield, ability to establish, and a rhizomatous growth form for site stabilization (USDA NRCS 2012). In contrast, locally sourced native seeds and seed sources are more likely to be adapted to the environmental conditions in the seed zones where they are collected.

Locally sourced, native seed may need one or more growing seasons to germinate and establish on a site due to seed dormancy or other physiologic mechanisms. Seed of nonnatives and native cultivars typically germinate and establish quickly because they are selected for little or no seed dormancy. However, this represents a tradeoff because nonnatives and native cultivars may not meet long-term habitat objectives for sage-grouse, pollinators, other wildlife species, or special status plant species. Additionally, using a nonnative species like crested wheatgrass will support site resistance to invasive annual grasses because it is a good competitor with cheatgrass. However, it is less likely to support long-term site resilience because of the low species diversity it maintains (see preceding discussion). Treatment effectiveness monitoring that tracks native seed sources and their performance in the field can be used to inform both native species and seed source selection (text box 6.1).

The Tradeoff between Seed Sources and Procurement. Until the seed market can be fully developed, there is a tradeoff between the species desired for a seed mix and their availability. Anticipating and planning for native species needed to develop a seed mix is an important aspect of project management because seed of desired native plant species and seed sources usually are not immediately available. At the local scale, it is possible to plan and collect local seed that can be sent to a grower to increase it to the desired quantities. Advance planning (such as performing project-specific seed collections and seed increase with a commercial grower) will make species more available, but this represents a tradeoff in how quickly a project can be implemented. Purchasing and using native cultivars or nonnative species is a tradeoff that saves time and money, allowing a project to move forward quickly. Native cultivars (such as 'Sherman' Sandberg bluegrass *[Poa secunda*] or 'Magnar' basin wildrye [*Leymus cinereus*]) or nonnative species (such as crested wheatgrass and forage kochia) are often immediately available and can be bought from the commercial market in large quantities. However, using native cultivars or nonnative species results in tradeoffs regarding potential adverse impacts to future resilience and resistance to invasive annual grasses and a need for follow-up management (see earlier discussion).

Conclusions

Balancing locally adapted seed sources, cultivars, and nonnative species against the realities of implementing a project in the field is a series of tradeoffs. Every project is unique and a one-size-fits-all approach will not work. Sometimes seeding is used as a way to mitigate management risk or simply as insurance. Regardless of why and what is being seeded, the judicious use of seed will not only save money, but also minimize the risk of unintended ecological consequences to naturally recovering native plant communities. As part of any decision to seed, potential tradeoffs should be carefully weighed against the potential future economic and ecosystem costs. Seeding should not always be the first choice. For example, where prescriptive treatments are desired to minimize erosion risks to infrastructure, one-time physical barriers (such as straw wattles and straw mulch) may be more desirable and cost-effective where sufficient native perennial plants exist to promote recovery (e.g., Robichaud et al. 2010).

References

Asay, K.H.; Hoeron, W.H.; Jensen, K.B.; [et al.]. 2001. Merits of native and introduced Triticeae grasses on semiarid rangelands. Canadian Journal of Plant Science. 81: 45–52.

Bakker, J.D.; Wilson, S.D. 2001. Competitive abilities of introduced and native grasses. Plant Ecology. 157: 117–125.

Bakker, J.D.; Wilson, S.D. 2004. Using ecological restoration to constrain biological invasion. Journal of Applied Ecology. 41: 1058–1064.

Benson, J.E.; Tveten, R.T.; Asher, M.G.; [et al.]. 2011. Shrub-steppe and grassland restoration manual for the Columbia River Basin. Olympia, WA: Washington Department of Fish and Wildlife. https://wdfw.wa.gov/publications/01330/. [Accessed May 23, 2018].

Bischoff, A.; Vonlanthen, B.; Steinger, T.; [et al.]. 2006. Seed provenance matters—Effects on germination of four plant species used for ecological restoration. Basic and Applied Ecology. 7: 347–359.

Blank, R.S.; Morgan, T. 2012. Suppression of *Bromus tectorum* L. by established perennial grasses: Potential mechanisms—Part One. Applied Environmental Soil Science. 2012: Article 632172.

Bower, A.D.; St. Clair, J.B.; Erickson, V. 2014. Generalized provisional seed zones for native plants. Ecological Applications. 24: 913–919.

Brooks, M.L.; Pyke, D.A. 2001. Invasive plants and fire in the deserts of North America. In: Galley, K.E.M; Wilson, T.P., eds. Proceedings of the invasive species workshop: The role of fire in the control and spread of invasive species. Miscell. Publ. No. 11. Tallahassee, FL: Tall Timbers Research Station: 1–14.

Chambers, J.C.; Roundy, B.A.; Blank, R.R.; [et al.]. 2007. What makes Great Basin sagebrush ecosystems invasible by *Bromus tectorum*? Ecological Monographs. 77: 117–145.

Chambers, J.C.; Beck, J.L.; Bradford, J.B.; [et al.]. 2017. Science framework for conservation and restoration of the sagebrush biome: Linking the Department of the Interior's Integrated Rangeland Fire Management Strategy to long-term strategic conservation actions. Part 1. Science basis and applications.

Gen. Tech. Rep. RMRS-GTR-360. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 213 p.

Clausen, J.; Keck, D.D.; Hiesey, W.M. 1941. Regional differentiation in plant species. American Naturalist. 75: 231–250.

Crémieux, L.; Bischoff, A.; Müller-Schärer, H.; [et al.]. 2010. Gene flow from foreign provenances into local plant populations: Fitness consequences and implications for biodiversity restoration. American Journal of Botany. 97: 94–100.

Davies, K.W.; Boyd, C.S.; Nafus, A.M. 2013. Restoring the sagebrush component in crested wheatgrass-dominated communities. Rangeland Ecology and Management. 66: 472–478.

Dumroese, R.K.; Luna T.; Richardson, B.A.; [et al.]. 2015. Conserving and restoring habitat for Greater sage-grouse and other sagebrush obligate wildlife: The crucial link of forbs and sagebrush diversity. Native Plants Journal. 16: 276–299.

Fansler, V.A.; Mangold, J.M. 2011. Restoring native plants to crested wheatgrass stands. Restoration Ecology. 19: 16–23.

Gray, E.C.; Muir, P.S. 2013. Does *Kochia prostrata* spread from seeded sites? An evaluation from southwestern Idaho, USA. Rangeland Ecology and Management. 66: 191–203.

Gunnell, K.T.; Monaco, T.A.; Call, C.A.; [et al.]. 2010. Seedling interference and niche differentiation between crested wheatgrass and contrasting native Great Basin species. Rangeland Ecology and Management. 63: 443–449.

Harrison, R.D.; Chatterton, N.J.; Waldron, B.L.; [et al.]. 2000. Forage kochia: Its compatibility and potential aggressiveness on intermountain rangelands. Utah Agricultural Experiment Station Research Report 162. Logan, UT: Utah State University. 66 p.

Heidinga, L.; Wilson, S.D. 2002. The impact of invading alien grass (*Agropyron cristatum*) on species turnover in native prairie. Diversity and Distributions. 8: 249–258.

Henderson, D.C.; Naeth, M.A. 2005. Multi-scale impacts of crested wheatgrass invasion in mixed-grass prairie. Biological Invasions. 7: 639–650.

Hereford, J. 2009. A quantitative survey of local adaptation and fitness trade-offs. American Naturalist. 173: 579–588.

Hiesey, W.M.; Clausen, J.; Keck, D.D. 1942. Relations between climate and intraspecific variation in plants. American Naturalist. 76: 5–22.

Hulet, A.; Roundy, B.A.; Jessop, B. 2010. Crested wheatgrass control and native plant establishment in Utah. Rangeland Ecology and Management. 63: 450–460.

Hull, A.C.; Klomp, G.J. 1967. Thickening and spread of crested wheatgrass stands on southern Idaho ranges. Journal of Range Management. 20: 222–227.

Humphrey, L.D.; Schupp, E.W. 2001. Seed banks of *Bromus tectorum*-dominated communities in the Great Basin. Western North American Naturalist. 61: 85–92.

Humphrey, L.D.; Schupp, E.W. 2002. Seedling survival from locally and commercially obtained seeds on two semiarid sites. Restoration Ecology. 10: 88–95.

James, D.G.; Seymour, L.; Lauby, G.; [et al.]. 2014. Beneficial insects attracted to native flowering buckwheats (*Eriogonum* Michx) in central Washington. Environmental Entomology. 43: 942–948.

Jensen, S.; Stettler, J. 2012. Applying provisional seed zones to plant materials development in the Great Basin and cultural practice notes. Presentation to the Great Basin Native Plant Project. http://www.fs.fed.us/rm/boise/research/shrub/projects/PowerPoint_Presentations/2012/Jensen.pdf. [Accessed May 23, 2018].

Johnson, R.; Stritch, L.; Olwell, P.; [et al.]. 2010. What are the best seed sources for ecosystem restoration on BLM and USFS lands? Native Plants Journal. 11: 117–131.

Jones, T.A.; Larson, S.R. 2005. Status and use of important native grasses adapted to sagebrush communities. In: Shaw, N.L.; Pellant, M.; Monsen, S.B., eds. Sage-grouse habitat restoration symposium proceedings; 2001 June 4–7; Boise, ID. Proceedings RMRS-P-38. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 49–55.

Joshi, J.; Schmid, B.; Caldeira, M.; [et al.]. 2001. Local adaptation enhances performance of common plant species. Ecology Letters. 4: 536–544.

Kilkenny, F.F. 2015. Genecological approaches to predicting the effects of climate change on plant populations. Natural Areas Journal. 35: 152–164.

Leger, E.A. 2008. The adaptive value of remnant native plants in invaded communities: An example from the Great Basin. Ecological Applications. 18: 1226–1235.

Leger, E.A.; Baughman, O.W. 2015. What seeds to plant in the Great Basin? Comparing traits prioritized in native plant cultivars and releases with those that promote survival in the field. Natural Areas Journal. 35: 54–68.

Leger, E.A.; Goergen, E.M.; Forbis de Queiroz, T. 2014. Can native annual forbs reduce *Bromus tectorum* biomass and indirectly facilitate establishment of a native perennial grass? Journal of Arid Environments. 102: 9–16.

Leimu, R.; Fischer, M. 2008. A meta-analysis of local adaptation in plants. PLoS ONE. 3: 1–8.

Madsen, M.D.; Davies, K.W.; Williams, C.J.; [et al.]. 2012. Agglomerating seeds to enhance native seedling emergence and growth. Journal of Applied Ecology. 49: 431–438.

Madsen, M.D.; Davies, K.W.; Mummey, D.L.; [et al.]. 2014. Improving restoration of exotic annual grass-invaded rangelands through activated carbon seed enhancement technologies. Rangeland Ecology and Management. 67: 61–67.

Marlette, G.M.; Anderson J.E. 1986. Seed banks and propagule dispersal in crested-wheatgrass stands. Journal of Applied Ecology. 23: 161–175.

McAdoo, J.K.; Swanson, J.C.; Murphy, P.J.; [et al.]. 2016. Evaluating strategies for facilitating native plant establishment in northern Nevada crested wheatgrass seedings. Restoration Ecology. 25: 53–62.

McKay, J.K.; Christian, C.E.; Harrison, S.; [et al.]. 2005. “How local is local?” A review of practical and conceptual issues in the genetics of restoration. Restoration Ecology. 13: 432–440.

Mijnsbruggea, K.V; Bischoff, A.; Smith, B. 2010. A question of origin: Where and how to collect seed for ecological restoration. Basic and Applied Ecology. 11: 300–311.

Miller, R.F.; Chambers, J.C.; Pellant, M. 2014. A field guide for selecting the most appropriate treatment in sagebrush and pinon-juniper ecosystems in the Great Basin: Evaluating resilience to disturbance and resistance to invasive annual grasses, and predicting vegetation response. Gen. Tech. Rep. RMRS-GTR-322-rev. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 68 p.

Miller, R.F.; Chambers, J.C.; Pellant, M. 2015. A field guide for rapid assessment of post-wildfire recovery potential in sagebrush and piñon-juniper ecosystems in the Great Basin: Evaluating resilience to disturbance and resistance to invasive annual grasses and predicting vegetation response. Gen. Tech. Rep. RMRS-GTR-338. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 70 p.

Miller, R.F.; Knick, S.T.; Pyke, D.A.; [et al.]. 2011. Characteristics of sagebrush habitats and limitations to long-term conservation. In: Knick, S.T.; Connelly, J.W., eds. Greater sage-grouse: Ecology and conservation of a landscape species and its habitats. Studies in Avian Biology 38. Berkeley, CA: University of California Press: 145–185.

Monaco, T.A.; Waldron, B.L.; Newhall, R.L.; [et al.]. 2003. Re-establishing perennial vegetation in cheatgrass monocultures-planting prostrate kochia in ‘greenstrips’ may be a viable option to decrease cheatgrass dominance. Rangelands. 25: 26–29.

Monsen, S.B.; Stevens, R; Shaw, N.L., comps. 2004a. Restoring western ranges and wildlands. Gen. Tech. Rep. RMRS-GTR-136-vol-1. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Pages 1–294 plus index.

Monsen, S.B.; Stevens, R; Shaw, N.L., comps. 2004b. Restoring western ranges and wildlands. Gen. Tech. Rep. RMRS-GTR-136-vol-2. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Pages 295–698 plus index.

Monsen, S.B.; Stevens, R; Shaw, N.L., comps. 2004c. Restoring western ranges and wildlands. Gen. Tech. Rep. RMRS-GTR-136-vol-3. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. Pages 699–884 plus appendices and index.

Nafus, A.M.; Svejcar, T.J.; Ganskopp, D.C.; [et al.]. 2015. Abundances of coplanted native bunchgrasses and crested wheatgrass after 13 years. Rangeland Ecology and Management. 68: 211–214.

Omernik, J.M. 1987. Ecoregions of the conterminous United States. Annals of the Association of American Geographers. 77: 118–125.

Ott, J.E.; Cox, R.D.; Shaw, N.L.; [et al.]. 2016. Postfire drill-seeding of Great Basin plants: Effects of contrasting drills on seeding and nonseeded species. Rangeland Ecology and Management. 69: 373–385.

Pellant, M. 1994. History and applications of the Intermountain greenstripping program. In: Monsen, S.B.; Kitchen, S.G., eds. Proceedings of the Ecology and Management of Annual Rangelands. Gen. Tech. Rep. GTR-INT-313. Ogden, UT: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station: 63–68.

Plant Conservation Alliance [PCA]. 2015. National seed strategy for rehabilitation and restoration 2015–2020. Washington, DC: U.S. Department of the Interior, Bureau of Land Management. 50 p. https://www.fs.fed.us/wildflowers/Native_Plant_Materials/documents/SeedStrategy081215.pdf. [Accessed May 23, 2018].

Pollinator Health Task Force. 2015. National strategy to promote the health of honey bees and other pollinators. Washington, DC: The White House. 58 p. https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/Pollinator%20Health%20Strategy%202015.pdf. [Accessed May 23, 2018].

Pyke, D.A.; Chambers, J.C.; Pellant, M.; [et al.]. 2015a. Restoration handbook for sagebrush steppe ecosystems with emphasis on greater sage-grouse habitat—Part 1. Concepts for understanding and applying restoration. Circular 1416. Washington, DC: U.S. Department of the Interior, U.S. Geological Survey. 44 p. https://doi.org/10.3133/cir1416

Pyke, D.A.; Chambers, J.C.; Pellant, M.; [et al.]. 2017. Restoration handbook for sagebrush steppe ecosystems with emphasis on greater sage-grouse habitat—Part 3. Site Level Restoration Decisions. Circular 1426. Washington, DC: U.S. Department of the Interior, U.S. Geological Survey. 62 p. https://www.treesearch.fs.fed.us/pubs/53743. [Accessed May 23, 2018].

Pyke, D.A.; Knick, S.T.; Chambers, J.C.; [et al.]. 2015b. Restoration handbook for sagebrush steppe ecosystems with emphasis on greater sage-grouse habitat—Part 2. Landscape Level Restoration Decisions. Circular 1418. Washington, DC: U.S. Department of the Interior, U.S. Geological Survey. 19 p. https://doi.org/10.3133/cir1418.

Rice, K.J.; Knapp, E.E. 2008. Effects of competition and life history stage on the expression of local adaptation in two native bunchgrasses. Restoration Ecology. 16: 12–23.

Richards, R.T.; Chambers, J.C.; Ross, C. 1998. Use of native plants on federal lands: Policy and practice. Journal of Range Management. 51: 625–632.

Richardson, B.A.; Ortiz, H.G.; Carlson, S.L.; [et al.]. 2015. Genetic and environmental effects on seed weight in subspecies on big sagebrush: Applications for restoration. Ecosphere 6: 1–13.

Robichaud, P.R.; Ashmun, L.E.; Sims, B.D. 2010. Post-fire treatment effectiveness for hillslope stabilization. Gen. Tech. Rep. RMRS-GTR-240. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 62 p.

Rowe, C.L.J.; Leger, E.A. 2012. Seed source affects establishment of *Elymus multisetus* in postfire revegetation in the Great Basin. Western North American Naturalist. 74: 543–553.

Sands, A.; Moser, A. 2012. Sagebrush restoration final report. March 24, 2012. Boise, ID: Idaho Department of Fish and Game. 19 p.

Schröder, R.; Prasse, R. 2013. From nursery into nature: A study on performance of cultivated varieties of native plants used in re-vegetation, their wild relatives and evolving wild × cultivar hybrids. Ecological Engineering. 60: 428–437.

St. Clair, J.B.; Kilkenny, F.F.; Johnson, R.C.; [et al.]. 2013. Genetic variation in adaptive traits and seed transfer zones for *Pseudoroegneria spicata* (bluebunch wheatgrass) in the northwestern United States. Evolutionary Applications. 6: 933–938.

Turesson, G. 1922. The genotypical response of the plant species to the habitat. Hereditas. 14: 99–152.

U.S. Department of Agriculture, Natural Resources Conservation Service [USDA NRCS]. 2012. 'Epharim' crested wheatgrass (*Agropyron cristatum*). A conservation plant release. Aberdeen, ID: U.S. Department of Agriculture, Natural Resources Conservation Service, Aberdeen Plant Materials Center. https://www.nrcs.usda.gov/Internet/FSE_PLANTMATERIALS/publications/idpmcrb11478.pdf. [Accessed May 23, 2018].

Uselman, S.M.; Snyder, K.A.; Leger, E.A.; [et al.]. 2014. First-year establishment, biomass, and seed production of early vs. late seral natives in two medusahead (*Taeniatherum caput-medusae*) invaded soils. Invasive Plant Science and Management. 7: 291–302.