5. INVASIVE PLANT MANAGEMENT

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Introduction

One of the most significant stressors to the sagebrush biome is expansion and dominance of nonnative ecosystem-transforming species, particularly invasive annual and perennial plants. Presidential Executive Orders 13112 and 13751 define an invasive species as "a non-native organism whose introduction causes or is likely to cause economic or environmental harm, or harm to human, animal, or plant health." The use of the term "invasive species" requires two basic criteria to be met: (1) the species is alien, nonnative, or exotic to the ecosystem in question; and (2) the species has been documented as causing harm as noted in the definition. In addition, invasive annual and perennial plant species are categorized as either regulated species (nonnative species regulated under State or Federal noxious weed laws), or unregulated species (nonnative species which may pose a threat but have not been officially designated as regulated or restricted under State or Federal law). Cheatgrass (*Bromus tectorum*), for example, is not a Federally designated noxious weed, nor a State-designated noxious weed in many western States, but there are other State and local restrictions associated with this species in some areas.

Based on this definition, the labeling of a species as invasive requires closely examining both the origin and the effects of the species. Native species that may influence management objectives within a particular ecosystem would not be defined as invasive. For example, juniper (*Juniperus* spp.) and piñon pine (*Pinus* spp.) expansion into sagebrush ecosystems is a natural process resulting from a variety of factors (Miller et al. 2013; Romme et al. 2009) (see section 4). Yet unlike native juniper and piñon pine expansion, the establishment and spread of invasive plants, such as cheatgrass, Dyer's woad (*Isatis tinctoria*), and many other high-risk invasive perennial and annual plants, is not a natural ecosystem process in the sagebrush biome. There are important differences in the short- and long-term impacts to the sagebrush biome from invasive plant species compared to native species. Each invasive plant carries a different level of risk and properly describing these stressors helps managers to more effectively focus their restoration and management activities across the landscape.

Many invasive plants respond positively to ecosystem disturbance (e.g., human development, improper grazing practices, wildfires) and spread through various pathways and vectors, such as roads, trails, and vehicles (Pollnac et al. 2012; Trombulak and Frissell 2000); transmission corridors; and fuel breaks. Invasive plant species can colonize new areas rapidly, even areas that are somewhat ecologically intact. Once established, invasive plant species can continue to

Top: Spraying invasive plants with herbicides using backpack sprayers (photo: USDOI National Park Service). Middle left: Dalmation toadflax (Cal-IPC.org.; photo by Joe DiTomaso). Middle center: Spotted knapweed (photo: Alaska Plant Materials Center, State of Alaska). Middle right: Rush skeletonweed (photo: Washington State Noxious Weed Control Board). Bottom: Constantia Fire, Long Valley, California (photo: Nolan Preece, used with permission).

spread across the landscape where suitable conditions exist. Invasive plant species can become ecologically dominant, creating near-monocultures that result in reduced wildlife habitat, recreational opportunities, livestock forage, and altered fire regimes (Pyke et al. 2016). For example, even after disturbances are removed, invasive annual grasses (e.g., cheatgrass) can remain dominant. Native species may show little recovery even decades later (Keeley et al. 2003; Stromberg and Griffin 1996; Stylinski and Allen 1999) due to seed limitations of native species (Seabloom et al. 2003) and adverse interactions among invasive and native plants at the seed and seedling stages (DiVittorio et al. 2007). The complete elimination of invasive annual grasses is unlikely in these areas as the exotic annuals are highly competitive with native species for limiting resources (HilleRisLambers et al. 2010). This type of ecosystem conversion to invasive plants degrades ecosystem function by affecting geomorphic processes, hydrology, nutrient cycling, community structure, composition, productivity, and regeneration of native species (Germino et al. 2016).

The magnitude of the risk or impact that invasive plants pose to sagebrush ecosystems varies and depends on site conditions and the species' characteristics. Invasive annual grasses, most notably cheatgrass, medusahead (*Taeniatherum caput-medusae*), and red brome (*Bromus rubens*) are arguably the most widespread ecosystem disruptors across the sagebrush biome. Yet many other invasive species are also responsible for environmental impacts to sagebrush ecosystems (Ielmini et al. 2015) and new invaders (Appendix 3) continue to add to the existing management burden. For example, leafy spurge (*Euphorbia esula*) disperses into riparian and wet meadow areas important to Greater sage-grouse (*Centrocercus urophasianus*; hereafter, GRSG) brood-rearing habitat. Tap-rooted invasive plants, such as spotted knapweed (*Centaurea maculosa*), Russian knapweed (*Acroptilon repens*), and yellow salsify (*Tragopogon dubius*), spread into upland sagebrush ecosystems, especially in areas that experience heavy livestock grazing and other disturbances (Hill et al. 2006; Prevey et al. 2010). Additionally, species such as Dalmatian toadflax (*Linaria dalmatica*) are spreading into moister areas throughout the sagebrush biome (Ielmini et al. 2015).

Land managers are tasked with controlling various species of invasive plants, but limited resources are available for invasive plant management. Invasive species ranking systems (e.g., USDOI FWS 2018) can assist land managers in ranking invasive plant species for level of threat, feasibility of control, and degree of negative impact, but this information is lacking for several species. Therefore, land managers face difficult decisions regarding how to use limited resources and whether to target high-risk pathways and vectors of invasion for efficiency; focus on specific invasive plant patches that are feasible to control, such as Early Detection and Rapid Response (EDRR) programs for targeted species; or treat the periphery of a large invasion to slow and contain the spread. The need to manage multiple invasive plant species while considering ecological impacts and social and political priorities often results in significant challenges in determining how to partition resources for invasive plant management. Achieving long-term ecosystem conservation and restoration goals for invasive plant-dominated landscapes requires a substantial increase in invasive plant management capacity and the management flexibility to better align invasive species management and native plant restoration activities. It also requires innovative approaches that capitalize on the targeted ecosystem's resilience to disturbance and resistance to invasive plant invasion.

Integrating Resilience and Resistance Concepts into Invasive Plant Species Management

An understanding of ecosystem resilience to disturbance and resistance to invasive plants can be used to help prioritize invasive plant management and determine effective management strategies. Resistance to invasive plants is of particular relevance to this section. The resistance of an ecosystem to an invasive plant is a function of (1) the suitability of the ecosystem's climate and soils for establishment and persistence of the invasive plant, and (2) the capacity of the native plant community to prevent increases in the invasive plant's population through factors such as competition, herbivory, and ability of native plants to adapt to environmental conditions (Chambers et al. 2014a). Soil temperature and moisture regimes are a primary determinant of a species' ability to establish and persist in a given ecosystem and are an important indicator of ecosystem resistance to invasive plants, such as invasive annual brome grasses (Brooks et al. 2016; Chambers et al. 2016). In areas with suitable climate and soils for invasion, increases in invasive plant populations are strongly influenced by interactions with the native perennial plant community. Disturbances or management activities that reduce abundance of native perennial grasses and biological soil crusts and increase the distances between perennial grasses often are associated with higher resource availability and increased competitive ability of invasive annual grasses (Chambers et al. 2007; Collins and Uno 1985; Reisner et al. 2013; Roundy et al. 2014; Salo 2005) and invasive forbs like spotted knapweed (Willard et al. 1988). Reductions in native perennial grasses and herbaceous species coupled with increases in invasive plants can decrease the resilience of an ecosystem or its capacity to recover following disturbances such as wildfire.

The following questions identify the basic invasive plant management information needs for informing management decisions in the context of resilience to disturbance and resistance to invasive plants:

- Where are the priority areas for management, how are they defined (e.g., GRSG habitat, mule deer [*Odocoileus hemionus*] wintering habitat, particular allotment, community at risk of wildfire), and where can resources be leveraged with partners and stakeholders for the greatest chance of success (e.g., relative resilience to disturbance and resistance to invasive plants)?
- What is the current state of invasion and how great is the risk for new invasion of priority management areas (e.g., areas of low resilience and resistance to invasive plants, significant disturbance levels, high density of vectors, other invasions in the area)?
- Which management strategies (e.g., prevention, EDRR, eradication, suppression, containment, or restoration) are feasible and within the level of return for investment desired for a particular site. For example, containment may be the only feasible strategy for a site with low resilience and resistance that is dominated by invasive annual grasses.
- Which tool(s) is most appropriate for the site condition and level of invasion (e.g., herbicide application on a new invasion for eradication, biocontrol for suppression when several hundred acres are infested, and restoration or postfire rehabilitation for low to moderate levels of infestation in areas with moderate to high resilience and resistance to invasive annual grasses)?
- Is a monitoring plan in place to determine whether the management objective was achieved and the invasion threat reduced, and whether subsequent treatments are needed?

Broad- to Mid-Scale Considerations

Using the Science Framework Approach to Inform Invasive Species Management

Many invasive plants, such as invasive annual grasses, represent persistent ecosystem threats (Chambers et al. 2017a) and are widely distributed across the sagebrush biome. The extensive nature of the invasion threat and limited resources for invasive plant management preclude addressing invasive species across the entire biome. Part 1 of the Science Framework provides an approach that uses assessments at the mid-scale to help prioritize areas for management and determine effective management strategies (Chambers et al. 2017a; hereafter, Part 1). Although the approach was developed with a focus on invasive annual grasses, it is applicable to other invasive plants where information exists on the environmental characteristics necessary for their establishment, growth and reproduction, and persistence. This approach is based on: (1) the likely response of an area to disturbance or stress due to threats and management actions (i.e., resilience to disturbance and resistance to invasive annual grasses), (2) the capacity of an area to support target species or resources, and (3) the predominant threats. A geospatial process is used that involves overlaying key data layers including resilience and resistance to invasive annual grasses as indicated by soil temperature and moisture regimes (Maestas et al. 2016), GRSG breeding habitat probabilities (Doherty et al. 2016) or habitats of other sagebrush dependent species, and the primary threats for the ecoregions or Management Zones in the assessment (Part 1, sections 8.1 and 8.2).

Geospatial data on invasive plant species distribution and abundance can be used in conjunction with other threats in the analyses to: (1) evaluate the level of risk of vegetation types and communities to invasion, (2) further refine target areas for management, and (3) determine the most appropriate type of management actions (e.g., Part 1, section 9.2.2, example 2: southwestern Wyoming). Data layers or methods for remotely sensing invasive plants exist for cheatgrass in portions of the Cold Deserts (Boyte and Wylie 2015, 2016; Boyte et al. 2017), spotted knapweed and babysbreath (*Gypsophila paniculata*) (Lass et al. 2005), and rush skeleton weed (*Chondrilla juncea*) (Kesoju et al. 2015). Data layers on roads and other vectors can be used to evaluate the level of risk for future spread of the invasives. Data on interacting threats (e.g., wildfire) can help provide an understanding of the patterns and spread of the invasive plant. Available data layers to consider are in Part 1, section 8.1 and Appendix 8.

The GRSG habitat resilience and resistance matrix (table 1.3) illustrates an area's relative resilience to disturbance and resistance to invasive annual grasses in relation to its probability of providing breeding habitat for GRSG. This matrix, along with table 5.1, provides a decision-support tool that helps to prioritize areas for invasive plant management actions and develop effective management strategies. Management strategies to address the predominant threats for sagebrush ecosystems including invasive plants are found in table 1.4 and table 5.2. The maps and analyses that managers derive from the geospatial approach described in the Science Framework are used along with table 1.3 to prioritize areas for management actions and develop management strategies.

Coordination and Collaboration

Coordination and collaboration provide an effective, strategic approach for managing invasive plant threats across land ownerships and jurisdictions by developing shared priorities and leveraging resources. Collaborative spatial analyses conducted with partners and stakeholders can help identify the extent and scope of invasive plants and identify priority areas for management. A participatory process guided by common, strategic approaches can be used to prioritize what, where, how, when, and by whom actions are implemented at the project level (Beier et al. 2016).

Areawide invasive plant management coordination provides an opportunity for diverse interests and multiple stakeholders to work collaboratively across the landscape to prevent and control nonnative plant invasions, and accomplish mutually beneficial landscape restoration goals. Coordination among stakeholders is critical when there are limited resources, and when management activities are redundant, are not in alignment with partners, or conflict with recommended invasive plant management strategies. One mechanism to increase coordination and collaboration is to develop and participate in local organizations that integrate noxious weed management resources across jurisdictional boundaries and benefit entire communities. An example is Cooperative Weed Management Area (CWMA) partnerships, voluntary organizations that increase communication, share resources, and ultimately increase capacity to manage the invasive plant threat and meet restoration goals. For instance, the Utah-Idaho CWMA partnership has treated medusahead by burning prior to spring herbicide application. The partnership worked with over 200 landowners for more than 10 years to control invasive plants (http://www.utahweed.org/PDF/U&ICWMA.pdf). Several resources for establishing a CWMA are provided online (e.g., http://www.weedcenter.org/management/ guidelines/tableofcontents.html and http://invasivespecies.idaho.gov/2017-cost-share-app); an example of a CWMA is at: http://www.utahweed.org/cwma.htm. Although there is no single model, most functional and effective CWMAs have adequate and sustainable funding, strong core leadership, and clearly defined boundaries and management roles. They often include a diversity of private, county, State, Federal, and tribal members.

CWMAs are established in many areas in the West to address invasive plant management issues. In the sagebrush biome, full geographic coverage of CWMA partnerships would be advantageous in preventing management and coordination gaps across the broader landscape. CWMA membership is difficult to sustain as financial limitations are increasing across rural land ownerships in most regions of the West. Although funding has drastically declined over the last several years, the National Fish and Wildlife Foundation, in cooperation with the Federal Interagency Committee for the Management of Noxious and Exotic Weeds, established the Pulling Together Initiative grant program (http://www.nfwf.org/pti/Pages/home.aspx) in part to encourage the development and sustainability of CWMAs across the United States (FICMNEW 1998). This national grant program is vital in supporting establishment and sustainability of local CWMAs. If financial support continued and increased, the Pulling Together Initiative grant program could expand the establishment and functional effectiveness of CWMAs across the sagebrush biome.

CWMAs could be strategically located to maximize their ability to address the full range of invasive plant species threats in the highest priority areas and to maximize restoration effectiveness. However, CWMAs have not consistently been invited, encouraged, or financially supported to become involved in setting management priorities for sagebrush conservation or invasive plant management within fire and fuel management planning. In some cases, CWMAs are hampered because of policy or procedural roadblocks that prevent establishment of formal agreements with the CWMAs or transfer of Federal or State funds to either the group or individual members within the CWMA. These roadblocks should be evaluated for a more responsive approach through governmental and nongovernmental coordination groups, such as State and county weed management agencies, interagency State-Federal coalitions, or other authorities.

A web-based networking system to connect the activities of individual CWMAs and share information across the sagebrush biome could be established and supported through partnerships with State agriculture departments, Landscape Conservation Cooperatives, Federal land management agencies, tribes, and other stakeholders in the public and private sector. Various programs exist for reporting noxious weed infestation (e.g., Early Detection and Distribution Mapping System [EDDMapS; http://www.eddmaps.org/]). However, State and Federal agencies differ in their level of compliance and consistency for sharing data and utilizing a centralized clearinghouse of invasive plant species occurrence data. Federal, State, and county agencies, nongovernmental organizations, and researchers interested in using these data are working together to address these needs (e.g., Western Governors Association Invasive Species Initiative, North American Invasive Species Management Association, EDDMapS, several western States).

Prevention, Early Detection, and Rapid Response

Prevention is the key to a successful invasive species program as it ensures that the management burden is not continually increased as a result of new invasions (table 5.1). Prevention is generally low cost and has a high return on investment because preventive measures are less costly than funding efforts to control infestations over multiple years. Identifying invasion-free areas allows land managers to focus resources where they are most needed and will have the greatest chance of success. Coordination with partners can help identify invasion-free areas across regions by conducting collaborative monitoring inventories and surveys (Mealor et al. 2013; Rew and Pokorny 2006). Uninvaded areas at a higher risk of invasion, such as those with low resilience and resistance to invasive plants or higher amounts of disturbance, should be considered for frequent monitoring to help keep them invasion free (tables 5.1, 5.2).

Geospatial analyses of the distribution and abundance of invasive plants can help identify uninvaded areas and other areas at increased risk for invasion. Data layers may include current invasion extent, resilience and resistance to invasive annual grasses (Part 1, fig. 33), vectors such as roads (Part 1, fig. 20), and disturbances such as oil and gas wells (Part 1, fig. 16), human development (Part 1, fig. 18), and wildfires (Part 1, fig. 34). Distinguishing between **surveyed uninvaded** areas and **unsurveyed** areas when recording occurrence of invasive plants and analyzing their distribution is necessary to evaluate management and monitoring efforts in uninvaded areas and determine future actions.

Prevention strategies help minimize the risk of expansion of invaded areas and maintain connectivity of intact, uninvaded areas; these strategies should be applied across the sagebrush biome. Considering consequences for new invasions when implementing management and development activities in invasion-free areas can help prevent invasion. For example, using certified weed-free straw, hay, and gravel for development or restoration projects is critical to prevent unintended introductions (table 5.1). The Great Basin portion of the sagebrush biome has substantial areas with low resilience and resistance to invasive annual grasses that are now invaded by these annual grasses. In contrast, the eastern portion of the biome contains large areas of moderate to high resistance to invasive annual grasses. However, uninvaded areas in the eastern portion of the range, especially those with lower resilience and resistance, are still at risk and should be identified for prevention strategies to keep "clean areas clean" and avoid large-scale invasion and dominance of invasive annual grasses as in the Great Basin. Both the Great Basin and the eastern portion of the range also have other invasive plants, such as medusahead, ventenata (*Ventenata dubia*), leafy spurge, and Russian knapweed, that should be monitored for expansion and prevented from further spread. Stringent triage measures based on impact and risk need to be developed for these species to assist with prevention.

Table 5.1—General management strategies for cheatgrass and other invasive plants based on the invasion state with an estimate of cost:benefit of return depending on site and neighboring conditions. Management strategies are based on the level of invasion for cheatgrass, but many of the concepts also apply to annual and perennial invasive forbs. The strategies for invasive plant management are prevention, Early Detection and Rapid Response (EDDR) (USDOI 2016), eradication, suppression, containment, and restoration. The invasion state is adapted from Mealor et al. (2013). Several best management practices for prevention were adapted from Cal-IPC (2012).

	Invasion state				
	Invasion free	**Trace (1–5%) with perennials**	**Mild (6–25%) with perennials**	**Moderate (26–50%) with perennials missing**	**Invasion dominated state**
Management strategies based on invasion level	**Prevention** • Manage for sufficient density and cover of native perennial grasses and forbs and biological soil crusts • Monitor high-risk priority areas for new invaders • Use certified weed-free straw, hay, mulch, and gravel for development or restoration • Avoid use of invasive species in fuel breaks • Minimize road and infrastructure development and disturbance • Clean clothing, footwear, equipment, and vehicle of invasive plant material for land or fire management activities (Cal-IPC 2012, Checklist E) • Provide training on invasive plant awareness • Incorporate invasive plant information and management into Fire Incident Action Plans	**Prevention** • Manage for sufficient density and cover of native perennial grasses and forbs and biological soil crusts • Limit soil disturbance and revegetate bare soil post-fire **EDRR** • Early Detection monitoring • Rapid Response treatment of new invasions **Eradication** • Consistent and multiple year treatments with monitoring • Promote desirable, native vegetation	**Prevention** • Manage for native perennial grasses and forbs and prevent further disturbance of biological soil crusts • Limit soil disturbance and revegetate bare soil post-fire **Suppression/ Containment** • Implement control treatments • Seed post-treatment and implement restoration where appropriate • Monitor for invasive plants post-fire and post-treatment • Monitor and manage invasive plants to maintain fuel management sites **Restoration** • Monitor and maintain desirable vegetation • Identify native seed sources • Consider revegetation after invasive plant or fire management	**Prevention** • Manage for native perennial grasses and forbs and prevent further disturbance of biological soil crusts **Suppression/ Containment** • Monitor for invasives post-fire with restoration • Locate fire lines to reduce additional disturbance and invasive plant spread where feasible **Restoration** • Implement restoration with seeding in areas lacking perennial grasses and forbs	**Containment or restoration** • For areas with high fire probability, consider fuel breaks adjacent to, not intersecting, relatively uninvaded areas and restored areas • Consider significant and consistent control treatments for high priority areas or areas adjacent to uninvaded areas • Consider restoration when invasion-dominated site is located between intact sagebrush habitat patches or between high priority areas
Cost:Benefit	Low cost:Highest return	Low cost:Very high return	Moderate cost:High return	Moderate to high cost:High return	High cost:Moderate return

Table 5.2—Management strategies for cheatgrass and other invasive plants based on the area's relative resilience to disturbance, resistance to invasive annual grasses, and the invasion state. Management strategies are based on the level of invasion for cheatgrass, but many of the concepts also apply to annual and perennial invasive forbs. The invasion state is adapted from Mealor et al. (2013); resilience and resistance (R&R) categories are based on Chambers et al. (2017a).

	Invasion free	**Trace (1–5%) with perennials**	**Mild (6–25%) with perennials**	**Moderate (26–50%) with perennials missing**	**Invasion dominated state**
High resilience and resistance	• Monitor priority areas for new invaders, especially with disturbance or wildfire • Identify uninvaded areas and minimize disturbance to prevent new introductions • Manage livestock to maintain or increase perennial native grasses and forbs • Possibly no action post-disturbance (wildfire)	• Conduct EDRR monitoring every 3–5 years until detected • For new, small populations that are detected, herbicide use may be most efficient, but repeated application is required until control is achieved • Support natural recovery	• Manage for native perennials • Implement periodic grazing deferment • Prioritize treatment areas to maximize effectiveness • Use spot herbicide treatment for 3–5 years • Seed natives post-herbicide treatment	• Implement periodic grazing deferment • Evaluate site conditions for integrated weed management when grazing or fire management used • Use spot herbicide treatments, rather than broadcast treatments, for at least 5–10 years • Seed natives post-herbicide treatment	• Restoration success possible both pre- and post-fire • Avoid seeding introduced species to prevent spread • Use integrated herbicide application and seeding • Consider sagebrush transplants • Locate and maintain fuel breaks to prevent invasive plant introduction and spread and avoid intersecting uninvaded areas
Recovery potential		Very high	High	High to moderate	Moderate
Moderate resilience and resistance	*Management strategies for moderate R&R depend on soil temperature and moisture regimes. Treat relatively cool and moist areas similarly to high R&R areas. Treat relatively warm and dry areas similarly to low R&R areas.*				
Recovery potential		High	Moderate	Moderate	Moderate to low
Low resilience and resistance	• Identify uninvaded areas and prioritize prevention • Conduct EDRR annually • Monitor areas that are high priority or adjacent to high priority areas frequently • Monitor disturbed areas frequently • Avoid fuel break placements that connect invaded and uninvaded areas and avoid intersecting uninvaded areas	• Develop an EDRR network in high priority areas • Promote desirable native vegetation • Monitor herbicide treatments and continue treating as needed • Minimize disturbance and suppress wildfire to prevent new introductions • Locate and maintain fuel breaks to prevent invasive plant spread • Prioritize postfire monitoring for invasive plants	• Identify high fire risk areas and identify invasive plant populations in these areas and travel routes to minimize spreading invasives • Use significant and consistent treatments to prevent crossing threshold into heavy infestation and manage for native perennials • Minimize disturbance and suppress wildfire • Locate and maintain fuel breaks to prevent invasive plant introduction and spread • Prioritize postfire monitoring for invasive plants with subsequent treatment and revegetation	• Identify high fire risk areas and invasive plant populations in these areas • Use significant and consistent treatments for containment and suppression in high priority areas to prevent crossing threshold into heavy infestation and to protect adjacent high quality habitat • Suppress wildfire • Avoid fuel breaks that connect invaded and uninvaded areas and try not to intersect uninvaded areas	• Restoration not feasible for most areas. Restoration in high priority area will require significant and long-term funding • Consider targeted grazing to reduce invasive annual grass fuels to reduce fire risk to adjacent higher priority areas • Consider herbicide application and integrated biocontrol at perimeter to prevent spread • Consider fuel breaks around perimeter of invaded area to contain fine fuels • Restoration may require repeated interventions • Consider seeding nonnatives where natives fail to establish
Recovery potential		Moderate	Low	Low	Low to none

Early Detection and Rapid Response (EDRR) strategies survey for those new invasive plants most likely to increase in abundance (text box 5.1, Appendix 3) and pursue treatment as quickly as possible. An overview of the National Framework for Early Detection and Rapid Response to invasive plants is available on the USDA National Invasive Information Center website (https://www.invasivespeciesinfo.gov/toolkit/detection.shtml). An example of how EDRR can be incorporated into a monitoring strategy is in text box 5.1. Early detection and rapid response strategies are cost-effective and successful because they focus on eliminating new, small invasions, which are less costly to treat and easier to eliminate (Chippendale 1991 in Hobbs and Humphries 1995; Keller et al. 2007; Leung et al. 2002). The removal of small, separate populations of invasive plants (table 5.1) is a high priority because they often expand more rapidly and cover potentially greater areas than the edge of a large, single source population (Cousens and Mortimer 1995; Moody and Mack 1988). Most invasive plants have a long lag period before they spread following introduction, so they can usually be eradicated if treated as soon as possible after detection. Early detection can make the difference between employing feasible offensive strategies versus retreating to defensive strategies, which usually result in an infinite financial commitment (Rejmanek and Pitcairn 2004).

Extensive outreach and communication about new invaders, their identification, and life history characteristics and identifying the areas that are most at risk can help foster detection, reporting, and rapid response (see Appendix 3). Establishing a communication network among landowners, public land management agencies, recreation groups, conservation organizations, botanists, horticulturalists, and weed organizations to report new invasive plant infestations will help meet detection and monitoring objectives. Targeting species of known concern and high-risk invasion pathways, such as low resistance areas, roadsides, and areas disturbed by human development, can be a successful detection strategy (table 5.2).

Text Box 5.1—Monitoring for Early Detection of Invasive Species

Early Detection and Rapid Response (EDRR) provides an opportunity to control the spread of invasive species (USDOI 2016). Monitoring for early detection of invasive species requires the following:

1. Identify known high-risk invasive species and provide training for rapid species detection and identification.
2. Coordinate priority monitoring areas across land management jurisdictions.
3. Identify locations of existing invasions and likely invasion pathways to identify areas where invasive species may first establish (e.g., recreation sites, trails, and roadsides, and in areas with treatments, recent fires, energy development, and other types of disturbance).
4. Survey, report, and verify the presence of invasive species before the population becomes established or spreads so widely that eradication is no longer feasible.
5. Utilize early detection tools that can be readily accessed and allow data to be recorded and shared among networks of Federal, State, private and nongovernmental partners (e.g., Early Detection and Distribution Mapping System [EDDMapS]).
6. Use invasive plant species presence and abundance as monitoring indicators in other vegetation monitoring programs (e.g., the Bureau of Land Management's Assessment, Inventory, and Monitoring [AIM] and the Natural Resources Conservation Service's National Resources Inventory [NRI]).
7. Develop management triggers designed to address early invasions. Monitoring plans can be greatly improved when an invasive species list or georeferenced abundance data are available (Brooks and Klinger 2009).

Agency programs such as forestry, grazing, energy development, recreation, wildlife, and wildfire management have the responsibility to incorporate invasive species management strategies (Federal Noxious Weed Act, 7 U.S.C. §§ 2801-2814, January 3, 1975, as amended 1988 and 1994) and coordinate management actions with CWMAs. These management programs can identify geographic areas within their program jurisdictions that have either known populations of invasive plants or low resistance to certain species. They can also identify areas that serve as sources of invasive plants and conduits for their spread. Source areas for invasive plants include recent ecosystem disturbances, such as wildfire or die-offs due to drought, and anthropogenic developments, such as oil and gas wells or cropland conversion. Mapping overlays of resilience and resistance with known populations of invasive plants, disturbed areas, and road and trail networks can provide a broad-scale assessment of where to focus invasive plant prevention and control measures. For example, suppression and control of invasive plants along roads that link invaded areas to non-invaded areas can help to prevent or minimize movement along this vector. Similarly, the potential for spread of invasive plants can be considered when siting linear firebreak networks and determining follow-up actions. Monitoring programs that involve multiple management jurisdictions and program areas can be used to evaluate both the spread of invasive plants and the effectiveness of control measures.

Local Scale Considerations

Management Strategies

Management of invasive plants and restoration of native species require the capacity to address the full suite of management activities spanning inventory and mapping, prevention, EDRR, suppression/reduction and containment, collaboration and partnership development, data collection and sharing, and restoration and rehabilitation. General project priorities for invasive plant management exist (text box 5.2), but alignment of regional strategic goals for conservation and restoration of sagebrush ecosystems and the involvement of partnerships (e.g., CWMA, State and county governments) are needed. There also may be areas within the sagebrush biome that require immediate invasive plant management actions to reduce threats to other rare or unique plants. This kind of need can be highlighted with coordination and communication at the local scale.

Resilience and resistance concepts and decision matrices can be used in project selection and design for invasive species management. At the project scale, specific ecological site description information (e.g., precipitation and temperature regimes, soil characteristics, vegetation composition), state-and-transition models, and available invasive plant assessment data (inventory and monitoring data, risk assessments, predicted occurrence) help set priorities for management actions (see Miller et al. 2014, 2015). Because invasions can vary in distribution and abundance across project areas, a critical first step in diagnosing the level of threat is to complete inventories and assessments within the project boundary.

Once the size and impact of the invasion are determined, an evaluation of the recovery potential (resilience and resistance to the specific invader) will help determine and prioritize treatment activities with the highest chance of success for invasive plant eradication, suppression, reduction, or containment (table 5.1). New invasions, low density invasions, and invasions in areas of high to moderate resilience align well with the strategies of early detection, rapid response, and

Text Box 5.2—Invasive Plant Management Priorities and Limitations

Invasive plant management priorities and limitations need to be considered when developing broad-scale approaches.

Invasive Plant Management Priorities

1. Assess the extent of the invasion for spatial distribution and abundance.
2. Prevent new infestations and implement Early Detection and Rapid Response to maintain areas without invasive plant infestations that are ecologically intact.
3. Reduce densities and cover of invasive plants with invasive plant management while native plant species are available to respond and before the invaders dominate.
4. Consider containment of large, well-established infestations to prevent perimeter spread, rather than full-scale costly control efforts that may have a low chance of success.
5. Conduct revegetation efforts in high priority areas with a high probability of success based on ecological condition when sufficient resources are available.

Invasive Plant Management Limitations

1. Competing priorities among land managers that prevent common regional and local prioritization of project areas may create multiple, inconsistent efforts.
2. For many invasive species, detailed ecological knowledge on climatically suitable areas for their establishment and spread is lacking. Thus, it is difficult to characterize ecosystem resistance to these species, identify areas most at risk of invasion, or determine the most appropriate and effective management tools and methods.
3. Inconsistent and incompatible administrative procedures for operations, datasets, and databases among partners can slow or hinder effective communication and implementation (Ielmini et al. 2015).

suppression or reduction (table 5.2). Multi-year, consistent treatments in areas with high to moderate resilience and resistance to invasive plants may achieve eradication of new or small infestations (table 5.2). Larger, well-established infestations are likely to need long-term treatment measures for potential suppression or containment on the perimeter of large invaded patches.

If funding is available and it is a high priority conservation area, it may be feasible to try to restore areas that have large, well-established infestations using an integrated approach which includes invasive control measures and revegetation (tables 5.1, 5.2). Restoration to desired conditions may be feasible in areas with moderate to high resilience. However, in areas with low resilience, repeated interventions and greater levels of financial resources may be necessary. In areas dominated by invasive annual grasses, it may not be possible to establish perennial plants without significant and costly investments. In these cases, managers should consider the return on restoration investment carefully and work with scientists to test new methods for protecting restored areas that have low resilience to fire. The conservation value of a site and the associated cost:return ratio and likelihood of success are used to determine where to place resources for invasive species management (table 5.1). Identification of treatment options is then based on site-specific characteristics, the invasive species, the degree of invasion, potential for native plant recovery, and resources available (table 5.2).

Maintain Intact Native Communities. The most successful tool for maintaining resistance to plant invasions is generally to manage for sufficient density and cover of native perennial grasses and forbs and biological soil crusts to prevent the establishment or population growth of the invader (Chambers et al. 2014a,b). For example, research shows that about 20 percent cover of perennial native grasses and forbs is needed in Wyoming big sagebrush sites to prevent significant increases in cheatgrass and other exotic annuals after management treatments (sagebrush mowing and prescribed fire) (Chambers et al. 2014b). Similarly, about 18 percent cover of perennial native grasses and forbs or 10 perennial grasses per square meter (about 1 perennial grass per square foot) is needed to exclude medusahead rye from these sites (Davies 2008).

Decreases in perennial herbaceous species and biological soil crusts and reductions in resistance to invasive plants result from improper livestock grazing (Adler et al. 2005; Reisner et al. 2013, 2015), high severity wildfire, and juniper and piñon expansion into sagebrush ecosystems (Miller et al. 2013). Reductions in perennial native grasses and forbs are associated with increases in sagebrush density and cover (Chambers et al. 2017b; Cooper 1953), and juniper and piñon densities, canopy cover, or basal area (Guenther et al. 2004; Madany and West 1983; Shinneman and Baker 2009; Soulé et al. 2004). The increases in woody fuels can cause higher severity wildfires with the potential to increase mortality of perennial native species (Miller et al. 2013).

Carefully managed livestock grazing is crucial to maintain perennial herbaceous species, forbs, and biological soil crusts and thus resistance to invasive plants. The livestock grazing strategies identified in the Science Framework are broadly applicable to the sagebrush biome (table 1.4 and section 7). Implementing livestock grazing strategies that incorporate periodic deferment from use during the critical growth period, especially for cool season grasses, can help ensure maintenance of a mixture of native perennial grasses. Adjustments in timing, duration, and intensity of livestock grazing may be needed to reduce invasive species. Livestock grazing that creates patches of bare ground can result in avenues for invasion of species such as spotted and Russian knapweed and is associated with increases in cheatgrass (Reisner et al. 2013).

Other threats to maintaining intact native communities will require diligence in monitoring for new invasions in response to land use and land management practices. Oil and gas development, road maintenance, construction, and potentially even fuel breaks may create disturbances that foster colonization of invasive plants or bring in material contaminated with weed seed. The extent and placement of fuel breaks to reduce fire risk need to be considered and designed carefully to ensure that they do not inadvertently increase subsequent fire risk by creating disturbances conducive to new invasions, especially in uninvaded areas (table 5.1 and section 4). Other measures for preventing new invasions include sanitizing equipment and vehicles pre- and post-access; requiring certified weed-free seed, gravel, topsoil, and hay for construction or restoration; and education and outreach to public, staff, and partners in identification and management of invaders (Mealor et al. 2013; Pyke et al. 2016).

No Action Post-Disturbance. Areas characterized as having moderate to high resilience and resistance (table 1.3: cells 1B, 1C, 2B, 2C) with no current invasions may not require management intervention following disturbances such as wildfire (tables 5.1, 5.2). If these areas have sufficient perennial native grasses and forbs prior to disturbance, they are likely to maintain resistance to most invasive plant species, and invasive species management resources may be better spent in other areas. For example, in relatively cold and moist areas with high ecosystem resilience, allowing the area to recover after wildfire without intervention may be the most effective strategy for preventing increases in invasive plants. However, if invasive plants occur in the area or there are significant fire management activities including access roads and vehicles, then resources should be spent on a monitoring strategy to determine whether the invasive plants increase or colonize. Funding mechanisms should remain available for restoration activities if a no-action approach is not successful.

Invasive Plant Removal and Treatment. Control measures shown to be successful in reducing and removing invasive plants include biological, cultural, physical, and chemical treatments. The 2017 Weed Management Handbook (Peachey 2017) and Weed Control in Natural Areas in the West (DiTomaso et al. 2013) are comprehensive guides to invasive plant management that provide summaries of the requirements and advantages of different tools. Selection of the appropriate tool will vary based on the invasive plant species, extent of the invasion, and resilience of the site. The integration of different controls in treating invasive plants may offer more success over the long term at project scales. When using control methods, practitioners need to consider health, environmental, and economic risks. Selection of controls based on consensus building for common threat-reduction objectives, biology of invader, site conditions, environmental factors, and best available technology can achieve desired outcomes while minimizing effects to nontarget species and the environment. Individual controls that can be used at the project scale are summarized next.

(1) Biological control is the use of natural enemies—predators, parasites, pathogens, and competitors—to control invasive plants over multiple years. Invasive plants have many natural enemies including insects and plant pathogens. Biological control is often considered when the invasion is large and well established (table 5.1) because host plant density is a determinant of whether the biological control agent can become established (table 1.3: cells 1A, 1B, 2A, 2B, 3A, 3B; table 5.2). In practice, biological control options are best determined when the land manager and biological control practitioner coordinate closely to build a long-term biological control plan that includes a strong monitoring component for the targeted invasive plant and the respective biological control agent(s). Site conditions are important for selecting the appropriate biological control agent(s) for the targeted invasive species. Several resources exist for biological control information, including the reference compendium of information available online at https://www.ibiocontrol.org/catalog/.

Other types of control agents for invasive annual grasses, especially cheatgrass, may include fungal pathogens (Meyer et al. 2016) and bacterial agents (Kennedy et al. 2001). These are often mistaken for biocontrol, but they do not function in the same way as predation or feeding behavior, which is typical of classic biocontrol. Applying bacterial agents (e.g., weed suppressive bacteria) may be considered a biopesticide application and requires different application guidelines and policy compliance under State and Federal regulations than classic biocontrols. Multiple trials are underway to evaluate the effectiveness and application guidelines for the use of fungal pathogens and bacterial agents as biopesticides. However, there is currently very limited information demonstrating the effectiveness of either fungal pathogens or bacterial agents for cheatgrass control or the potential effects of these controls on native species. Fungal pathogens do result in large cheatgrass die-off areas that may provide restoration opportunities (Meyer et al. 2016).

Species such as knapweeds and leafy spurge have several biological control agents that may provide support for strategies of containment and suppression (Anderson et al. 2000). Integration of biocontrols with other control measures can have advantages and disadvantages. For example, herbicides could be used around the perimeter of large invaded patches with biocontrols released in the center of the patches to increase overall control. In contrast, release of the biocontrol with herbicide application at the time when biocontrols emerge may result in loss of the biocontrol.

(2) Cultural controls are management practices that reduce establishment, reproduction, dispersal, or survival of the invasive plant. For example, management actions that maintain or increase native perennial herbaceous species can help control many invasive plant species. Other cultural controls, such as prescribed fire or targeted grazing, can impact native communities and are best applied in areas dominated by the invasive plant. Typically, these are lower priority areas for sagebrush conservation and restoration (table 1.3: cells 2A and 3A; table 5.2), but they may be used to meet habitat objectives such as increasing habitat connectivity or establishing fuel breaks.

Prescribed fire may serve as a cultural control for cheatgrass dominated areas if applied during seed maturation in the spring; however, it is rarely an option due to narrow implementation requirements (Mealor et al. 2013). Prescribed fire may also be used as part of an integrated management strategy. Prescribed fire implemented when conditions are safe for burning can reduce standing litter and litter mats in cheatgrass dominated areas (Jones et al. 2015a,b). Reducing the litter in areas dominated by invasive plants can improve effectiveness of certain types of herbicide applications by allowing the herbicide to reach the soil surface (DiTomaso and Johnson 2006). It can also facilitate an integrated restoration approach that includes reducing litter through repeated burning (Jones et al. 2015b) or through prescribed grazing (Frost and Launchbaugh 2003); seeding with sterile cover crops such as common wheat (*Triticum aestivum*) to decrease cheatgrass reproduction and, thus, seedbanks; and then seeding the desired native perennial species (Jones et al. 2015a). If properly implemented, prescribed fire can provide some level of reduction for both invasive perennial and annual grasses and annual forbs. However, prescribed fire does not decrease, and may increase, perennial and biennial invasive forbs (DiTomaso and Johnson 2006).

The removal of cheatgrass by fire or livestock grazing may create conditions that allow release of perennial invasive plants, resulting in a bigger issue. Native species may take many years to increase from low densities following the removal of landscape disturbances such as grazing, perhaps due to seed limitation (Seabloom et al. 2003) or adverse interactions at seed and seedling stages (DiVittorio et al. 2007). In addition, prevention and early detection methods may be needed for recent prescribed fire (and wildfire) operations to ensure that suppression activities do not inadvertently increase risk for invasive plant colonization and spread.

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 (Launchbaugh and Walker 2006). Sheep and goats are effective tools for reducing invasive plants such as leafy spurge, spotted knapweed, and cheatgrass (Mosely 1996; Mosely et al. 2016). Intense sheep grazing of cheatgrass dominated sites can effectively suppress or even eliminate cheatgrass stands in as little as 2 years as was done in the urban interface above Carson City, Nevada (Mosley 1996). However, the effects of correctly applied targeted grazing are generally slow and cumulative (Launchbaugh and Walker 2006) and still need to be tested for applicability across broad areas.

Managed grazing may also reduce the risk and extent of wildfire in cheatgrass dominated areas (Diamond et al. 2009, 2012; Walker 2006). Because livestock grazing reduces herbaceous vegetation (fine fuels), grazing may reduce the extent of wildfire (Walker 2006) (table 5.2). Further, livestock tend to graze some areas more intensely than others, so grazing may create patchy vegetation that reduces the continuity of fuel loads and the fires that might burn those fuels (Walker 2006). In sagebrush ecosystems, exploratory high intensity targeted grazing to create fuel breaks can be tested by confining livestock to a strip of land with temporary fencing. In a fenced Wyoming big sagebrush (*Artemisia tridentata* ssp. *wyomingensis*) ecosystem, cattle removed 80 to 90 percent of *B. tectorum* biomass in May during the boot phenological stage (Diamond et al. 2009). Grazing resulted in reductions in flame length and rate of spread compared to nongrazed plots in the first year; cheatgrass biomass and cover were reduced to the point that fires did not carry in the grazed plots in the second year (Diamond et al. 2009). However, grazing resulted in an increase of invasive annual forbs and Sandberg bluegrass (*Poa secunda*) (Diamond et al. 2012). This demonstrates there may be tradeoffs that will require secondary or additional management actions for other invasive species, such as the invasive annual forbs that responded to the grazing.

Effective grazing programs for invasive plant control require a clear statement of the kind of animal, timing, and rate of grazing necessary to suppress the invasive plant (Launchbaugh and Walker 2006). A successful grazing prescription should: (1) cause significant reduction in the target plant, (2) limit effects on the surrounding vegetation, and (3) be integrated with other control methods as part of an overall management strategy. Because targeted grazing by livestock is typically focused on heavily invaded areas, follow-up management such as seeding of the target area with the desired species may be needed. In big sagebrush areas with a cheatgrass understory where grazing is used to suppress cheatgrass, it may be possible to interseed the sagebrush with perennial grasses and forbs after treatment (Huber-Sannwald and Pyke 2005).

(3) Mechanical and physical controls such as hand pulling, mowing, or disking before seed production kill invasive plants directly, block establishment, or make the environment unsuitable for establishment. To date, these methods have not been widely applied to invasive annual grasses or perennial invasive plants in sagebrush ecosystems. There are potential tradeoffs of destroying biological soil crusts with some of these methods.

(4) Chemical control is the use of pesticides, which include herbicides, fungicides, or biopesticides (as mentioned in the discussion of biocontrols). Pesticides are typically used as an efficient and cost-effective approach to control invasive plant infestations, and, like other integrated pest management techniques, are best used in combination with other treatment approaches for more effective, long-term control. Ecological type or site descriptions and state-and-transition models that integrate information on resilience and resistance to invasive annual grasses (see Part 1, Appendices 5 and 6) can help determine whether herbicides are the best control method for larger invasions. Herbicides can be very useful for eradicating small patches of invasive plants or interrupting the spread of large patches along advancing fronts by containing the perimeter (Rinella et al. 2009) (tables 5.1, 5.2). In some situations, large-scale herbicide applications have been used to treat well-established plant invasions before implementing native plant restoration actions, in order to maximize effectiveness across large landscapes or along border areas. Evaluating the degree and extent of neighboring invasions can provide information on whether the invasive species can recolonize from a neighboring untreated area. Additionally, evaluating the existing seedbanks within a treated area can provide information to help determine whether repeated treatments are needed and, if so, for how long (e.g., 3–15 years).

Several basic elements should be included in all pesticide (herbicide) use proposals and application plans prior to implementing any herbicide application by trained and experienced personnel. These include proper selection of the appropriate herbicide product and adjuvants for the targeted invasive species, site condition, and the appropriate application technique and timing. Detailed knowledge of the soil and water conditions and other environmental concerns in the treatment area is also needed. Proper application of appropriate herbicidal products can be an effective solution for managing established invasive plant populations. Although there may be short-term collateral damage, proper herbicide application planning greatly reduces the chance of unintended negative impacts to nontarget native plants and associated fish and wildlife in the treatment area. For example, to minimize effects, herbicide applications may involve spot-spraying of localized invasive patches within the area by using a backpack sprayer, rather than aerial spraying the entire area, which may increase the risk of nontarget impacts. Further, while broadcast spray is a method for treating large, well-established invasions, the level of reduction in density or coverage accomplished and the effects on nontarget native plant communities, soils, or biological crusts, and costs of multi-year treatments needed should be carefully considered before implementation.

Conclusions

Sagebrush ecosystem conservation must recognize the need for greater investment in preventing additional plant invasions and limiting the spread of existing invasions across the entire sagebrush biome. This type of investment will support land owners and managers in a proactive management approach rather than the reactionary approach that is currently in place. Without prevention and a proactive approach, the ongoing expansion of invasive plants will continue to outpace restoration efforts and resources. Areas could be prioritized for proactive invasive plant management based on resources of concern, community needs, and opportunities for success according to resilience and resistance to invasion and current ecological site conditions such as the level of invasion. Uninvaded areas could be identified and monitored for new plant invasions and, if invasions occur, quickly treated and eradicated. Invasive annual grass control is the key to preventing and reducing uncharacteristic fuel and fire regimes. Partnerships are critical and must be developed to provide consistent invasive plant management to maintain weed-free areas and prevent mild invasions from spreading and crossing thresholds into heavy infestations. An all-hands-on-deck effort to leverage resources for restoration efforts is needed in high priority areas. Combating invasive plants pre- and postfire and addressing the technical, policy, communication, and operational challenges needs to be a priority. Addressing these challenges will help to prevent negative effects to ranching livelihoods and recreational opportunities and protect the sagebrush biome from overall ecosystem degradation.

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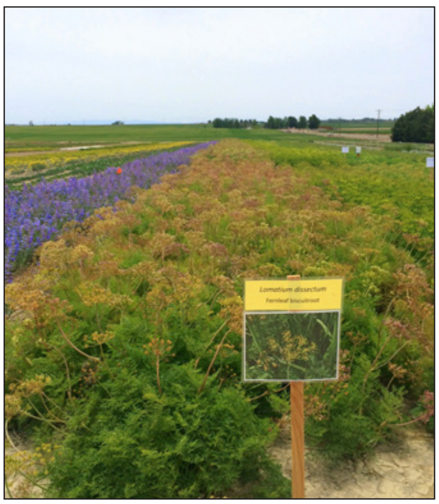
Lomatium dissectum
Fernleaf biscuitroot