



Managing for Resilience to Fire and Resistance to Annual Grass Invasion in Upland Sagebrush Steppe

John Day Fossil Beds National Monument

Natural Resource Report NPS/UCBN/NRR—2020/2144



ON THE COVER

The lightning-ignited Hancock Fire burned across the Clarno Unit of the John Day Fossil Beds National Monument during late August 2011 (NPS photo).

Managing for Resilience to Fire and Resistance to Annual Grass Invasion in Upland Sagebrush Steppe

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Executive Summary

Sagebrush steppe ecosystems have been described as one of the most imperiled ecosystems in North America due to a combination of threats from human and ecological factors (Noss et al. 1995, Davies et al. 2011, Davies et al. 2012). Degradation of sagebrush steppe has led to declining abundance and productivity of endemic floral and faunal assemblages, soil system health, and ecological functions within and outside protected area boundaries across the western United States. Published assessments (e.g., Caicco et al. 1995, Stoms et al. 1998) of the amount of healthy, intact sagebrush and bunchgrass steppe in western American protected areas have reported that steppe ecosystems are not well represented in the protected-area network of the US, underscoring concerns for preserving these resources for future generations, and underscoring the value of NPS units that contain and manage steppe communities.

Consistent with widespread concern for these ecosystems, the Pacific West Region (DOI Unified Regions 8, 9, 10, and 12) of the National Park Service (NPS) has asked a team of experts from Oregon State University and NPS to synthesize best-available science about resilience to fire and other stressors and resistance to weed invasion into management guidance documents and geodatabases for each of the 8 parks in the region that contain and are managing significant amounts of sagebrush steppe. These parks are Big Hole National Battlefield (BIHO), City of Rocks National Reserve (CIRO), Craters of the Moon National Monument & Preserve (CRMO), Hagerman Fossil Beds National Monument (HAFO), John Day Fossil Beds National Monument (JODA), Lake Roosevelt National Recreation Area (LARO) in the Upper Columbia Basin Network; Great Basin National Park (GRBA) in the Mojave Network; and Lava Beds National Monument (LBE) in the Klamath Network.

Vegetation monitoring is occurring in all of these parks as part of the NPS vital signs monitoring program. The Upper Columbia Basin Network is targeting sagebrush steppe as a distinct vital sign for monitoring, whereas sagebrush steppe is integrated into a more general upland vegetation monitoring program in the other two networks. Several of these parks, notably JODA, have also pursued use of prescribed fire, and fire effects monitoring has occurred in JODA for ~20 years. Inventories of soils, vegetation, and natural resource condition have been conducted in all of these parks as part of the NPS Natural Resources Challenge (12 basic inventories). Findings from all of these inventory and monitoring activities provide the central place-based information for the syntheses and geodatabases. The broader scientific literature about sagebrush steppe ecology and about resilience to fire and resistance to annual grass invasion establish the theoretical and conceptual foundations for this syntheses and associated geodatabases.

This report for John Day Fossil Beds National Monument (JODA) is the first in an anticipated series of 8 park steppe syntheses, each accompanied by park steppe geodatabases (<https://irma.nps.gov/Datastore/Reference/Profile/2271774>) that provide the mapping environment and spatially-explicit guidance for where park management activities are likely to be most effective. Sagebrush steppe vegetation has been mapped in JODA and covers most of the vegetated uplands in the park (Figures 1 and 2). The type of sagebrush steppe ecosystems that occur in JODA are

characterized as Wyoming and basin big sagebrush (named for the dominant subspecies of big sagebrush in these systems), well understood to be inherently of low resilience to fire and low resistance to annual grass invasion because of their low productivity. These kinds of sagebrush steppe ecosystems are also difficult to restore because low productivity creates high ecological inertia.

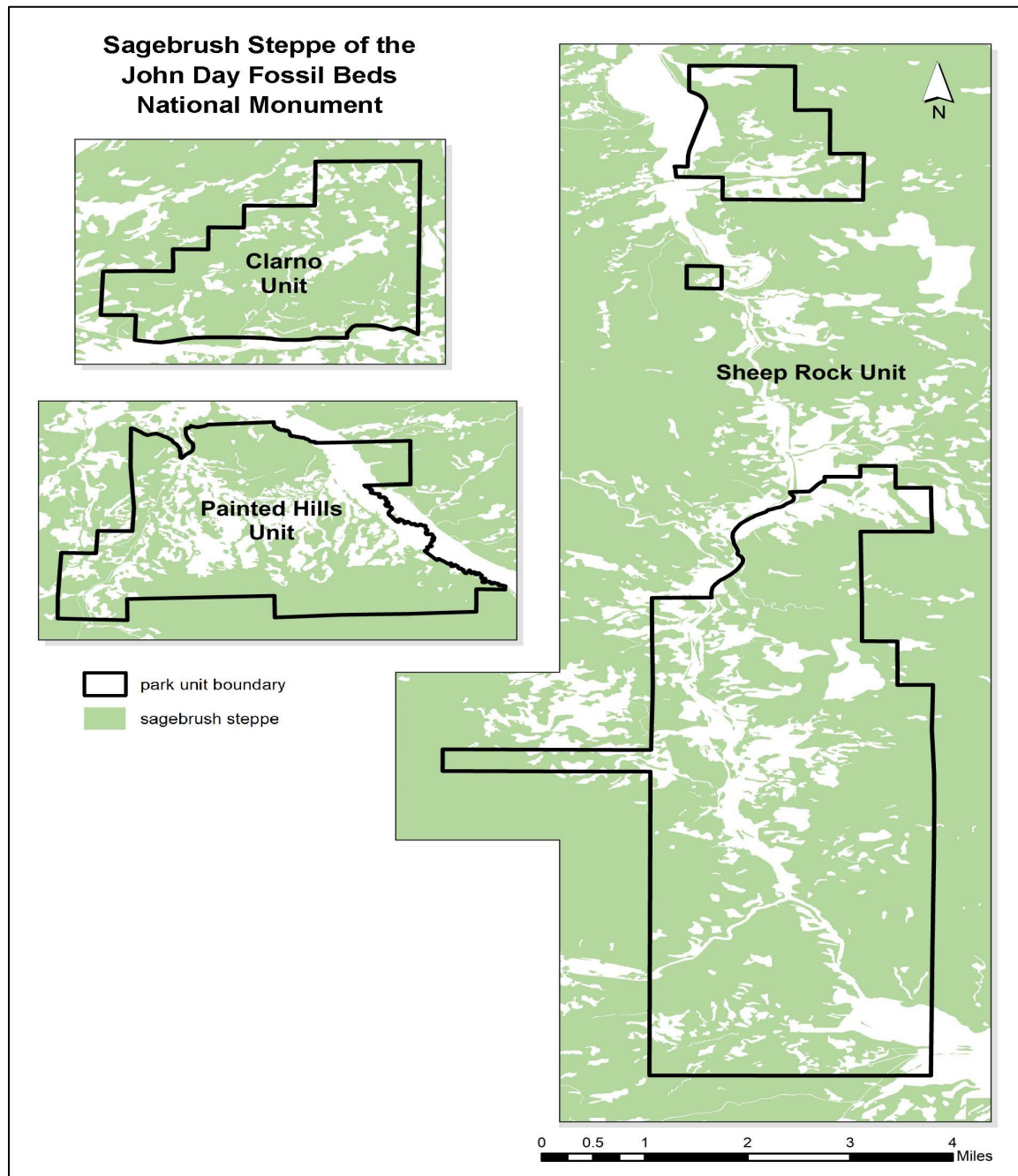


Figure 1. Map of the steppe vegetation in and surrounding all three units of the John Day Fossil Beds National Monument.



Figure 2. View of Picture Gorge and the John Day River, south end of the Sheep Rock Unit of the John Day Fossil Beds National Monument. Expanses of bunchgrass steppe are visible on the slopes, and weedy big sagebrush and riparian vegetation visible in the foreground (NPS photo).

Recent assessments of how climate change is likely to affect resilience and resistance across the west suggest that JODA steppe will remain a low-resilient and resistant system for the foreseeable future. This ecological predicament presents a fundamental challenge to JODA natural resources management. Historic grazing prior to Monument establishment, weed invasion, and fires have all accelerated the processes of degradation in JODA steppe. The current composition of steppe plant communities in the Monument is dominated by non-native annual grasses of Eurasian origin that increase wildfire frequency and spatial extent, and are also highly competitive in post-fire conditions. It is evident that within the past 20 years, non-native annual grass cover has increased in response to both wildfires and prescribed burns at JODA. However, north-facing slopes where effective soil moisture and productivity is higher continue to support native bunchgrass communities, and these are prioritized for protection from further degradation. Strategic fire suppression and weed control around the perimeters of these quasi-intact bunchgrass stands is recommended, as is a moratorium on prescribed burning. Restoration of areas degraded by non-native annual grasses is costly and unlikely to be successful without high resource input, especially in areas not benefitting from topographically mediated soil moisture availability (i.e., low elevation areas and south-facing slopes). Focusing

resources on the protection and possible enhancement and expansion of bunchgrass-dominant communities should prove to be more effective.

Research and monitoring at JODA have facilitated a greater understanding of disturbance and invasion ecology of the region, and has enabled management plans to be based on best possible science; however, continued research and monitoring is imperative as climatic shifts and novel invasive species threaten to further alter ecosystem dynamics. Park specific knowledge of factors of resistance to invasion and resilience to disturbance should be incorporated into decision making documents such as fire management plans (FMP), burned-area emergency response (BAER) plans, ecologically-based invasive-plant management (EBIPM) plans, and restoration plans. The existing 2015 EBIPM plan (Hoh et al. 2015) for JODA incorporates concepts of resistance and resilience, and should be viewed as an important guiding document with specific steps outlined to protect upland bunchgrass communities.

Suggested revisions to the JODA FMP are included in this synthesis, as is generalized text for future BAER plans, if needed. A geodatabase with base cartography, soils, vegetation, and fire history is provided as a companion to this synthesis and can be used for spatially-explicit park planning. An annotated bibliography of scientific information relevant to resilience and resistance in sagebrush steppe, and in JODA specifically, has been developed to support this synthesis and is available in the appendix. Appendices also include suggestions for interpretive material focused on sagebrush steppe ecology and resilience/resistance, as well as a recommended seed mix for a common ecological site found within the Monument.

Summary of Management Recommendations

Protection Strategies

- Prioritize cooler north-facing slopes and other areas of intact remnant native vegetation for protection and as central points for restoration because they tend to support more resilient and resistant native bunchgrass steppe. Avoid land uses or management activities in these areas that are likely to disturb soils, reduce native plant cover or inadvertently spread invasive plant seeds.
- Develop strategic fire suppression and response plans that prioritize protection of high-integrity plant communities based on resources provided in this synthesis, including revisions to existing Fire Management Plans and Burned Area Emergency Response plans (see section 5) and the 2015 EBIPM plan for JODA (Hoh et al. 2015). Where possible, avoid developing fire breaks through intact native vegetation patches to avoid soil and native plant disturbance.
- Strategic fire breaks can be developed to protect high-integrity plant communities by fall application of Imazapic followed by spring application of Imazapic and glyphosate in areas infested by exotic plant species. These fuel breaks can then be seeded with desirable plant species to re-establish site resistance and reduce the spread of exotic species.
- Strategically place firefighting resources for prompt fire response in highly susceptible areas with valuable and intact resources (i.e., *Priority 1* areas; Chambers et al. 2019).

- Limit management activities and recreational access in areas with intact biocrusts as these soils are an important component of site resilience and resistance and are very sensitive to disturbance. Provide signage that discourages hiking in these areas.
- Integrate resilience/resistance information into park interpretive information to inform visitors, encourage appropriate use and enlist volunteer support for active projects.

Vegetation Management

- Avoid use of prescribed and/or wildland fire as a vegetation management strategy throughout the Monument. Prescribed fire has led to establishment of exotic understory species (Williams et al. 2017), and has been ineffective in removing juniper at sites with reduced ladder fuels (Clark et al. 2018).
- Avoid leaving juniper carcasses in place or burning in slash piles following mechanical treatment because they provide safe sites for invasive weeds.
- Management of exotic species invaded sites must be ecologically-based (i.e., treat the whole system), as exotic plants may leave lasting system-wide legacies. Specific recommendations for a systems-based approach to exotic species management can be found in the existing JODA Ecologically-Based Invasive Plant Management Plan (Hoh et al. 2015).
- Consider active vegetation maintenance strategies (mechanical or chemical treatments) that mimic natural disturbance to recover the natural range of variation in intact high resilience sites (Chambers et al. 2014 a). Avoid use of mechanical equipment in areas with intact biocrusts and generally in low-resilience sites.
- Develop generalized Burned Area Emergency Response (BAER) text based on recommendations provided in Appendix D that incorporates immediate post-fire resilience and resistance management strategies and can be used to expedite JODA BAER plans.
- Prioritize treatments described in BAER planning in areas that will receive the most significant benefit from post-fire restoration (Chambers et al. 2019).

Monitoring and Data Collection

- Continue monitoring and research within the park to improve understanding of local patterns of invasion and ecology of exotic species and identify high-priority remnant patches.
- Identify opportunities to establish pilot cooperative projects with adjacent landowners that coordinate monitoring, mapping, and treatment of exotic invasive plants.
- Prioritize incorporation of intact biocrusts into existing monitoring activities and develop spatial maps that display these areas.
- Monitor intact plant communities for signs that they might benefit from disturbance. Examples are reduced plant productivity in bunchgrass communities due to self-shading, or encroachment of undesirable woody species.
- Incorporate early detection mapping strategies for invasive species into existing vegetation monitoring programs.

Restoration Actions

- Utilize ecological site descriptions and associated historic climax plant communities (HCPC) to develop site-appropriate native seed mixes for restoration projects and post-fire response, with an emphasis on foundation species like bluebunch wheatgrass and big sagebrush species.
- Create supplemental islands of fertility by installing restoration gardens using out-planting to compliment seeding in spatial proximity to burned areas and in restoration areas. Out-plant potted bunchgrasses, forbs, and shrubs along with seeding in restoration activities, as established plants have a greater likelihood of survival and offer greater resistance to invasive annual grasses.
- Consider establishment of on-site native plant propagation facilities to support native plant restoration projects. If on-site facilities are not feasible, collaborate with regional partners to establish off-site facilities to which native seed stock can be sent for propagation of site-adapted plant material.
- Consider the use of biocrust inoculation in restoration activities (e.g., coinciding with seeding), or at sites where bunchgrass communities are intact but biocrusts have been disturbed.

Key information needs for resilience-based management at JODA.

- Updated assessment of degree of departure from ecological site reference conditions for sites predicted to be high-resilience within the Monument. This information can be used to further prioritize areas for restoration activities before irreversible ecological thresholds are reached.
- Spatial inventory and mapping of intact biocrust distribution within the Monument. Soils supporting robust biocrusts are an integral part of site resilience to disturbance and resistance to invasion. Mapping will allow for more strategic management decisions across a broad spectrum of planning activities (recreation, fire, vegetation management, cultural resource management, etc.).
- Development of interpretative materials that integrate ecologically-based vegetation management plans with recreation and cultural resource values to communicate the value and vulnerability of sagebrush steppe ecosystems to visitors.

Acknowledgments

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1. Introduction

Sagebrush steppe ecosystems have been described as one of the most imperiled ecosystems in North America due to a combination of threats from human and ecological factors (Noss et al. 1995, Davies et al. 2011, Davies et al. 2012). Degradation of sagebrush steppe has led to declining abundance and productivity of endemic floral and faunal assemblages, soil system health, and ecological functions within and outside protected area boundaries across the western United States. Published assessments (e.g., Caicco et al. 1995, Stoms et al. 1998) of the amount of healthy, intact sagebrush and bunchgrass steppe in western American protected areas have reported that steppe ecosystems are not well represented in the protected-area network of the US, underscoring concerns for preserving these resources for future generations, and underscoring the value of NPS units that contain and manage steppe communities.

Consistent with widespread concern for these ecosystems, the Pacific West Region (DOI Unified Regions 8, 9, 10, and 12) of the National Park Service has asked a team of experts from Oregon State University and National Park Service to synthesize best-available science about resilience to fire and other stressors and resistance to weed invasion into management guidance documents and geodatabases for each of the 8 parks in the region that contain and are managing significant amounts of sagebrush steppe. These parks are Big Hole National Battlefield (BIHO), City of Rocks National Reserve (CIRO), Craters of the Moon National Monument & Preserve (CRMO), Hagerman Fossil Beds National Monument (HAFO), John Day Fossil Beds National Monument (JODA), Lake Roosevelt National Recreation Area (LARO) in the Upper Columbia Basin Network; Great Basin National Park (GRBA) in the Mojave Network; and Lava Beds National Monument (LBE) in the Klamath Network. Vegetation monitoring is occurring in all of these parks as part of the NPS vital signs monitoring program. The Upper Columbia Basin Network is targeting sagebrush steppe as a distinct vital sign for monitoring, whereas sagebrush steppe is integrated into a more general upland vegetation monitoring program in the other two networks. Several of these parks, notably JODA, have also pursued use of prescribed fire and fire effects monitoring has occurred in JODA for ~20 years. Inventories of soils, vegetation, and natural resource condition have been conducted in all of these parks as part of the NPS Natural Resources Challenge (12 basic inventories). Findings from all of these inventory and monitoring activities provide the central place-based information for the syntheses and geodatabases. The broader scientific literature about sagebrush steppe ecology and about resilience to fire and resistance to annual grass invasion establish the theoretical and conceptual foundations for these syntheses and geodatabases.

This report for John Day Fossil Beds National Monument is the first in an anticipated series of 8 park steppe syntheses, each accompanied by park steppe geodatabases that provide the mapping environment and spatially-explicit guidance for where park management activities are likely to be most effective. Sagebrush steppe vegetation covers effectively all of the vegetated uplands in the park (Figures 1 and 2), underscoring the utility of this report and accompanying geodatabase to the Monument's natural resources program.

Background

Management of sagebrush steppe ecosystems within park boundaries is critical for supporting regional conservation initiatives and consistent with agency priorities for natural resource conservation. The task, however, is complicated by uncertainty associated with park resource responses to climate change, land use intensification beyond administrative boundaries, changing disturbance regimes, and species invasions. In recent years, results of NPS monitoring and other scientific studies have made apparent that these parks are being over-run by weeds following fire events and that fire and weed management plans would benefit from integration of recent science related to ecosystem resilience to disturbance and resistance to invasion. This is particularly relevant at JODA, where low-elevation sagebrush steppe ecosystems exhibit inherently low resilience to fire and low resistance to weed invasion. Invasion by annual grasses of Eurasian origin, including a newly documented invasive species (*Ventenata dubia*) not thought to be present in low-elevation sagebrush steppe until very recently (see Nicolli et al. 2020), have become ubiquitous in the Monument. These rapid shifts to annual grasslands are ecologically novel, and present substantial challenges for evidence-based management of natural resources (Kueffer 2014, Radeloff et al. 2015). Successfully managing these ecosystems will require a more active and adaptive approach than has been practiced in the past. Use of predictive models that present different scenarios and that highlight the uncertainties about ecosystem trajectories are required. In general, resource management goals, including those that address wildland fire management, will need to be highly dynamic and be based on maintaining or enhancing ecological resilience and resistance with respect to historic and contemporary disturbances rather than on pursuit of fixed ecosystem states associated with specific historic or pre-historic time periods that are no longer achievable.

Ecological Resilience and Resistance

Ecological resilience describes the ability of an ecosystem to return to a functional state where critical ecological structures (e.g., species, soils, and micro-climates) and associated processes (e.g., nutrient cycling, hydrologic cycle, successional change) are maintained following disturbances such as fire (Holling 1973, Walker et al. 1999, Gunderson 2000, Miller et al. 2000, Chambers et al. 2007, Miller et al. 2013, Chambers et al. 2014). Resistance is a similar concept that describes the ability of an ecosystem to actually resist change from disturbance, biological invasion, or other stress. Systems with resistance will retain fundamental structure, processes, and functions despite stressors or disturbance (Folke et al., 2004). Systems with resilience will temporarily change in response to stress but then return back to pre-stress conditions. Within the context of sagebrush steppe, resilience is used to describe the ability to recover from grazing, fire, and drought, while resistance is used to describe the ability to keep annual grass invasion at bay (D'Antonio and Thomsen 2004, Miller et al. 2013, Chambers et al. 2014). Ecological resistance and resilience are often influenced by the same suite of environmental and biological factors, including relative health of vegetation communities, soil properties, topography and climate (Koniak 1983, 1985, West 1983, Everett and Sharrow 1985, Chambers et al. 2007, Miller et al. 2013, Chambers et al. 2014).

Managing for Resilience and Resistance in John Day Fossil Beds National Monument Sagebrush Steppe

Managing for resilience and resistance within sagebrush steppe protected areas is a recent concept, with few examples of long-term application available for reference to a given park. As a result, protected area managers must adopt an adaptive approach, wherein best-practices derived from the emerging literature on resilience and resistance (e.g., Miller et al. 2013, Chambers et al. 2014, Chambers et al. 2019) are implemented, monitored, and re-evaluated based on site-specific results. This active approach may at first seem like a departure from traditional preservation-based approaches to park management, but is consistent with recent protected-area management guidance (e.g., Chapin et al. 2006, Cole et al. 2008, Hobbs et al. 2009) and internal Department of Interior (DOI) and NPS initiatives (e.g., Crist et al. 2019). NPS Director's Order 100 (rescinded in 2017) specified that the agency should manage park resources with an emphasis on resilience:

“To achieve the stewardship goal and set priorities for conservation, restoration, and protection of resources, the NPS will emphasize resilience, connectivity at land/seascape scales, and life-cycle stewardship as guiding strategies for resource management. Application of these strategies in resource management will be informed by scientific and scholarly research and traditional ecological knowledge.”

As an NPS unit containing sagebrush steppe ecosystems, JODA is an important repository of nationally-significant natural resources. JODA also serves as an outstanding laboratory for application of resilience and resistance theory and practice, such that lessons learned from management efforts to maintain or increase resilience and resistance in JODA can be applied to other relevant park units.

2. Sagebrush Steppe Ecosystem Conditions and Influences on Resilience and Resistance in the John Day Fossil Beds National Monument

Key Points:

- Similar steppe plant communities are found across all of the Monument units, providing a common basis for management strategies. However, site variation in topography, soils, and micro-climates affect plant community potentials for resilience and resistance, creating opportunities for strategic management.
- All of the ecological sites associated with upland steppe soils and plant communities are inherently of low resilience and resistance and share a common vulnerability to transition from shrub- and bunchgrass-dominated states to degraded states dominated by cheatgrass (*Bromus tectorum*) and other invasive annual grasses.
- Cooler north-facing slopes tend to support more resilient and resistant native bunchgrass steppe which can be prioritized for protection.
- The most widespread upland native plant associations in the Monument are those dominated by western juniper (*Juniperus occidentalis*), big sagebrush (*Artemisia tridentata*), and bluebunch wheatgrass (*Pseudoroegneria spicata*). The most common (>2600 acres) vegetation map class within JODA is an herbaceous vegetation complex dominated by bluebunch wheatgrass and Sandberg bluegrass (*Poa secunda*). Many of these plant communities have been severely degraded by prior land use, exotic annual grass invasion, and fire to the extent that the big sagebrush overstory has been removed in most of the uplands.
- Recent wildfire and prescribed fires have negatively impacted the majority of upland steppe in the Monument, accelerating removal of native shrub cover which is slow to recover from fire, and accelerating conversion to annual grasslands.
- Big sagebrush and bluebunch wheatgrass are foundation species for steppe communities found in the Monument, and can be used as indicators for overall site integrity, and potential resilience and resistance (Sheley et al. 2006, Chambers and Wisdom 2009, Miller et al. 2013, Chambers et al. 2014, Chambers et al. 2019).

Sagebrush Steppe Ecosystems in the John Day Fossil Beds National Monument

John Day Fossil Beds National Monument is separated into three geographically distinct Units; the Sheep Rock Unit (8916 acres), the Clarno Unit (1969 acres), and the Painted Hills Unit (3129 acres). Together the Units comprise 14,056 acres and support upland plant communities classified as "intermontane sagebrush steppe" (Bell and Hinson 2010). Figure 1 illustrates the amount of sagebrush steppe within each of the three Monument units. Vegetation communities of the intermontane sagebrush steppe within the Monument consist of a mixture of forbs, shrubs, and dryland grasses, with western juniper present as scattered open savannah in the uplands (Bell and Hinson 2010). A 2010 natural resources condition assessment (Bell and Hinson 2010), supported by a concurrent comprehensive vegetation inventory (Erixson et al. 2011) identified that the most

widespread upland plant associations in the Monument were those dominated by western juniper, big sagebrush, and bluebunch wheatgrass. The most common (>2600 acres) map class within JODA was an herbaceous vegetation complex dominated by bluebunch wheatgrass and Sandberg bluegrass. The subspecies of big sagebrush that is found in the Monument is predominantly Wyoming big sagebrush (*A. t. wyomingensis*). In deeper soils (e.g., flat valley bottoms) basin big sagebrush (*A. t. tridentata*) is common. Both of these overstory big sagebrush subspecies are associated with inherently low-resilient and low-resistant sagebrush steppe because they grow in dry (low productivity) ecoregions. In contrast and as a point of reference, mountain big sagebrush (*A. t. vaseyana*) is associated with relatively high resilience and resistance because of its association with more productive (cooler, wetter conditions) areas (e.g., at elevations above those of JODA).

Figure 3 updates the maps in Figure 1 with distinctions between the bluebunch wheatgrass dominated steppe plant associations and other steppe plant associations. Figure 4 shows a photograph of an intact stand of bluebunch wheatgrass steppe on a north-facing slope in the Clarno Unit of JODA. Figure 5 is a schematic that illustrates the resilience and resistance gradient in terms of productivity and sagebrush steppe community types as characterized by overstory big sagebrush subspecies.

Contemporary conditions of Monument steppe plant communities are severely degraded from recent wildfires and annual grass invasion. Cheatgrass is particularly ubiquitous throughout the Monument. For example, NPS vital signs monitoring teams rarely encounter cheatgrass-free sites, and the percentage of large-sample randomly-located monitoring plots with cheatgrass (frequency of occurrence) is routinely ~95%. More worrisome is the rapid rates of increase by medusahead rye (*Taeniatherum caput-medusae*) and ventenata grass in the Monument. Several analyses of both the NPS fire effects monitoring and NPS vital signs monitoring data have demonstrated a clear increase in annual grass invasion as a result of fire in recent decades (Rodhouse et al. 2014, Reed-Dustin et al. 2016, Mata-Gonzalez et al. 2018, Esposito et al. 2019, Nicolli et al. 2020).

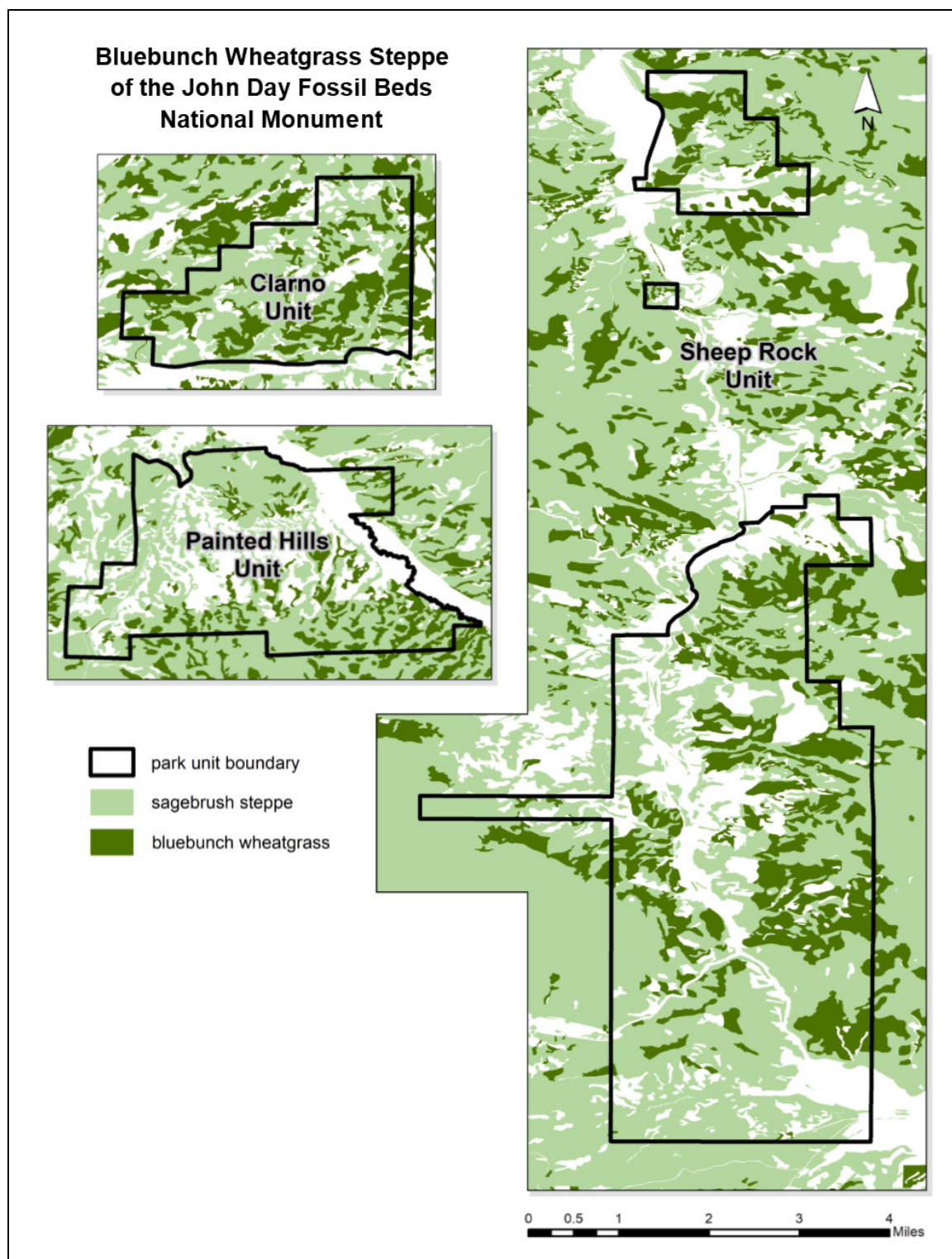


Figure 3. Distribution of bluebunch wheatgrass (*Pseudoroegneria spicata*) and sagebrush steppe in the John Day Fossil Beds National Monument. Bluebunch wheatgrass is an important foundation species in the Monument and occurs widely as a dominant or co-dominant native perennial grass in many other steppe plant communities.



Figure 4. A robust stand of bluebunch wheatgrass (*Pseudoroegneria spicata*) in the Clarno Unit of the John Day Fossil Beds National Monument. Fire scars (burned western juniper) from the 1995 wildfire are visible in the background.

Sagebrush Steppe Soils and Ecological Site Descriptions in the John Day Fossil Beds National Monument

NPS and the Natural Resources Conservation Service (NRCS) collaborated on soils inventories for NPS units, including JODA, as part of the Natural Resources Challenge (the 12 basic inventories). Results of the JODA soils inventory can be found at (<https://irma.nps.gov/DataStore/Reference/Profile/1048909>). Results of the inventory revealed that all of the soil types and associated ecological sites are of inherently low resilience to fire and resistance to annual grass invasion. The entire Monument contains soils that are droughty clay and clay-loam aridisols (semi-arid desert soils) and mollisols (temperate grassland soils) that are classified taxonomically as mesic in temperature regime and aridic in moisture regime. These kinds of soils typically support Wyoming and basin big sagebrush community types of low productivity and, in general, are highly invasible, especially after fires. Figure 5, reproduced from Chambers et al. (2014), illustrates the inherently low-resilience/low-resistance position of Wyoming sagebrush steppe relative to other western American semi-arid shrublands. Notably, Bradford et al. (2019) evaluated the likelihood of changes to soils-dependent resilience and resistance across western American

sagebrush steppe under climate change scenarios (this is included in the JODA geodatabase). Their area of assessment included the Monument area and their results suggest that JODA will continue to face inherently low resilient/resistant conditions for the foreseeable future.

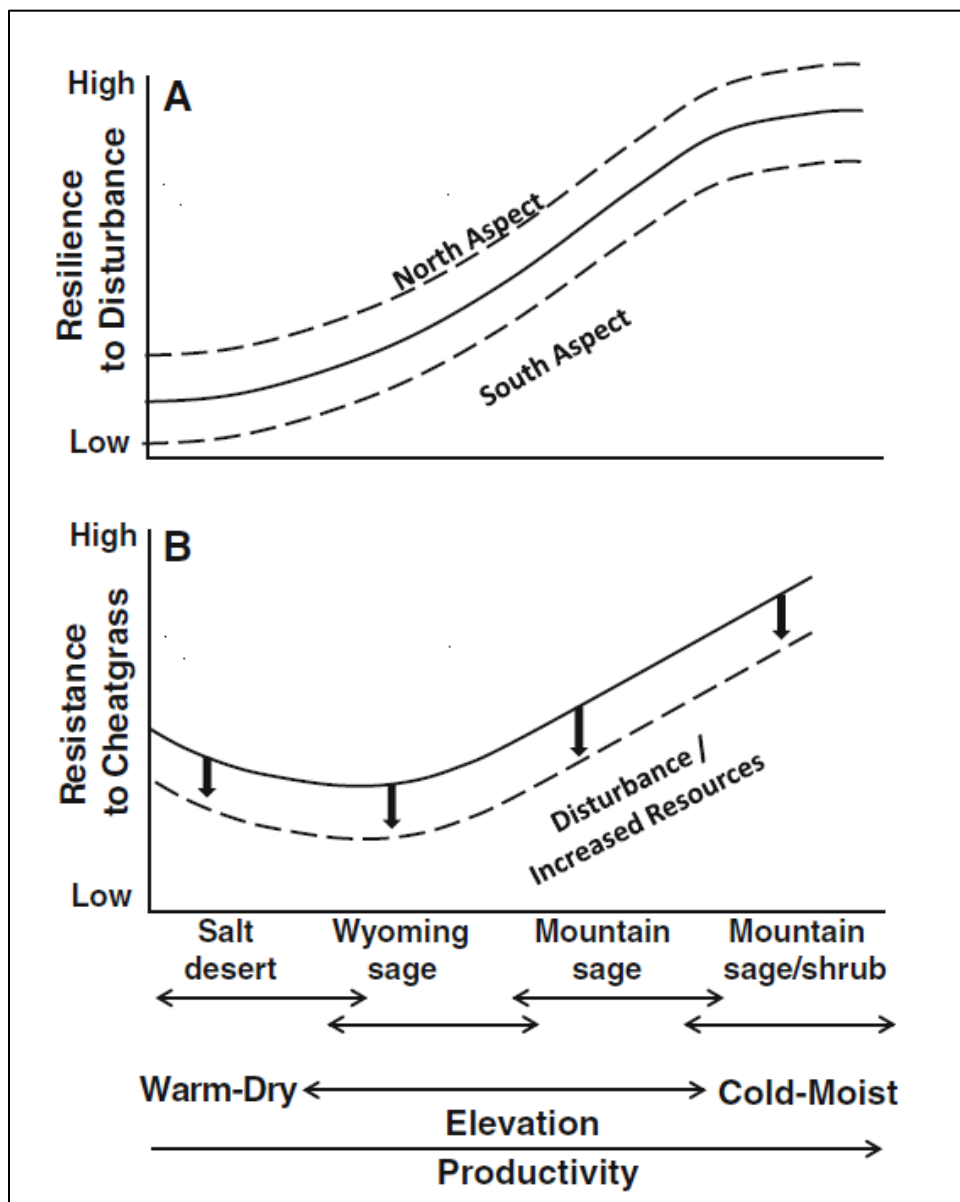


Figure 5. Diagrams from Chambers et al. (2014) of generalized resistance to cheatgrass invasion along productivity (effective soil moisture) gradients in western North American sagebrush steppe. Panel A shows the variation in resistance mediated by topography. Panel B shows the variation in resistance along elevational gradients. The John Day Fossil Beds National Monument, which supports low-productivity soils and Wyoming sagebrush steppe communities falls in the “bottom of the trough” in panel B.

The ecological sites associated with these low-resilience and low-resistance biophysical conditions are known to be highly vulnerable to threshold transition from native plant communities dominated

by large-stature bunchgrasses such as bluebunch wheatgrass and native shrubs such as big sagebrush to invaded annual grasslands dominated by cheatgrass, medusahead, and, increasingly, ventenata grass. This is illustrated by the state-transition diagram in Figure 6, which was reproduced from one of the NRCS ecological site descriptions for JODA upland soils (specifically John Day Droughty Shallow South 9–12” precipitation zone, R010XB052OR). The diagram is generalizable for the entire Monument. Note that the diagram shows likely pathways that cross thresholds to disturbance state 3, dominated by annual grasslands, and unlikely pathways that show a return to pre-disturbance states. These kinds of dry, low-productivity sites are very difficult to restore back to pre-disturbance conditions. However, if restoration targets are needed, the ecological site descriptions for JODA provide benchmark reference conditions descriptions, including pounds per acre (biomass) for dominant and sub-dominant native shrubs, forbs, and grasses. These are summarized in the project geodatabase (<https://irma.nps.gov/Datastore/Reference/Profile/2271774>), with links to complete NRCS descriptions for full details.

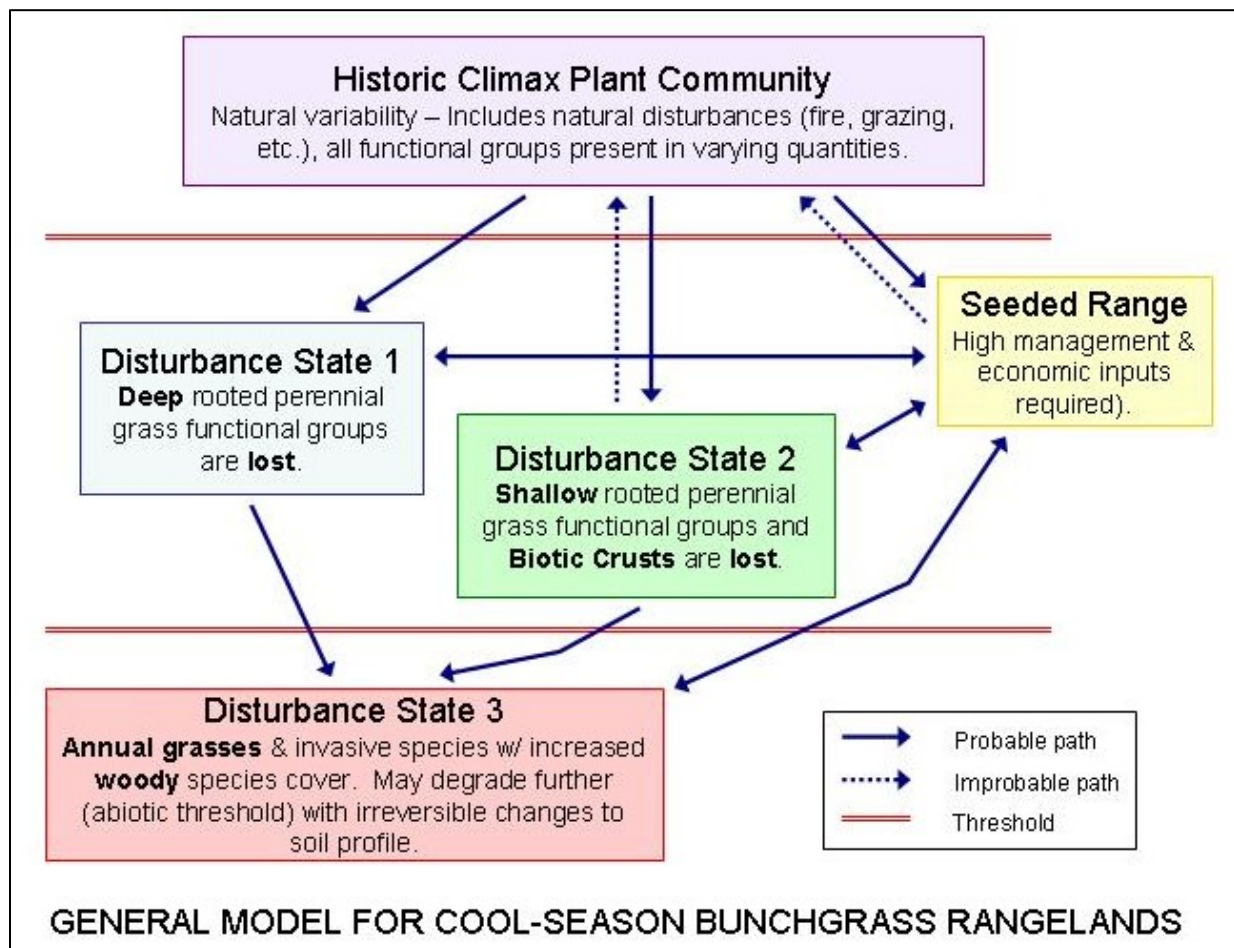


Figure 6. A state-transition diagram from an ecological site description for JODA uplands (specifically John Day Droughty Shallow South 9–12” precipitation zone, R010XB052OR).

Fire history in the John Day Fossil Beds National Monument

The first well-documented fire in JODA was the lightning-ignited Hancock Canyon fire in the Clarno Unit in August 1985. The fire reportedly burned 640 acres within the NPS boundary (also acreage outside NPS jurisdiction). No perimeter map is available. Lightning-ignited fires burned across the Clarno Unit in 1994, 1995, and 2011 (Figure 7). Lightning-ignited fires burned the Blue Basin area of Sheep Rock Unit in 2015 (Figure 7). Prescribed fires were systematically applied as a management tool in Painted Hills and Sheep Rock Units during 1999–2007 (Figure 7). Wildfires and prescribed fires have clearly accelerated state transitions of JODA steppe plant communities from pre-disturbance and disturbance states 1 and 2 to disturbance state 3 (see Figure 6) where annual grass monocultures dominate the landscape.

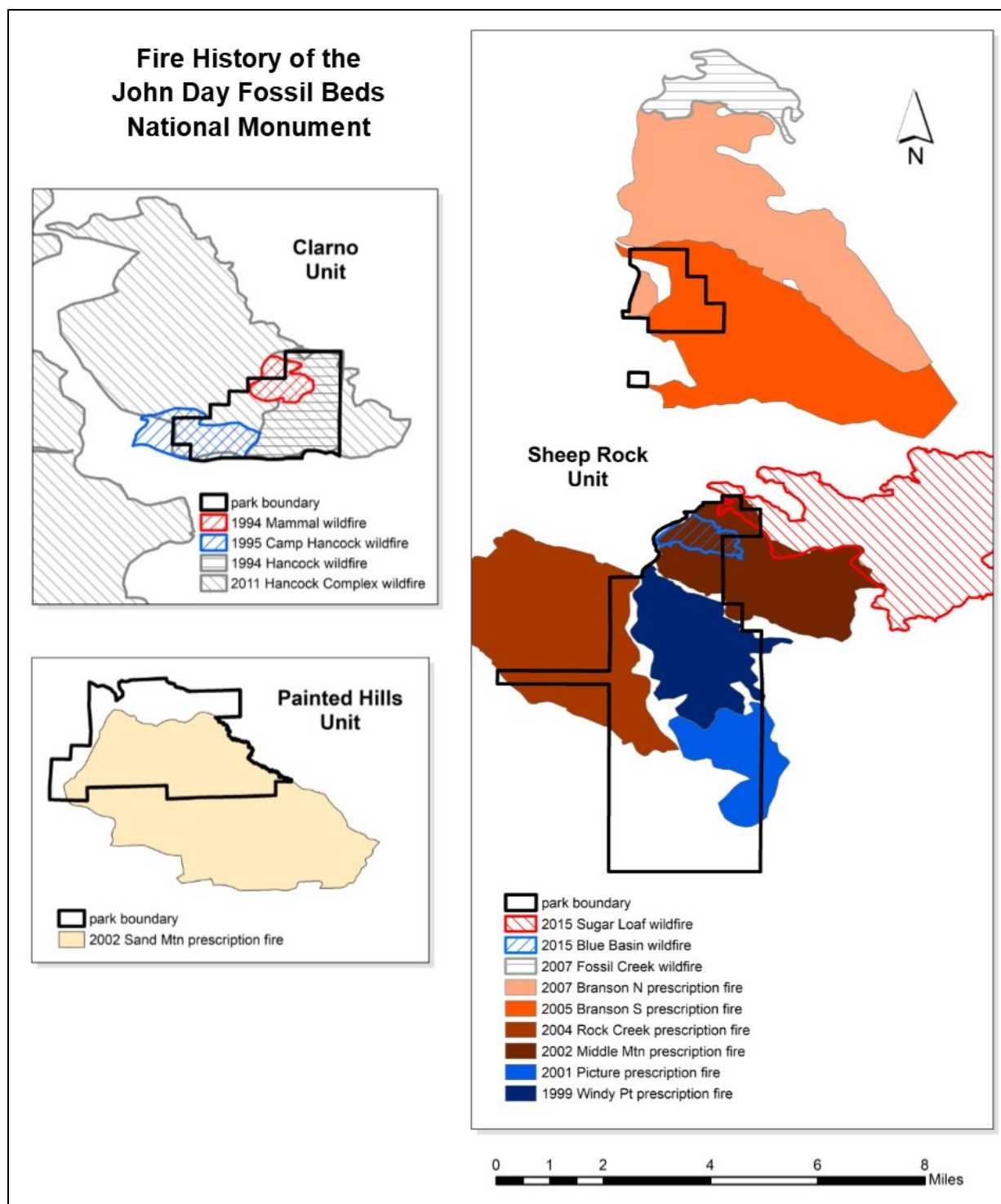


Figure 7. Fire history in John Day Fossil Beds National Monument, 1994–2019. Earlier fires are reported from Clarno (~1985) but no fire perimeter is available.

3. Impacts of Land-Use and Invasion

Management Implications:

Section 3.2

- Juniper management within the Monument has included prescribed burning in the past, but this method is questionable, due in part to the establishment of exotic understory species that tends to occur after fire (Williams et al. 2017), and also to the ineffectiveness of fire in removing juniper at sites with reduced ladder fuels (Clark et al. 2018).
- Mechanical removal of juniper has been used in the Monument and provides a more precise, albeit more resource-intensive, means of management. However, juniper carcasses left in place provide safe sites for invasive weeds such as scotch thistle. Burning of juniper slash can also result in weed invasion.
- Management of juniper is most effective in Phase 1 encroachment, and at sites lacking an annual grass understory, which, if present, will expand after juniper removal.
- If juniper densities have reached Phase 2 or 3 levels, then efforts to restore soil function and native seed presence are likely necessary to compliment juniper removal.

Section 3.3

- Continued monitoring and research within the park will aid in understanding the local patterns of invasion and ecology of exotic species, which is an integral part of invasive plant management planning.
- Restoration strategies for exotic species invaded sites must be ecologically-based (i.e., treat the whole system), as exotic plants may leave lasting system-wide legacies.
- Novel strategies such as biological controls and recently advanced herbicides may be part of an invasive plant treatment strategy, most effectively when used strategically following a prioritization of JODA uplands (e.g., see the EBIPM prioritization of JODA developed by Rodhouse et al. 2014 and incorporated into Hoh et al. 2015).
- Implement the existing JODA Ecologically-Based Invasive Plant Management Plan (Hoh et al. 2014).
- Cooperation with adjacent landowners and coordinated monitoring, mapping, and treatment, will increase efficacy of management actions seeking to address a landscape scale issue, in part by decreasing invasive plant pressure from outside the park.

Section 3.4

- Prescribed fire is an ineffective and high-risk management tool at JODA.
- Strategic fire suppression and response plans that prioritize protection of high-integrity plant communities are vital for the preservation of native plant assemblages and ecosystem resilience at JODA.
- Update Fire Management Plans and Burned Area Emergency Response plans with resiliency-based management suggestions (see section 5).

Overview

Sagebrush steppe ecosystems within JODA are primarily threatened by invasive plant species and subsequent altered fire cycles. By understanding and adapting to these threats, managers can identify best management practices for promoting resiliency within the park.

Although many historic land-uses within JODA and the outlying basin have been modified or terminated, the ecological legacy (e.g., altered plant community and soils) of prior land use remains. Exotic invasive species have the potential to alter ecological function and reduce ecosystem services at JODA. Established and novel invaders alter nutrient cycles, fire regimes, wildlife habitat quality, and limit above and belowground biodiversity. Further possible effects of annual grass invasion include altered resource competition, rates of resource supply, geomorphological processes, and microclimates (D'Antonio and Vitousek 1994).

Past and present threats in JODA influence ecological resilience and present challenges for ecologically-based management. The following sections provide an overview of specific threats and their relative importance to managers.

3.1 Land-Use Legacies

Historic land-use patterns of the Monument and surrounding area have significantly altered resistance and resilience throughout the Monument. Cultivation prior to Monument establishment converted wide landscapes of steppe ecosystems into agriculture that are now abandoned and in various stages of recovery or permanently degraded (Daubenmire 1975, Rickard and Sauer 1982, Standish et al. 2007, Morris et al. 2015). These abandoned cultivated lands are often rapidly colonized by exotic vegetation (Stewart and Hull 1949, Hobbs and Atkins 1991, Krug and Krug 2007, Morris et al. 2015), which may then apply propagule pressure to surrounding sites.

Historic sheep grazing at the Monument has likely impacted current site resilience and resistance by influencing successional pathways (Stylinski and Allen 1999, Morris et al. 2015), shifting outcomes of plant competition, and altering soil composition, hydrology, and nutrient dynamics (Bahre, 1991, Suding and Hobbs 2009, Grman and Suding, 2010, Morris et al. 2011, Ripplinger et al. 2015). Lasting soil-legacies of altered plant communities may even be responsible for shifting ecosystems into alternate stable states (Rickard and Sauer 1982, Coffin et al. 1996, Stylinski and Allen 1999, Cramer et al. 2008, Morris et al. 2015).

While legacies of land-use and invasion threaten to modify portions of the Monument beyond site capacity for self-repair, opportunity exists for some degraded areas as well as for the maintenance of intact vegetation communities.

The biophysical variation both within and among the Monument's three widely separated units make it necessary to apply knowledge of drivers of resilience and resistance at the site, landscape, and regional levels. There is not a single "one-size-fits-all" approach.

Pairing the knowledge of current and potential threats and challenges with factors which confer resilience and resistance at the levels mentioned can assist managers in developing management

strategies for prevailing restoration needs along with identifying and mitigating potential trajectories of change.

3.2 Western juniper encroachment

Historic juniper woodlands were restricted to rocky outcrops and low productivity sites (Miller et al. 1999). Increased levels of atmospheric CO₂, fire suppression, and a decrease in historic precipitation have all likely contributed to juniper expansion (Young and Evans 1981, Strand et al., 2008, Weiner et al., 2016). While juniper is native to JODA, expansion, and encroachment to new areas and increases in population density are requiring new management procedures throughout the park (Miller et al. 2005, Yeo and Rodhouse 2013).

The continued replacement of bunchgrass, forb, and shrub communities by juniper is a concern throughout the sagebrush steppe biome (Bunting et al., 1999; Miller et al., 2005, Miller et al., 2008; Weiner et al., 2016). Juniper encroachment at the Monument will result in reduced ecological functions at invaded sites, as well as reduced factors of ecosystem resilience and resistance. At JODA, prescribed fires in woodland plots dominated by juniper resulted in increased cheatgrass cover of 301%, while post-fire cheatgrass cover only increased 135% in brush dominated plots (Reed-Dustin et al. 2016). Mechanical removal of juniper is a much safer strategy although there are also risks associated with the remaining tree carcasses—burning of slash can damage soils and lead to weed invasion.

Identifying phases of western juniper dominance, as presented by Miller et al. (2005), is essential for understanding changing landscape conditions:

Phase I – Juniper is present but shrubs and herbaceous vegetation are still dominant.

Phase II – Juniper is codominant with shrubs and herbaceous vegetation, but outcompeting the understory component for available moisture.

Phase III – Juniper is the dominant species influencing ecological processes at the site. The lack of an herbaceous understory promotes run-off, and soil erosion.

As juniper dominance increases, shrub and herbaceous cover decreases, along with ladder fuels, ground nesting bird habitat, structural complexity, and seed pools (Burkhardt and Tisdale 1969, Adams 1975, Bunting et al. 1999, Miller et al. 2000, Roberts and Jones 2000, Schaefer et al. 2003, Miller et al. 2005). This shift in phase from savannah to woodland conditions complicates treatment and recovery of understory and juniper removal is most successful during early phase I stages.

3.3 Exotic Plant Invasion

The spread of exotic species throughout the Monument is a substantial management concern, especially annual grasses of Eurasian and North African origin. These exotic species diminish resiliency of park ecosystems by altering fire regimes, nutrient cycles, and soil moisture content.

Exotic invasive species have become dominant across much of the Monument's upland steppe, leading to establishment of novel ecosystems (such as those primarily composed of cheatgrass and/or

medusahead). In fact, cheatgrass has become ubiquitous throughout the uplands, and NPS vital signs monitoring routinely find that cheatgrass occurs in >95% of monitored areas. In the Clarno Unit, where annual monitoring has taken place following the 2011 wildfire, stands with heavy infestation of medusahead (>50% cover) increased from 7% of the monitored area in 2011 to 20% of the monitored area by 2017 (Smith et al. 2017). Ventenata, apparently a recent arrival in the Monument, has also spread rapidly (Nicolli et al. 2020).

Exotic species invasion is often dictated by site-specific characteristics, which can translate into management strategies for preventing, controlling or eliminating invasive plant dispersal (Radosевич et al. 2003, Thuiller et al. 2013, Jones et al. 2018). Factors contributing to invasion success often have opposite corollaries, considered factors of resistance to invasion.

Biotic and abiotic site characteristics can contribute to invasion success (Jones et al. 2018). At JODA, biotic factors contributing to invasion success include loss of perennial bunchgrasses, and native plant diversity in general, due to historic grazing and fire. Past disturbances could have also altered soil microbial communities, but while those alterations may have been transient, exotic plants such as cheatgrass and mustard species actively condition the soil microbial community for their benefit (Bainard et al. 2009, Blank and Morgan 2013). At JODA, abiotic factors contributing to invasion success include moisture, topography (low elevation and south facing slopes), and soil texture (soils with high clay content; Young et al. 1999, Rodhouse et al. 2014, Esposito et al. 2019). Soils with high clay content may be especially susceptible to invasion by the annual grass medusahead, possibly due to that species' root morphology (fine roots and long root hairs), affinity for moist sites (Esposito et al. 2019), and enhanced competitiveness due to soil conditioning in clayey soils (Perkins and Nowak 2013).

Incorporating drivers of invasion into ecosystem management plans within the park will help to preserve remaining ecological integrity and prevent further resource degradation in steppe communities (e.g. Hoh et al. 2015). Problematically, however, the variability in response of invasive species to site characteristics (Esposito et al. 2019), as well as the variability in impacts of invasive species is such that some invasive plants at JODA might invade sites lacking characteristic factors of invasion, and may persist at sites due to unknown alterations in site conditions (likely soils related).

Partnering a knowledge base of biotic and abiotic characteristics that drive invasion and limit resilience with an adaptive management plan will help preserve priority sites throughout the monument (Jones et al. 2018). Prevention of invasive species establishment may include maintaining healthy populations of foundation plant species such as native bunchgrasses that increase resistance to invasion by reducing available nutrients and soil moisture for exotics to obtain (Davis et al., 2000; Davis and Pelsor 2001, Shea and Chesson 2002, Daehler 2003, Chambers et al. 2007, Prevey et al. 2010, Hulet et al. 2015).

Connecting, cooperating, and working with adjacent landowners to control the spread of invasive, exotic species (Bell and Hinson 2010), as well as early detection, mapping and aggressive treatment in coordination with existing vegetation monitoring programs can increase likelihood of a successful invasive plant management plan. Biological control agents for exotic species may also be a

management option. There are multiple options for knapweed species, such as *Cyphocleonus achates* (knapweed root weevil). *Pseudomonas fluorescens* (a soil bacteria) affects the root system of cheatgrass and has been utilized in effective restoration of native bunchgrasses. *Pyrenophora seminaperda* (Black Fingers of Death) is a fungus that colonizes cheatgrass, eventually fruiting out of dormant cheatgrass seeds. Chemical treatments will likely continue to be a part of invasive plant management. The ubiquitous broad-spectrum herbicide Glyphosate is still used on many invasive plants, however, more selective pre-emergent herbicides such as Imazapic, and Aminopyralid may be especially effective for invasive annual grass management (depending on timing of the application).

3.4 Annual grass-fire cycle

Ecological transitions from native bunchgrass and sagebrush-dominated communities to invasive-annual grass-dominated communities result in altered fire regimes (e.g., see the state-transition diagram in Figure 6). Historic sagebrush steppe ecosystems dominated by woody shrubs and bunchgrasses-maintained fire regimes on a 100 to 300-year cycle (Bukowski and Baker 2013). Plant phenology, plant spacing and lack of litter accumulation in native bunchgrass communities typically limits spatial extent and severity of fire (Innes 2019).

In contrast, invasive annual grasses tend to desiccate sooner than native bunchgrass communities and become flammable due to their high surface to volume area ratio (D'Antonio and Vitousek 1994). Annual grasses also produce a greater amount of standing dead material that is highly continuous, and becomes flammable earlier in the season compared to native bunchgrasses (D'Antonio and Vitousek 1994). Annual grasses are a threat to the Monument as they encourage more intense fires and escalate fire frequency (D'Antonio and Vitousek 1994). After a fire disturbance, exotic grasses establish more rapidly than native perennial grasses, reinforcing the effects of this altered fire cycle (D'Antonio and Vitousek 1994). Figure 8 illustrates the annual grass-fire cycle.

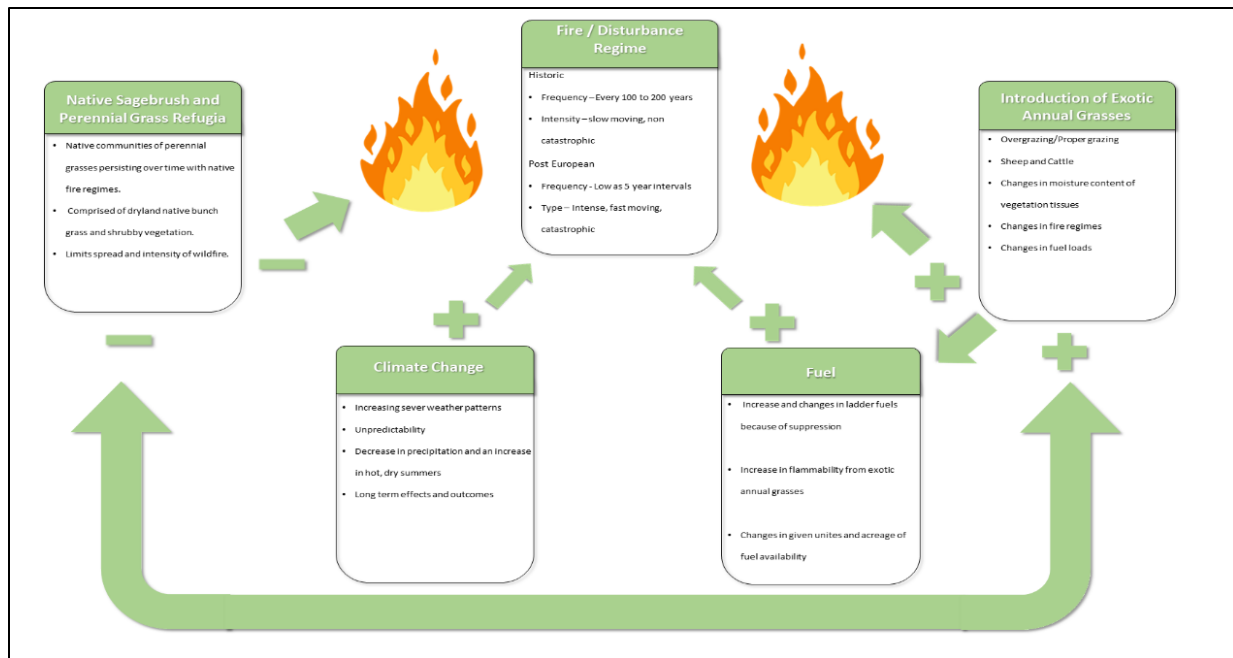


Figure 8. Invasive annual grass fire cycle model derived from D'Antonio and Vitousek (1992) and Brooks et al. (2004).

As a result, invasive annual grasses are changing historic fire cycles and causing shifts in fuel properties which alter fire characteristics throughout the landscape (Brooks et al. 2004, Bukowski and Baker 2013). Sites dominated by invasive annual grasses will not return to native-dominated states without intensive and costly restoration.

In general, wildfires across the western sagebrush steppe are increasing in extent and severity (Weiner et al. 2016). This has numerous effects on the local and regional ecosystem due to changes in vegetation composition and soil productivity (Madsen et al. 2012, Weiner et al. 2016). Along with the changing fire intervals and vegetation composition, mixed-severity fire is decreasing and fuels and fires alike are becoming increasingly homogeneous (Hessburg et al. 2016). Mixed-severity fires are a critical component of maintaining landscapes that foster biodiversity and provide vegetation complexity important for wildlife (Hessburg et al. 2016).

4. Conservation and restoration practices based on factors of ecological resilience to disturbance and resistance to annual grass invasion

Management Implications:

Section 4.1

- Develop fire and vegetation management plans using maps that are based on site-specific attributes (e.g. soils) that describe resilience and resistance. Maps for this purpose are available in the 2015 EBIPM plan for JODA (Hoh et al. 2015).

Section 4.2

- Prioritize protection of intact bunchgrass steppe from fire and anthropogenic disturbance. Maps for this purpose are provided in the 2015 EBIPM plan for JODA (Hoh et al. 2015).
- Utilize diverse native seed mixes in restoration activities, with an emphasis on foundation species like bluebunch wheatgrass.
- Out-plant potted bunchgrasses, forbs, and shrubs along with seeding in restoration activities, as established plants have a greater likelihood of survival.
- Mechanically or chemically thin trees and shrubs to maintain historic patchiness or reduce single species dominance in plant communities.
- Consider establishment of on-site native plant propagation facilities to support native plant restoration projects. If on-site facilities are not feasible, collaborate with regional partners to establish off-site facilities to which native seed stock can be sent for propagation of site-adapted plant material.

Section 4.3

- Identify sites with intact biocrusts and limit access to, or provide signage that discourages hiking on those sites.
- Consider the use of biocrust inoculation in restoration activities (e.g., coinciding with seeding), or at sites where bunchgrass communities are intact, but biocrusts have been disturbed.

Section 4.4

- Identify remnant populations and fire refugia as resilient sites for high-impact restoration projects.
- Create supplemental islands of fertility by installing restoration gardens using out-planting to compliment seeding in spatial proximity to burned areas.

Section 4.5

- Monitor intact plant communities for signs that they might benefit from disturbance. Examples are reduced plant productivity in bunchgrass communities due to self-shading, or encroachment of undesirable woody species.

- Prioritize vegetation maintenance strategies (e.g., mechanical treatment) in intact high resilience sites.
- Mimic periodic disturbance with mechanical and/or chemical fuels reduction methods rather than fire.

Overview

Building an understanding of the mechanisms that drive biological integrity and ecosystem health in sagebrush steppe provides an opportunity to adapt management practices to actively treat the affected ecosystem components, and to address realized threats of ecosystem change (Chambers et al. 2014a).

Multiple factors influence ecosystem resilience to disturbance and resistance to invasion, and can be both abiotic and biotic site characteristics. Abiotic factors largely mediate moisture availability, and can be easily translated into decision-making tools such as resilience maps used for management prioritization (Rodhouse et al. 2014, Maestas et al. 2016, Chambers et al. 2019, Bradford et al. 2019). Biotic factors include plant community structure as well as individual species contributions of plants, fungi, and bacteria. Many of the components discussed in this section play a role in shaping both resilience and resistance, as the two are not mutually exclusive. For instance, the two primary factors attributed to sagebrush-steppe ecosystem resilience and resistance are climate and topography (Brooks and Chambers 2011).

4.1 Moisture Availability

Climate

Moisture availability in sagebrush steppe ecosystems is the main driving force behind plant community composition, as well as the greatest impediment to restoration. In general, sagebrush steppe ecosystems receive 16–42 cm (6.2–15.5 in) of precipitation, typically in winter months, and have moderate to high plant productivity (Brooks and Chambers 2011, Chambers et al. 2014a). Higher elevation sagebrush steppe ecosystems have greater productivity in contrast to the basin and Wyoming big sagebrush steppe ecosystems that occur in JODA (Brooks and Chambers 2011). Factors limiting soil moisture in low- and mid-elevation shrub-steppe ecosystems include increased average annual temperatures and greater evaporation rates. Other influences to soil moisture include topography and associated runoff rates (steeper slopes cause higher runoff) and soil attributes such as texture that reduce soil moisture holding capacity.

The timing of precipitation also influences system resilience as regular summer precipitation in cooler climates limits cheatgrass establishment due to increased competition from native perennial grasses (Sala et al. 1997, Bradley et al. 2009, Chambers et al. 2014a). In contrast, variable moisture regimes limit system invasibility in the lower elevations (Chambers et al. 2014a,b). High precipitation years increase herbaceous vegetation, whereas drought years limit plant establishment and growth, including cheatgrass (West and York 2002).

Elevation

Resilience to disturbance and resistance to environmental changes in plant community structure increases with elevation (Chambers et al. 2007). Higher elevation sagebrush ecosystems are

associated with greater resilience resulting from increased resource availability and productivity in comparison to mid-elevation sites (West 1983, Smith and Nowak 1990, Condon et al. 2011, Davies et al. 2012, Chambers et al. 2014a). Factors influencing increased resilience in higher elevations include cooler annual temperatures, increased precipitation, higher plant productivity, and enhanced soil development.

Higher elevation shrub-steppe ecosystems have more fire-tolerant shrubs and greater perennial grass and forb biomass, which reduces the likelihood of plant community transition after disturbance (Davies et al. 2012, Chambers et al. 2014a). Plant productivity is related to soil development and nutrient resources which also increase with elevation (Chambers et al. 2014a). Mid-elevation sagebrush steppe ecosystems, like those which occur in the Monument, are at the highest risk of invasion due to moderate precipitation and temperature, generating optimal conditions for cheatgrass to germinate, grow, and reproduce (Meyer et al. 2001, Chambers et al. 2007, Chambers et al. 2014a).

Topography

Topographical and climatic gradients influence sagebrush steppe ecosystem resilience at local and regional scales (Chambers et al. 2014). At JODA, intact bunchgrass communities are positively correlated with steep, north facing slopes (Rodhouse et al. 2014, Esposito et al. 2019). Sites affected by fire at JODA are also more likely to return to pre-fire conditions, or return to pre-fire conditions quicker, if they are located on steep, north facing slopes rather than low elevation, south facing slopes (Reed-Dustin et al. 2016, Mata-Gonzalez et al. 2018). Interestingly, increases in precipitation at JODA seems to increase cover of cheatgrass, medusahead and the weedy native subshrub broom snakeweed (*Gutierrezia sarothrae*) more than big sagebrush or bluebunch wheatgrass (Esposito et al. 2019).

Soils

Soil temperatures in higher elevations are characterized as frigid to cyric (cool and cold) with moisture regimes classified as xeric to ustic (moist) (Chambers et al. 2014 a, b). In contrast, the Wyoming big sagebrush steppe ecosystems in JODA and other low-elevation steppe have warm, or mesic, soil temperatures and dry, or aridic, soil moisture regimes (Chambers et al., 2014 a, b). Cold temperatures hinder cheatgrass growth and reproduction, whereas increased soil temperature and reduced soil moisture are associated with low resilience and resistance to invasion (Chambers et al., 2007; Chambers et al., 2014 a, b). It is this reason that JODA exhibits inherently low resilience to fire and low resistance to weed invasion.

Site-specific attributes contributing to resilience and resistance including soils, topography, and climate, lead to variability in system response to disturbances such as fire, as well as management interventions. Updated maps reflecting spatially-explicit resilience and resistance will lead to better outcomes and protection of high value plant communities.

4.2 Plant Community Structure

Foundation Species

Species which are considered to have disproportionate impacts on vegetation community composition, water availability, nutrient cycling, and other vital ecosystem processes are defined as

foundation species (Jones et al. 1994, Ellison et al. 2005, Prevéy et al. 2010). Big sagebrush and bluebunch wheatgrass are considered foundation species in sagebrush steppe due to their prevalence within cold-desert ecosystems and significant influence on ecosystem function (Dobrowolski et al. 1990, Smith et al. 1997, Prevéy et al. 2010).

Foundation species and their subsequent communities such as big sagebrush associations are critical for reducing invasibility as they decrease available resources such as nutrients and available soil water (Prevéy et al. 2010). Disturbances like fire and land-use changes often disturb and remove foundation species, further diminishing sagebrush steppe ecosystem resistance (Ellison et al. 2005, Prevéy et al. 2010). Rodhouse et al. (2014) and the JODA EBIPM plan (Hoh et al. 2015) demonstrate how landscape prioritization for resource protection and restoration can be facilitated by predictive modeling and mapping of foundation species distribution and abundance.

Native perennial bunchgrass cover

The relative presence of native perennial bunchgrasses is a critical component of resistance in sagebrush steppe ecosystems, and identification and protection of intact bunchgrass steppe from fire and anthropogenic disturbance should be a high priority at the Monument. Studies have found that annual grasses (i.e., cheatgrass) have strong negative associations with native perennial species richness and biodiversity. Riesner et al. (2013) found that the presence of bunchgrasses in Wyoming big sagebrush steppe ecosystems was correlated with reduced cheatgrass cover. Increased perennial grasses along with biological soil crust cover and shrub density decrease annual grass cover (Bansal and Sheley 2017). Furthermore, tall, tussock type bunchgrasses, such as bluebunch wheatgrass, can act as barriers to seedling dispersal of medusahead (Davies 2008). Soils conditioned by bunchgrass communities may also reduce establishment of diffuse knapweed (*Centaurea diffusa*) when compared with soils conditioned by a weedy community (Kulmatiski et al. 2004, Meiman et al. 2006).

Intact native bunchgrasses effectively out-compete invasive annual grasses. Out-planting mature native bunchgrasses for restoration projects may provide greater resistance to annual grass invasion, as mature bunchgrasses demonstrate superior competitive ability with some exotic species, and improved survival compared to seeded treatments (McGlone et al. 2012, Dettweiler-Robinson et al. 2013, Humphrey and Schupp 2004). High abundance of bunchgrasses, specifically bluebunch wheatgrass, bottlebrush squirreltail (*Elymus elemoides*), Thurber's needlegrass (*Achnatherum thurberianum*), and Sandberg bluegrass (*Poa secunda*), has been shown to decrease nutrient and water availability for cheatgrass over time and at multiple soil depths (Booth et al., 2003; Riesner et al. 2013). In some cases, bunchgrasses may facilitate sagebrush establishment as well (Booth et al. 2003). In a comparison study with both squirreltail and cheatgrass, sagebrush grew to be much larger when grown with squirreltail (Booth et al. 2003). Booth et al. (2003) also found that bottlebrush squirreltail (*Elymus elymoides*) cover of 15–20% can suppress and even eliminate cheatgrass invasion.

Moderate cover of native bunchgrasses also influences post-fire resilience, but only if invasive annual grass cover remains low, and if livestock have been removed (Ellsworth et al. 2016). Invasive annual grass and higher abundances of perennial grass cover can limit post-fire sagebrush seedling

presence. However, Germino et al. (2018) observed that pre-fire bunchgrass cover of around 40% decreased the risk of exotic grass invasion and allowed for sagebrush establishment post-fire (Germino et al. 2018).

Species Diversity

Plant species diversity tends to result in optimal resource capture, limiting resources available to support invasive species establishment and persistence. Therefore, maintaining or enhancing plant community diversity is a key component of a management strategy focused on resilience and resistance.

Sagebrush steppe ecosystems have an extensive array of vascular plants, but a majority of the community is comprised of a relatively small number of woody and herbaceous species (Tisdale et al. 1969, Tisdale and Hironaka 1989). Big sagebrush communities ideally consist of a mosaic of perennial bunchgrasses, native shrubs, and perennial and annual forbs and are considered to be in good condition when there are plentiful native plants in the understory and few if any invasive annual grasses present (West 1988, Davies et al. 2006, Maczko et al. 2011, Pyke 2010, Ellsworth et al. 2016).

Importantly, native plant species diversity influences sagebrush steppe resilience (Spasojevic et al. 2016). Increased native species biodiversity can drive ecosystem resilience through redundancy, meaning that if any one species disappears from a system, it can be replaced by another species which performs similar ecological functions in diverse ecosystems (Holling 1973 Spasojevic et al. 2016). Seeding with a diverse native seed mix can improve long-term resistance to invasion and reduce complications associated with establishment of non-native plants introduced via seed mixes (Ott et al. 2019, Davies et al. 2019). Seeding with site adapted propagules rather than seed obtained from generalized sources may also increase the effectiveness of restoration treatments (Germino et al. 2018, Brabec et al. 2019).

Spatial Distribution

Plant gaps, or the distance between plants, also affect ecological site resistance in sagebrush steppe communities. Native perennial bunchgrasses that have increased distances between individuals characterized by connected bare soil cover are associated with higher cheatgrass cover (Reisner et al. 2013). High abundance of perennial bunchgrasses can effectively limit cheatgrass invasion by reducing gap connectivity and decreasing nutrient and water availability (Chambers et al. 2007, Prev  y et al. 2010, Reisner et al. 2013).

Conversely, the plant gap effect is limited to perennial bunchgrasses in sagebrush steppe ecosystems, as increased shrub cover is positively associated with annual grass cover (Griffith 2010). Cheatgrass germination, growth, and survival have been shown to increase in shrub microhabitats due to increased soil fertility and favorable microclimatic conditions (Griffith 2010). Shrub interspaces, alternatively, have reduced soil fertility and microclimatic conditions allowing for annual grass persistence (Griffith 2010). Differences in the effects of plant community gaps on ecological resistance between both perennial bunchgrasses and shrubs indicate the importance of landscape heterogeneity and biodiversity in sagebrush steppe ecosystems.

4.3 Biological Soil Crusts

Biological soil crusts (hereafter biocrusts) are complex biotic associations consisting of cyanobacteria, algae, microfungi, lichens and bryophytes which interact with soil particles to create a physical crust, altering soil surface characteristics (Belnap and Lange 2002, Hilty et al. 2004). Areas characterized by harsh conditions generated by reduced precipitation and increased temperature, like those found in the Great Basin, typically support biocrusts (Belnap and Lange 2002).

Biocrusts occupy the interstitial spaces between trees, shrubs, and grasses, and can cover 80% or more of the soil surface (Nash and Moser 1982, Belnap and Lange 2002). The presence of biocrusts in sagebrush steppe ecosystems is highly beneficial to the ecological community as they can fix and sequester carbon and stabilize soil surfaces, reducing wind and water erosion (Beymer and Klopatek 1991, Williams et al. 1995, Eldridge 1998, Leys and Eldridge 1998, Hilty et al. 2004). Biocrusts also have nitrogen-fixing capabilities and can increase native plant communities through the provision of nutrients (Harper and Belnap 2001, Hilty et al. 2004). The relative presence of mosses, a single component of biocrusts, can increase lichen cover, which positively influences bunchgrass cover and composition (Condon and Pyke 2018).

Biocrusts can limit annual grass establishment when present in plant interspaces by reducing the availability of "safe sites for establishment" (Reisner et al. 2013). The occurrence of biocrusts is associated with shrub cover, but factors such as increased litter height, annual grass biomass, and increased tree and litter cover, and soil disturbance from grazing and wildland fire can limit biocrust presence (Eldridge 1998, Bansal and Sheley 2017, Reisner et al. 2013).

Reintroduction or enhancement of biocrust communities has been applied in restoration of semi-arid environments (Bowker 2007), and is effective either through spore dispersal or soil surface transplants (Chicouine et al. 2016). Restoration of biocrusts could potentially coincide with seeding, or at sites where bunchgrass communities are intact, but biocrusts have been disturbed. Biocrusts are easily damaged, and identifying sites with intact biocrusts and limiting access to, or providing signage that discourages disturbing those sites could limit the loss of this resource.

4.4 Satellite and Persistent Native Plant Communities

Biological Legacies & Fire Refugia

Pre-fire community composition of woody and herbaceous species coupled with severity and frequency of disturbance influences whether or not survivors remain after a wildland fire event (Boyd and Davies 2017). Remnant survivors are referred to as biological legacies and are essential for the regeneration of native vegetation and natural ecological processes (Franklin et al., 2000, 2002, Siedl et al. 2014, Ellsworth 2016). Legacies reduce the impacts of soil erosion and nutrient loss, and increase seed-bank resources for future recolonization (Seidl et al. 2014). Groups of remnant survivors are the foundation of fire refugia which can influence the trajectory of sagebrush steppe ecosystem regeneration (Franklin et al. 2000, Meddens et al. 2018).

Refugia, as described by Meddens et al. (2018), are "*components of ecosystems which biodiversity can retreat to, persist in, and potentially expand from as environmental conditions change.*" Fire refugia are associated with areas that are not disturbed as frequently or severely by wildfire and

provide critical habitat for vegetation and wildlife during and after wildland fire events (Robinson et al. 2013, Meddens et al. 2018).

Unburned patches of sagebrush steppe would presumably influence post-fire recovery and ecosystem resilience in sagebrush steppe ecosystems (Meddens et al. 2018). For instance, the distance to the nearest seed source and condition of the vegetation community pre-fire affects the ability of *A. tridentata* and other native herbaceous species to regenerate post-fire (Miller et al. 2013, Mata-González et al. 2018, Germino et al. 2018).

Remnant burned Wyoming big sagebrush can influence seedling establishment of native perennial grasses when seeded post-fire (Boyd and Davies 2010). A study conducted by Boyd and Davies (2010) found that native seedling densities were 24 times greater in sub-canopy microsites when compared to interspaces. Plant height and reproduction also increased in burned sagebrush microsites, but not in the interspaces (Boyd and Davies 2010). These findings suggest that the microsites created below the sagebrush canopy after fire act as fire refugia and generate favorable resources for native plant establishment (Boyd and Davies 2010).

Fertile Islands & Seed Sources

Revegetation of sagebrush steppe ecosystems is also reliant on the pre-fire composition of soil nutrients and seed sources (Harper 1997, Allen and Norwak 2008, Boyd and Davies 2010, Ellsworth and Kauffman 2013). Soil nutrients dispersed in a mosaic-like pattern across landscapes create post-fire 'fertile' or 'resource islands' which support native perennial grass and forb growth and reproduction after a disturbance (Boyd and Davies 2010).

Resource islands are found beneath the sagebrush canopy layer and provide additional nutrient resources, organic matter, and soil aggregation compared to spaces between native shrubs (Jackson and Caldwell 1993 a, b, Schlesinger et al. 1996, Boyd and Davies 2010, Germino et al. 2018). Wildland fire changes the spatial arrangement of resources across landscapes but burned sagebrush sub-canopies can act as resource islands, encouraging the establishment and growth of native grasses (Davies et al. 2009, Boyd and Davies 2010).

Even in small amounts, resource islands can facilitate sagebrush regeneration (Germino et al. 2018). Resource island presence was associated with nearly a 50% increase in sagebrush occupancy when the shrub was seeded post-fire, indicating the importance of intact sagebrush cover before wildland fire (Germino et al. 2018).

Resource island cover influences resilience by providing beneficial conditions for native seedling establishment; however, the post-disturbance composition of a seed bank can either limit or increase system resilience (Boyd and Davies 2010, Germino et al. 2018, Miller et al. 2013). Sagebrush seedbanks are essential for the re-colonization of burned areas considering big sagebrush plants cannot re-sprout after fire and are slow to recover (Blaisdell 1968, West 1983 b, Schlaepfer et al. 2014, Mata-González et al. 2018). Natural regeneration can take 3–50 years or more depending on the sagebrush species and site characteristics (Bunting et al. 1987, Ziegenhagen 2003, Miller and Heyerdahl 2008, Ziegenhagen and Miller 2009, Miller et al. 2013).

4.5 Natural Disturbance Regimes

Severity, type, and frequency of disturbance paired with topographic and climatic influences are primary drivers of sagebrush steppe ecosystem structure and composition (Chambers 2014 a, Siepel et al. 2018). Fire is considered the principal disturbance in sagebrush steppe ecosystems and can have lasting effects on native shrub species, especially in areas of low productivity (Wright and Bailey 1982, Conelly et al. 2004, Miller et al. 2011, Evers et al. 2013). Wildland fire, the primary inherent disturbance in sagebrush ecosystems, is influenced by and interacts with other ecological and human-caused disturbances, which can alter severity and frequency (Davies et al. 2009, Evers et al. 2013, Chambers et al. 2014 a).

Perennial grass species recovery is dependent on the season of disturbance (i.e., fall burning) and growth form (Wright and Bailey 1982). Mortality can be high for leafy bunchgrasses, due to densely clustered culms which can burn for up to 3 hours post-fire; however, perennial species like bluebunch wheatgrass, crested wheatgrass species, and bottlebrush squirreltail are less sensitive due to reduced leaves and coarse stems (Wright and Bailey 1982). Many perennial forbs may remain undamaged after wildland fire disturbance and have successfully regenerated to pre-burn levels within 30-years (Wright and Bailey 1982). However, regeneration and plant community resilience to change diminishes by and with prolonged and frequent disturbance (Wright and Bailey 1982). Additionally, disturbance type can alter fire rotation and ecosystem resilience (Evers 2013, Chambers et al. 2014 a, Siepel et al. 2018).

Unaltered sagebrush ecosystems may respond positively to preventative management which incorporates natural disturbance regimes, further increasing ecological resilience and landscape variability (Chambers 2005). However, it is likely that conditions in degraded areas have deviated too far from the historic range of variability to apply natural and historical disturbance principles to ecological restoration (Suding et al. 2004, Davies et al. 2009). Light to moderate grazing impacts may actually improve plant performance and increase resilience and resistance of native plant communities in the absence of periodic fire (Davies et al. 2016). Though Davies and Bates (2014) found that mowing increased annual grass/forb densities in Wyoming big sagebrush, less invasive treatments (e.g., hand-trimming) may be appropriate at smaller spatial scales.

5. Integrated Fire and Exotic Invasive Plant Management Planning

Management Implications

- Adopt proposed Fire Management Plan revisions that restrict use of fire (wildland and prescribed) as a management tool, advocate for active vegetation management strategies (e.g. mechanical treatments and restoration) and emphasize rapid response exotic species approaches.
- Update the Fire Management Plan on a regular basis to include a cohesive fuels reduction/vegetation management program which treats intact priority areas identified via resiliency mapping tools (Taylor et al. 2013, Rodhouse et al. 2014, Chambers et al. 2019).
- Develop generalized Burned Area Emergency Response (BAER) text that incorporates immediate post-fire resilience and resistance management strategies and can be used to expedite JODA BAER plans.
- Prioritize treatments described in BAER planning in areas that will receive the most significant benefit from post-fire restoration (Chambers et al. 2019).
- Strategically place firefighting resources for prompt fire response in highly susceptible areas with valuable and intact resources (i.e., *Priority 1* areas; Chambers et al. 2019).
- Prioritize use of existing Ecologically-Based Invasive Plant Management Plan (Hoh et al. 2015). Incorporate early detection mapping strategies into existing vegetation monitoring programs.
- Implement pre-fire restoration treatments in intact sagebrush steppe ecosystems throughout the Monument, which mimic natural disturbance to recover the natural range of variation (Chambers et al. 2014 a).

Overview

Wildland fire remains the most significant disturbance affecting sagebrush steppe ecosystems in the Monument. Despite the historic importance of fire as a determinant of ecological resilience, current conditions in the Monument and risk of exotic annual grass invasion limit its utility as a management tool. Existing fire management and post-fire management plans for the Monument are out of step with state-of-the-science understanding of ecological resilience and resistance, as well as the threat posed by emerging annual exotic grass-fire cycles. Exotic plant invasions can be conceived as a disturbance in some systems, but the current distribution and abundance of exotic species within the Monument, combined with propagule pressure from seed sources on adjacent private lands, should be considered a persistent, chronic stress. The interdependent nature of exotic annual grass invasion ecology and fire requires holistic and coordinated fire and invasive plant management approaches. In the following sections we present recommendations for an updated Fire Management Plan (FMP) and underscore the importance of fully implementing the existing Ecologically Based Invasive Plant Management (EBIPM) plan. We also provide generalized text written for burned-area response planning and emergency rehabilitation (BAER and related plans) that can expedite immediate response following future fire events.

5.1 Suggested Revisions to the JODA FMP (2004)

The purpose of this section is to provide the scientific basis for updates to the June 2004 Wildland Fire Management Plan (FMP) for the Monument. Suggested revisions reflect contemporary scientific understanding circa 2019. We base our recommendations on current understandings of the fire ecology of North American sagebrush steppe ecosystems, and vegetation community responses to fire within the Monument itself. We draw on the concepts of resistance to invasion and resilience to disturbance that are well established and increasingly applied to inform our understanding of the risks of prescribed and wildland fires present for increasing exotic annual grass invasion. The exotic annual grasses present at the Monument have increased the risk of ignition and spread of wildfire due to the flammability, density, and continuity of annual grass litter. There is also an increased risk of post-fire invasion by annual grasses into previously uninvaded sites due to the amount of annual grass seed present in the soil. The active annual grass-fire cycles now established in all Monument uplands require management priorities to shift to fire prevention, post-fire mitigation of annual grass re-establishment via pre-emergent herbicide application, and the use of mechanical and chemical methods of invasive plant treatment rather than use of prescribed burns that was used by the Monument historically and advocated in the 2004 FMP.

Specific recommendations for revision to the 2004 JODA Wildland Fire Management Plan are provided in Appendix C. Highlighted management implications from proposed revision include the following:

1. Removal of prescribed and wildland fire as management tools within the Monument. Information derived from extensive vegetation and fire effects monitoring conducted in the Monument clearly indicate that risks associated with vegetation state changes to communities dominated by exotic annual grasses outweigh the potential benefits of fire.
2. Strategic fire suppression and active vegetation management that mimics or approximates disturbance is supported at JODA. Vegetation management approaches should be tailored to specific site characteristics, particularly given the current distribution of exotic annual grasses within the Monument.
3. Explicit incorporation of exotic annual grass fire cycle information and annual grass fire ecology into FMPs.

5.2 Systems-based Invasive Plant Management

The 2009 General Management Plan for JODA (NPS 2009) specified management goals of restoring native bunchgrass/sagebrush steppe plant communities where feasible and sustainable while minimizing the presence of nonnative species. Meeting these goals will require strategic investment in: 1) protection/enhancement of remaining high-integrity plant communities; and 2) targeted restoration projects in degraded areas. The 2015 Ecologically Based Invasive Plant Management (EBIPM; Hoh et al. 2015) plan for the Monument was explicitly developed to address this need. The plan is available in digital format from the Upper Columbia Basin Network website (<https://www.nps.gov/im/ucbn/index.htm>).

EBIPM is a decision support tool that can be used to holistically manage exotic invasive plants. The process utilizes science-based knowledge of primary causes of successional change to develop solutions and restoration treatments for degraded rangelands (Sheley et al. 2010). To operationalize the concept for landscape-scale application, Rodhouse et al. (2014) developed a modelling approach that results in prioritization of management areas based on the status (relative abundance) of foundation species. Priority management areas for JODA were conceived as follows (and see Figure 9):

Priority 1: Areas to prevent weed infestations. Generally, these are areas with no weed infestation and are considered ecologically intact (>25% bluebunch wheatgrass cover).

Priority 2: Areas of weed containment or control, with some native bunchgrass present (>5% bluebunch wheatgrass cover).

Priority 3: Areas which have high degradation and will require treatments aimed at revegetation with no native bunchgrass present.

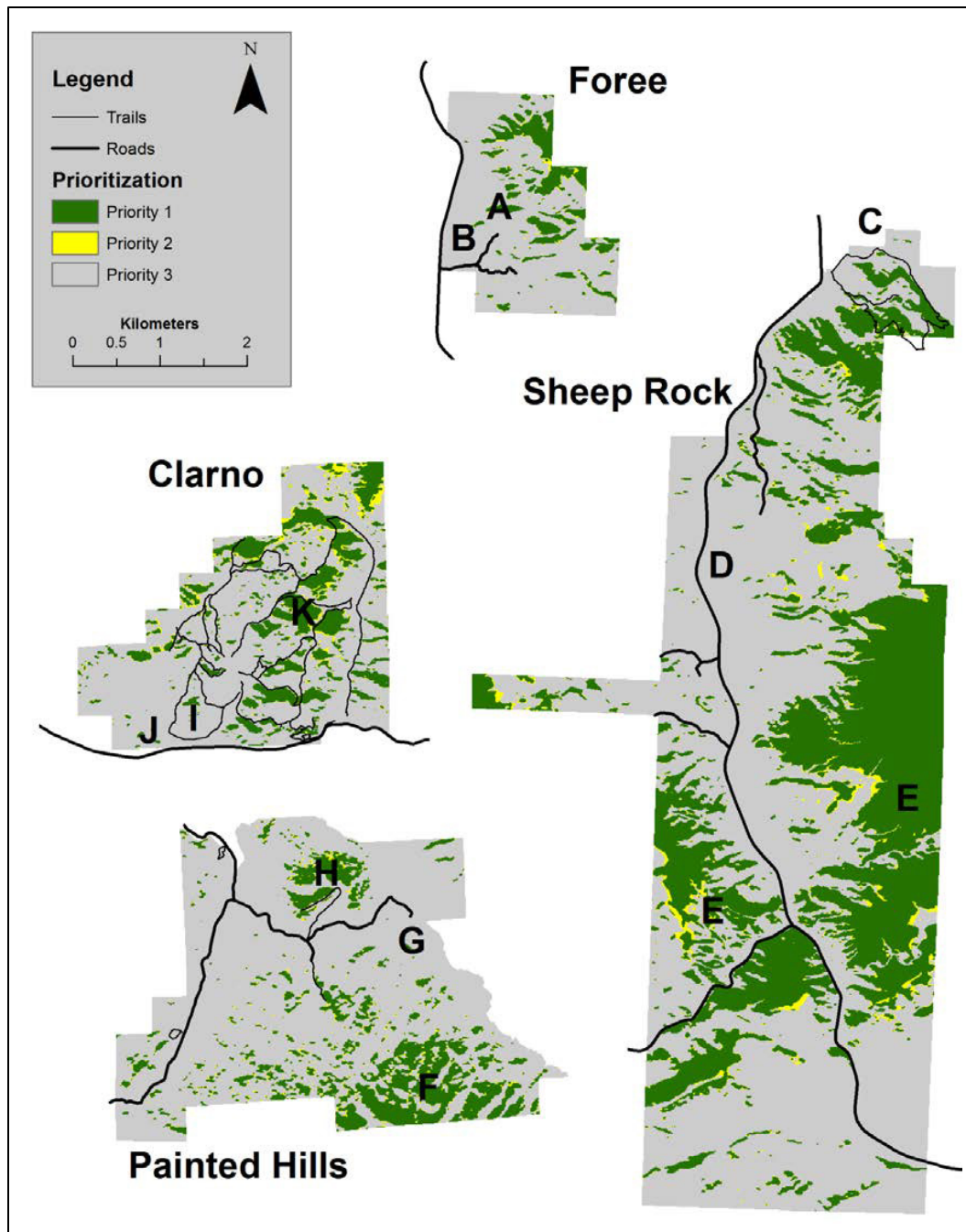


Figure 9. Priority vegetation management areas in John Day Fossil Beds National Monument as a function of foundation species cover. Reproduced from Rodhouse et al. (2014).

The EBIPM plan for JODA also prescribed a generalized management approach for priority management areas (Figure 10). Given the relatively large spatial area categorized as Priority 1 in the Monument, the plan specified 10 Priority 1 areas for initial application of the process (sites A-K in Figure 9). These sites offer high potential for success, are easily accessible and are highly visible to Monument visitors. The full list of Priority 1 sites with descriptions is included in Table 1.

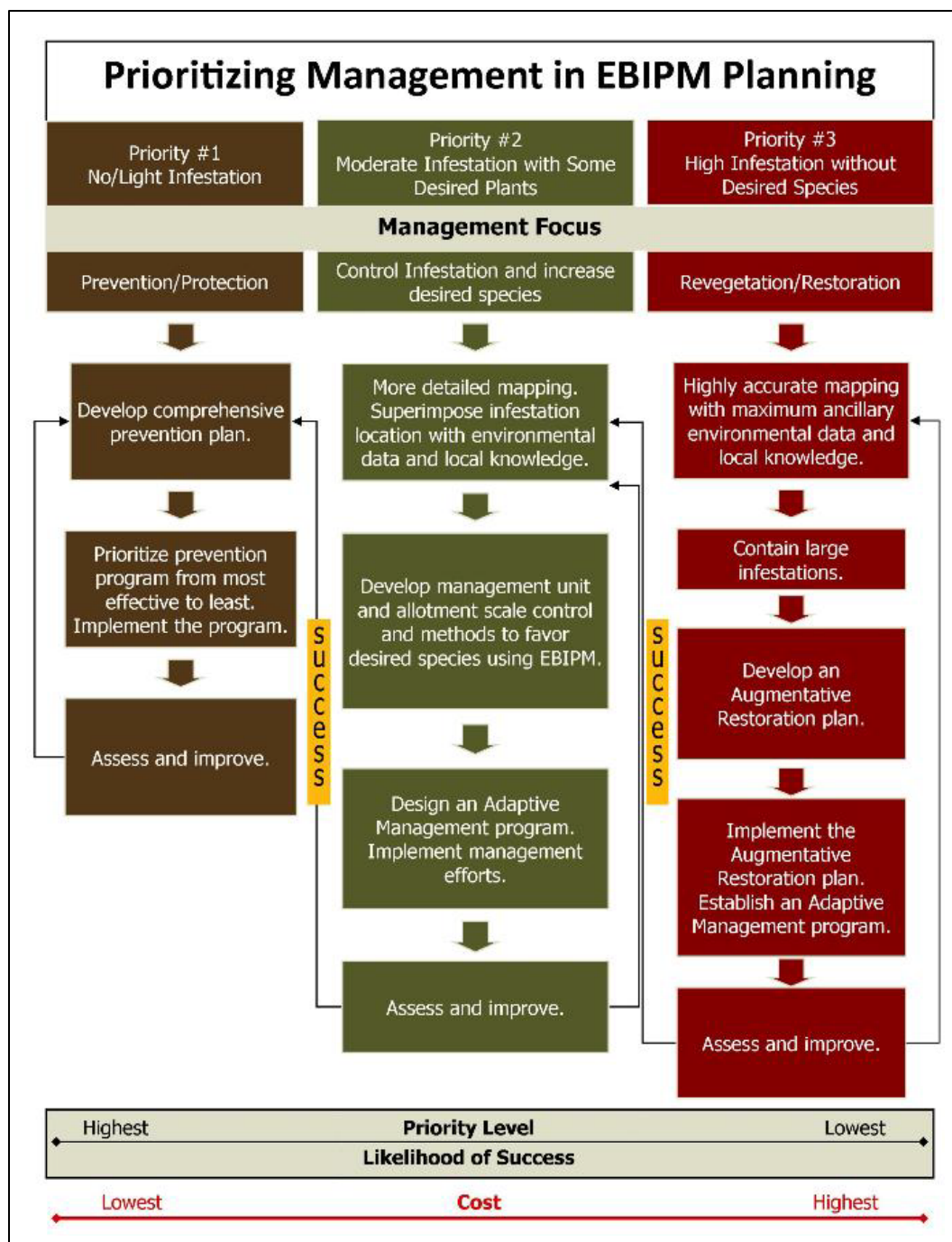


Figure 10. Management schematic for implementation of EBIPM at JODA. Reproduced from Hoh et al. (2015).

Table 1. Priority 1 areas recommended for application of EBIPM approaches in John Day Fossil Beds National Monument. Adapted from Hoh et al. (2015).

Monument Unit	Location Description	Resource Values	Threats
Foree Sub-unit	West of the restroom and between the Flood of Fire and Story in Stone trails	Unburned bluebunch wheatgrass, Wyoming sagebrush and native forbs	Dalmatian toadflax, diffuse knapweed, common mullein, and cheatgrass
Foree Sub-unit	Just off the entrance road to the west and just off the Fire of Flood trail to the west after crossing the drainage	Re-establishing bluebunch wheatgrass following the 2007 fire	Dalmatian toadflax, diffuse knapweed, common mullein, and cheatgrass
Sheep Rock	North slopes of Middle Mountain near Blue Basin	Several areas with high native bunchgrass cover	Dalmatian toadflax and common mullein
Sheep Rock	West side of Hwy 19 on the north-facing slopes of the foothills from the visitor center south to Picture Gorge	Areas with good native bunchgrass cover	Dalmatian toadflax, Scotch thistle, cheatgrass and medusahead.
Sheep Rock	Research Natural Area on east side of the John Day River above Waterspout Gulch and the west side of the river spanning Rock Creek and U.S. Highway 26	Near pristine native plant communities that experienced infrequent grazing	Limited accessibility in the event of wildland fire and subsequent exotic species invasion
Painted Hills	South Boundary	Relatively large area of bluebunch wheatgrass	Whitetop, Russian knapweed, medusahead, and cheatgrass; limited accessibility
Painted Hills	Bridge Creek Floodplain-south of the picnic area restrooms	Greasewood community containing bluebunch wheatgrass and basin wildrye	Russian knapweed, whitetop, and kochia
Painted Hills	North-facing slope of Carroll Rim	High native bunchgrass cover	Medusahead transport from lower slopes via foot traffic along the trail
Clarno	North-facing slopes (higher elevations) above the road to Hancock Field Station via the Equisetum and Mimulus Trails	Good native bunchgrass cover	Medusahead, cheatgrass, Russian knapweed, Dalmatian toadflax and common mullein
Clarno	North-facing slopes adjacent to the Pictograph Trail	Good bluebunch wheatgrass cover	Medusahead, cheatgrass, Dalmatian toadflax and common mullein.

The remainder of the EBIPM plan provides a detailed blueprint for successful implementation at high priority sites. The 2015 EBIPM for JODA is a key ingredient for maintaining (and potentially enhancing) ecological resilience of vegetation communities within the Monument. As such, we strongly recommend fully implementing the existing plan.

5.3 Recommendations for Burned Area Assessments and Planning

The purpose of this section is to propose content for inclusion into future burned area assessment and planning documents at JODA. Recommendations provided here are based on information derived from the peer-reviewed literature summarized in this document and are consistent with existing Department of Interior guidance documents. More specifically, this content is designed to complement guidance provided by the 2006 Interagency Burned Area Emergency Response Handbook and the USDA Science Framework for Conservation and Restoration of the Sagebrush Biome (Crist et al. 2019). Successful implementation of these recommendations is reliant on incorporation of the existing EBIPM plan for JODA (Hoh et al. 2015) into integrated fire and vegetation management planning. Detailed recommendations are provided in Appendix D.

Proposed Objectives for Future Burned Area Assessments

1. Evaluate potential for non-native plant expansion and encroachment into native plant communities within fire perimeter.
2. Provide management recommendations to treat areas of existing exotic annual grass invasion adjacent to the burned area perimeter and prevent expansion into the burned area.
3. Provide management recommendations to protect remnant native vegetation and enhance recovery in burned areas unlikely to recover naturally from fire damage.

Summary of Recommendations

1. Explicitly incorporate strategies identified in the 2015 EBIPM for JODA into future Burned Area Emergency Response plans.
2. Burned area assessments should emphasize impacts to foundation species, and in particular big sagebrush and bluebunch wheatgrass. Assessment should also identify the proximity of intact sagebrush/bunchgrass steppe to burned area as a key component of specific restoration strategies.
3. Burned area assessments should describe evidence of annual invasive grass expansion into the burned area, as well as the extent of annual exotic grass invasion in areas adjacent to the burned area perimeter.
4. Early detection and spot treatment of prioritized noxious weeds.
5. Targeted broadcast herbicide application for high priority restoration sites and prevention of escalated fire cycle regime. Invasive plant treatments should be combined with native plant seeding and/or outplanting mature plants.
6. Create strategically located big sage and bunchgrass islands of fertility within burned areas by seeding and outplanting.

6. Conclusions

Well-established concern for the sustainability of sagebrush steppe ecosystems underscores the need for effective protected area management strategies where these systems occur. Given the extent of sagebrush steppe vegetation present in JODA, prioritization of these areas is an important opportunity to support continent-wide conservation initiatives. Further, priority protection and enhancement of sagebrush steppe ecosystems in the Monument is entirely consistent with NPS system-wide and park-specific management guidance.

Effective management of sagebrush steppe vegetation in the Monument will require up-to-date understanding of ecosystem resilience and resistance science, particularly as applied to specific ecological sites present in Monument units. Spatially-explicit representation of Monument ecosystem resilience and resistance is made possible by combining newly developed mapping approaches with results from ongoing vegetation monitoring programs, both of which are highlighted in this document. Generally speaking, sagebrush steppe ecosystems in the Monument are characterized by low resistance to disturbance and low resilience following disturbance, as indicated by the significant increase in exotic annual grass cover in areas affected by both prescribed and wildland fire. Exceptions to Monument-wide low resilience exist, particularly on steep north-facing slopes where intact native bunchgrass communities are still present. Additional opportunity areas specified in previous management documents are reiterated here. Based on our analysis of the literature and Monument-specific monitoring and research, resilience and resistance-based management for the Monument should prioritize wildland fire suppression, avoidance of prescribed fire as a management tool and vegetation management strategies that protect and enhance intact native plant communities while reducing threats associated with exotic annual grass invasion.

Managing for ecosystem resilience and resistance in JODA will also require that management strategies be consistent across resource management planning applications, including fire management, vegetation management, cultural resource management and recreation management. In particular, the interdependence between fire and exotic annual grass invasion requires a holistic approach that integrates pre-fire, fire event and post-fire management planning with ecologically-based invasive plant management strategies. This integrated approach is essential for mitigation and/or elimination of the sources of ecosystem stress that drive exotic annual grass invasion and subsequent loss of native plant diversity and abundance in sagebrush steppe. We provide evidence-based recommendations for updating Monument fire management plans to better incorporate resistance and resilience concepts. We also provide evidence to support implementation of the 2015 EBIPM plan, which includes specific guidance for integration of ecologically-based invasive plant management strategies into cultural, recreation and vegetation management plans.

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Appendix A. Annotated Bibliography

Sagebrush Steppe Resilience to Disturbance and Resistance to Invasion: An Annotated Bibliography for Managers.

Summary

This annotated bibliography provides an overview of literature related to the importance of sagebrush steppe ecosystems, threats to those systems, and factors that contribute to sagebrush steppe resilience to disturbance and resistance to invasion. Sources include peer-reviewed literature published in scientific journals, peer-reviewed agency documents and agency monitoring report summaries. Information summarized here is organized into focal themes for easy navigation and rapid referencing. Themes can be found on the following pages:

Annual Grass and Noxious Weed Invasion Ecology (pg. A-1)

Sagebrush Steppe System Responses to Fire (pg. A-12)

Sagebrush Steppe Restoration Strategies (pg. A-22)

General Sagebrush Steppe Vegetation Conditions (pg. A-33)

Ecological Resilience and Resistance Concepts and Protected Area Management (pg. A-38)

Biocrust Ecology and Influence in Rangeland Ecosystems (pg. A-44)

Annual Grass and Noxious Weed Invasion Ecology

Aguirre, L., & Johnson, D.A. 1991. Influence of temperature and cheatgrass competition on seedling development of two bunchgrasses. *Journal of Range Management* 4:347–354.

This study was conducted to determine the influence of both cheatgrass competition and temperature in regard to three planting densities on seedling root and shoot development of bluebunch wheatgrass cultivars. Temperature affected shoot and root parameters for all species, though the effect of temperature varied between cheatgrass and the two cultivars. Cheatgrass seedling growth was greater on average than the bunchgrasses at all temperatures and reduced the growth of both cultivars. The study suggests that native bunchgrass competition with cheatgrass is dependent on life history strategies, such that successful competitors should respond similarly to cheatgrass under varying temperature regimes.

Bagchi, S., Briske, D., Bestelmeyer, B., & Ben Wu, X. 2013. Assessing resilience and state-transition models with historical records of cheatgrass *Bromus tectorum* invasion in North American sagebrush-steppe. *Journal of Applied Ecology* 50(5):1131–1141.

Quantified the historical response of native vegetation to cheatgrass invasion including natural and anthropogenic drivers of native species and community change and the temporal scale at which changes occurred. At the site with higher initial species diversity, cheatgrass invasion reached a peak density but did not change overall composition of the community. In fact, that site seemed to recover to previous species composition following the peak of cheatgrass density. In contrast, at the site with

lower initial plant diversity, several transitions from native species dominance to cheatgrass dominance were detected. Cheatgrass invisibility is likely to vary between specific sites as a result of unique site attributes more so than disturbance history and total annual precipitation. Long-term vegetation monitoring, with emphasis on detection of community transitions, may be the most effective tool for evaluating site resistance to invasion and resilience to disturbance.

Bangert, R., & Huntly, N. 2010. The distribution of native and exotic plants in a naturally fragmented sagebrush-steppe landscape. *Biological Invasions* 12(6):1627–1640.

Tested whether the MacArthur-Wilson Hypothesis, environmental variables, or origin of native plants and interactions with exotics impacted native and exotic species diversity and distribution in sagebrush steppe environments in Idaho. Plant species richness was most strongly impacted by proximity to a railroad (vector for species spread) and cover of exotic species, wherein sagebrush habitats closer to the railroad and containing greater cover of exotic species exhibited lower native plant diversity. Given the relative lack of disturbance (as measured in this study) in habitat patches distant from the railroad, the authors suggest that the main influence of the railroad may have been as a propagule source for spread of invasives. One implication of this may be that sources of seed spread, rather than site disturbance, may be an important step in reducing the impacts of invasive plants on native plant communities.

Bansal, S and R.L. Sheley 2017. Annual grass invasion in sagebrush steppe: the relative importance of climate, soil properties and biotic interactions. *Oecologia* 181:543–557.

The authors sought to quantify the historical response of native vegetation to cheatgrass invasion, including natural and anthropogenic drivers of native species and community change, and the temporal scale at which changes occurred. High species diversity correlated with reduced cheatgrass invasibility. Communities that shared similar species (low species diversity) experienced frequent state transitions. Transitions were not temporally uniform, did not correlate with precipitation, and occurred before cheatgrass reached maximum abundance. Knowledge of historical frequency, magnitude, directionality and temporal scale of transitions may improve understanding of ecosystem resilience and application to management.

Blank, R. and T. Morgan. 2013. Soil engineering facilitates downy brome (*Bromus tectorum*) growth — a case study. *Invasive Plant Science and Management* 6(3):391–400.

Evaluated long term soil conditioning effects of *Bromus tectorum*, and subsequent effects on *Bromus tectorum* growth in conditioned soils. Aboveground biomass was significantly greater for *Bromus tectorum* plants grown in invaded soils. Plants grown in invaded soils contained higher concentrations of nitrogen, calcium, and copper, and lower concentrations of manganese, phosphorus, and zinc in relation to plants grown in non-invaded soils. Invaded soils contained higher concentrations of nitrogen, phosphorus and manganese. Soils invaded by *Bromus tectorum* may (depending on time since invasion) be conditioned in ways which facilitate re-invasion after *Bromus tectorum* removal due to altered nutrient cycling.

Booth, M., M.M. Caldwell, and J. Stark. 2003. Overlapping resource use in three Great Basin species: implications for community invasibility and vegetation dynamics. *Journal of Ecology* 91(1): 36–48.

Examined competitive relationships between squirreltail, cheatgrass, and sagebrush in Curlew Valley, Utah. Significantly more sagebrush seedlings established in sites containing squirreltail but not cheatgrass. Cheatgrass abundance decreased with squirreltail presence. Squirreltail cover of 20% or greater effectively suppresses cheatgrass establishment and allows for the persistence of sagebrush due to both temporal and intensity differences in resource utilization and uptake. Cheatgrass was able to deplete soil moisture at higher rates than perennial grasses. Sagebrush that grew alone and with squirreltail were larger than those growing with cheatgrass present. Restoration projects should include native perennial species which facilitate plant associations with native shrubs and reduce invasive establishment and proliferation.

Bradley, B., A. Curtis, C. Fusco, E. Abatzoglou, J. Balch, J. Dadashi and T. Tuanmu. 2018. Cheatgrass (*Bromus tectorum*) distribution in the intermountain western United States and its relationship to fire frequency, seasonality, and ignitions. *Biological Invasions* 20(6):1493–1506.

Used a satellite-based model of cheatgrass distribution in the hydrographic Great Basin from 2001–2014 field survey data. Measured early cheatgrass productivity and annual variability to re-evaluate relationships between fire frequency and cheatgrass, percent cover of cheatgrass and fire frequency, differences in fire seasonality in regions with cheatgrass and links to anthropogenic fire sources from prior fire analysis. Average percent cover in pixels where cheatgrass was present was 21 ± 21 SD. The spatial model predictor most strongly associated with cheatgrass cover was early season phenology in years with above average precipitation and elevation. Areas associated with cheatgrass were more likely to burn than areas without cheatgrass, and were also more likely to burn multiple times. Humans started 74.5% of fires in areas infested with cheatgrass, generally from fireworks and on the fourth of July. Managers should be aware of the types of anthropogenic activities which occur near cheatgrass infestations. Roads, power lines, trails, and railroads act as vectors of dispersal; humans with access to these areas can increase chances of early season ignition.

Bradley, B. A. 2009. Regional analysis of the impacts of climate change on cheatgrass invasion shows potential risk and opportunity. *Global Change Biology* 15(1):196–208.

Presented a bioclimatic envelope model for cheatgrass in the western US by using regional presence data and climate predictors to model climatic habitat under recent/current climate conditions. Estimated the spatial extent of cheatgrass, including increases and decreases of habitat suitability under future climate change scenarios. Summer, annual and spring precipitation variables were the best predictors of climate suitability for cheatgrass invasion. Increased summer precipitation may increase water availability to native plants during *B. tectorum* dormancy, allowing perennials to be more competitive. Managers can prioritize vegetation treatments by identifying priority at-risk land area and predicted climate changes that increase risk.

Brummer, T. J., K.T. Taylor, J. Rotella, B.D. Maxwell, J. L. Rew and M. Lavin. 2016. Drivers of *Bromus tectorum* abundance in the western North American sagebrush steppe. *Ecosystems* 19(6):986–1000.

Sought to determine the most important drivers of cheatgrass abundance to assist in the prediction of current and future distribution and impact of cheatgrass, and aid in finding where it will be a potentially significant invasive species. Dominant predictor variables for cheatgrass abundance were July precipitation, mean temperature of the driest quarter, native grass canopy cover, and dominance of crested wheatgrass. Sites with less than 10mm of July precipitation and temperatures of the driest annual quarter greater than 15°C were associated with high cheatgrass abundance. Canopy cover consisting of greater than 25% native grasses was associated with little or no canopy cover of cheatgrass. Crested wheatgrass was also associated with reduced cover of cheatgrass. Low elevation sagebrush steppe ecosystems are most likely to transform into cheatgrass dominated landscapes due to warmer temperatures and low precipitation. Managers should avoid heavy physical disturbance during restoration efforts in areas that are less susceptible to state transitions as increased disturbance can cause cheatgrass invasion. Instead, low disturbance methods like broadcast seeding should be applied.

Chambers, J. C., B.A. Roundy, R.R. Blank, S.E. Meyer and A. Whittaker. 2007. What makes the Great Basin sagebrush ecosystems invisable by *Bromus tectorum*? *Ecological Monographs* 77(1):117–145.

Examined invasion susceptibility (invasibility) of cheatgrass in sagebrush steppe ecosystems due to fire and herbaceous species removal along a topographical gradient. Prescribed fire and removal of herbaceous vegetation affected resource availability in all treated areas. Native perennial and annual grass cover were not affected by burning after the first year of treatment at study sites. Plant removal caused the greatest changes in the first year following treatment. Affects to soil water availability from removal lasted for multiple years and were highly variable at lower elevations, but effects from burning only occurred during the first year following treatment. Plant removal significantly impacted nitrate and overall cover which varied by site. Cooler temperatures and shorter growing seasons reduced cheatgrass seed production, biomass, and establishment in high-mid elevation sites. No significant differences were recorded in cheatgrass emergence and survival following fire or vegetation removal, but seed production and biomass increased after either treatment and significantly increased when the treatments were paired. Growing season and precipitation variability, which change along an elevational gradient, had the greatest impact on emergence, survival, biomass and seed production. Squirreltail and other native vegetation with similar life cycles to cheatgrass can be significant competitors and reduce overall invasibility by exotic annual grasses. Goals to reduce sagebrush-steppe ecosystem loss can be achieved by restoring and maintaining native perennial vegetation.

Condon, L. A. and D.A. Pyke. 2018. Fire and grazing influence site resistance to *Bromus tectorum* through their effects on shrub, bunchgrass and biocrust communities in the Great Basin (USA). *Ecosystems* 21(7):1416–1431.

Provides a comprehensive understanding of the role of the biotic community which includes shrubs, native bunchgrasses, and biotic crusts in maintaining site resistance to cheatgrass in the presence of fire and grazing across the region. The authors hypothesized that individual fires lead to temporary

declines in site resistance, but that decreases in grazing intensity by livestock, either before or after the fire, would lead to increase in site resistance, mediated through increases in the cover of native bunchgrasses and biocrusts and through reductions in the distances between perennial plants. Model results showed that neither fire or grazing generated direct impacts on *B. tectorum* cover itself, but rather the effects were expressed indirectly through impacts on other biotic factors. Increased cover of native bunchgrass, bare ground, and lichen and reduced gap size were associated with reduced cheatgrass cover. Changes to the biotic community driven by both fire and grazing modify site resistance to cheatgrass. Although fire and grazing did not directly impact study site integrity and annual grass resistance, they did impact other biotic factors which themselves reduced resistance. Bunchgrass and shrub cover were the two most important biotic factors relating to site resistance to cheatgrass invasion.

D'Antonio, C.M. and P.M. Vitousek. 1992. Biological invasions by exotic grasses, the grass/fire cycle, and global change. *Annual Review of Ecology and Systematics* 23(1):63–87.

Reviewed global exotic grass invasion emphasizing the effects of exotic annual grasses, and highlight instances of exotic annual grass driven fire cycles. Ecosystem effects of grass invasion include competition for resources, altered rates of resource supply, altered geomorphological processes that can lead to changes in soil moisture regimes, microclimatic effects, and altered fire regimes. Grass-fire cycles have been studied in Hawaii, the Western U.S., Central and South America, and Australia. While it is clear that annual grass invasion can severely alter ecosystem processes including fire regimes the authors concluded that more intensive studies of impacts of annual grass invasion on fire regimes were needed, rather than simple descriptions or speculation. A large aspect of any invasive plant management should be understanding the impacts of and reasons for invasion. Understanding the connection between invasive annual grasses and fire indicates that prescribed fire is likely to benefit exotic annual grasses rather remove them.

Daehler, C. 2003. Performance comparisons of co-occurring native and alien invasive plants: implications for conservation and restoration. *Annual Review of Ecology, Evolution, and Systematics* 34:183–211.

Determined whether invasive plant species outperform native plants in areas where they co-occur based on peer-reviewed literature that compared the performance of co-occurring native and invasive species, and provided recommendations for the management of invasive species. Generally, native plants had similar performance capacity when compared to invasive plants. Additionally, "super-invaders" are relatively rare, as there are not many invasive species with superior performance abilities to that of native species. However, in disturbed areas or areas decoupled from the natural disturbance regimes, invaders were shown to have performance advantages. To augment native species performance, the author recommends actions such as maintaining intact ecosystems, focusing on restoration sites showing the most promise, active management of disturbance and plant resource availability, and the manipulation of disturbance. However, the continued increase of invasive species, altered disturbance regimes, and climate change may limit the maintenance of native plant communities in ecosystems.

Davies, K. W. 2008. Medusahead dispersal and establishment in sagebrush steppe plant communities. *Rangeland Ecology & Management* 61(1):110–115.

Sought to determine timing and spatial extent of *T. caput-medusae* seed dispersal from invaded areas without large animal, vehicle, and human dispersal vectors and to research establishment rates of medusahead and invasion variance based on plant community type. Medusahead dispersal decreased as distance increased. Five of the 23 transects captured medusahead seeds at 2 m from the invasion front, and no seeds were trapped >2 m from the invasion front. Seed dispersal began in July and ended in October. Medusahead infestation density, slope, and aspect did not correlate with distance, timing, or quantity of seed dispersal. Seed introduction rate influenced medusahead density and cover. Establishment was greater at the highest seed introduction rate. Medusahead cover was not found to differ between 10 and 100 seed per m² introduction. Bunchgrass density negatively impacted medusahead cover, but annual grass density positively influenced medusahead cover. Containment zones (~3 m) that limit vehicle or wildlife traffic around infested areas could limit dispersal of medusahead and further limit invasion in surrounding plant communities. Limiting livestock grazing, vehicle travel, and human activity during the months of seed dispersal (July–October) could also reduce risk of invasibility. Native grass density limits medusahead establishment. Preventing medusahead invasion will most likely be more cost effective and successful than trying to control it after establishment.

Davies, K.W., & Sheley, R.L. 2007. Conceptual framework for preventing the spatial dispersal of invasive plants. *Weed Science* 55(2):178–184.

Proposed an initial framework for invasive plant management that integrates ecology of invasive plant dispersal with prevention management. Vector characteristics that promote invasive seed dispersal are attachment, attractant, aerodynamic properties, buoyancy, self-propelled, and location. Seeds can also be dispersed through multiple vectors which, in some cases, significantly increases dispersal distance. It is critical to identify which vectors are the most important for appropriate management of each species based on site conditions (source/infestation) and morphology. Limiting dispersal can reduce invasion of intact vegetation communities which can reduce short- and long-term costs of community maintenance and development of resilience and resistance to fire and alien species establishment.

Davis, M. A. and M. Pelsor. 2001. Experimental support for a resource-based mechanistic model of invasibility. *Ecology Letters* 4: 421–428.

Tested the prediction of the fluctuating resource hypothesis and determined that resource availability, altered by water and disturbance treatments, strongly influenced competition and invasibility. Additionally, changes to resource availability on the scale of a few weeks affected the invasion success of the study species, with long-lasting effects. Importantly, dry plots were more susceptible to invasion after the disturbance treatment was applied, as it limited native vegetation resource uptake and reduces seedling establishment, allowing for increased soil water for invasive species. In general, increased invasibility was influenced by increased resource availability through mechanisms that limit native community resource uptake or resource additions beyond the capacity for native plant utilization. Historical events likely played a role in the random distribution or limitation of resources, influencing prior invasions.

Ditomaso, J. 2000. Invasive weeds in rangelands: species, impacts, and management. *Weed Science* 48(2):255–265.

Identified common invasive species of rangelands and introduce methods of controlling establishment and invasion and possibilities for restoration of degraded rangelands. Multiple factors promote the spread of invasive species across rangelands (e.g., human activity, overgrazing, and suppression of wildfires). Noxious and invasive weeds cause a financial impact estimated at \$2 billion (in 2000) in U.S. rangelands, and they wreak ecological havoc. There are management tools that can decrease invasibility like mechanical controls, cultural controls, biological controls, and chemical controls. Typically, a single control method is not enough to reduce invasive species infiltrating rangelands, and an integrated approach is required. The prevention of weed establishment is less expensive than ecological restoration as the eradication of invasive species is both costly and labor-intensive.

Humphrey, L. D and E.W. Schupp. 2004. Competition as a barrier to establishment of a native perennial grass (*Elymus elymoides*) in alien annual grass (*Bromus tectorum*) communities. *Journal of Arid Environments* 58(4):405–422.

Sought to understand the factors responsible for the stability of cheatgrass and for the establishment and stability of perennial-plant communities. Cheatgrass (BRTE) neighbors reduced biomass of Squirreltail (ELEL) at the end of the first growing season, but ELEL did not (at Dugway). At Tintic, both BRTE and ELEL neighbors reduced biomass of ELEL, and first-year biomass of BRTE was reduced by ELEL and BRTE neighbors. ELEL survival was reduced by BRTE densities at Tintic. Growth characteristics in ELEL were also reduced by BRTE densities, but more in the first year than in the second year. BRTE influences plant performance and survival of ELEL through competition in the first year of growth, but those influences are substantially lower in the second year. This indicates that mature ELEL plants may have reduced susceptibility to BRTE competition because they have superior ability to access deeper soil moisture. The most obvious implication is that management actions that reduce competitive ability or survival of cheatgrass during the first year of native plant seedling growth will increase native plant performance and survival. Also, using mature ELEL plants in restoration treatments may increase site resistance to BRTE.

Jones, L. C., N. Norton and T.S. Prather. 2018. Indicators of *ventenata* (*Ventenata dubia*) invasion in sagebrush steppe rangelands. *Invasive Plant Science and Management* 11(1):1–9.

Investigated *V. dubia* expansion into sagebrush steppe. *Ventenata* was present across a wide elevational range and plant community types located in areas of higher precipitation. The invasive favored rocky, shallow, clayey soils with low potassium and phosphorus levels. Results suggested that Medusahead cover increased as *ventenata* cover increased, but cheatgrass decreased. Native plant species richness was lower in plots with high *ventenata* cover. Increased *ventenata* presence was also associated with native annual forbs that inhabit disturbed, moist habitats. *V. dubia* is considered to be in the early stages of invasion in sagebrush steppe. Areas that did have high *ventenata* cover also had decreased native plant species richness and diversity. *Ventenata* was observed primarily in ephemerally wet areas or with species that indicated ephemeral moisture. Source-sink dynamics may explain why *Ventenata* has moved into drier, sagebrush steppe ecosystems compared to the grass's historical preference of moist environments. Managers should search for moist microhabitats and species which persist in those environments as well as locations

associated with medusahead to limit invasion as well as focus restoration efforts on moist habitats as they may act as source populations for ventenata.

Kulmatiski, A., K. Beard and J. Stark. 2004. Finding endemic soil-based controls for weed growth. *Weed Technology* 18:1353–1358.

Sought to determine if soils conditioned by a bunchgrass steppe community (dominated by bluebunch wheatgrass) would affect the growth of native and/or invasive species versus those same plants being grown in soil conditioned by weedy species. Cover of knapweed (*Centaurea diffusa*) was reduced from 15 to 8 percent when grown in bunchgrass conditioned soils versus weed conditioned soils. Bunchgrass steppe plant cover was also reduced in bunchgrass conditioned soils versus weed dominated soils, but not to the same degree as the reduction in knapweed. Intact bunchgrass steppe conditioned soils can be considered an aspect of resistance to invasion of at least some species. Disturbances that alter edaphic conditions are then likely to assist in establishment of some invasive species, and restoration of native, late seral soil conditions may be necessary prior to effective aboveground restoration.

Lovtang, S. and Gregg Riegel. 2012. Predicting the occurrence of downy brome (*bromus tectorum*) in Central Oregon. *Invasive Plant Science and Management* 5(1):83–91.

Predicted likely areas of cheatgrass presence in central Oregon over a spatial extent at which managers work, with consideration of climate change. The dominant predictor variables of cheatgrass presence were distance to the nearest road, total trees per acre, total juniper trees per acre, average minimum May temperature, and average March precipitation. Total cheatgrass cover varied by site. The model predicted the absence of cheatgrass 94% of the time in minimally disturbed sites. Cheatgrass was predicted in drier and warmer areas. Despite competition for nitrogen and soil moisture, western juniper occurrence is associated with cheatgrass presence. Juniper removal is positively associated with increased total grass cover, with native grass cover increasing over time. Fire was not found to be a dominant predictor variable of cheatgrass but rather the removal of trees from thinning, burning, or mowing was. Ecosystems that are relatively unaltered by cheatgrass may experience invasion as climate change pursues.

McGlone, C., M. Sieg, C. Kolb and H. Nietupsky. 2012. Established native perennial grasses out-compete an invasive annual grass regardless of soil water and nutrient availability. *Plant Ecology* 213(3):445–457.

Studied the influence of multiple variables on the reproduction and growth of cheatgrass and two native bunchgrasses in a greenhouse control environment. Cheatgrass production was negatively influenced by established native perennial bunchgrasses bottlebrush squirreltail and western wheatgrass. Squirreltail reduced above-ground biomass of cheatgrass by 86%. These findings support the hypothesis that cheatgrass is strongly influenced by interspecific competition. Both seed weight and germination were lower in cheatgrass monocultures as opposed to when grown in established perennial grass plots. Individual native bunchgrass production increased as cheatgrass increased, indicating that intraspecific competition was the most significant regulator of biomass production in perennial grasses, further demonstrating that native perennial grasses can be strong competitors to invasive annual grasses. Competitive dominance of perennial bunchgrasses over cheatgrass has been maintained in experiments applying both low and high availabilities of soil water, nitrogen, and

phosphorus. Revegetating with adult native perennial bunchgrasses can compete against cheatgrass in a variety of environmental conditions influenced by both abiotic and biotic factors.

Meiman, P.J., E.F. Redente, and M.W. Paschke. 2006. The role of the native soil community in the invasion ecology of spotted (*Centaurea maculosa* auct. non Lam.) and diffuse (*Centaurea diffusa* Lam.) knapweed. *Applied Soil Ecology* 32:77–88.

Compared seedling emergence and production of two native plant species (*Pseudoroegneria spicata* and *Achilles millefolium*) and two exotic knapweed species (*Centaurea maculosa*, and *C. diffusa*) when grown in soil conditioned by a native sagebrush steppe plant community, and soil conditioned by knapweed. *Pseudoroegneria spicata* and *C. diffusa* grew better in autoclaved than biologically active soil conditioned by native plants, while *C. maculosa* did not. Soils conditioned by both knapweeds did not negatively affect growth of either native plant. *Centaurea maculosa* conditioned soil was beneficial for the growth of *C. maculosa* plants, while *C. diffusa* did not benefit from growing in soil conditioned by plants of the same species. Two related invasive knapweed species reacted differently to native plant conditioned soils, revealing differential "strategies" for invasion. *Centaurea maculosa* appears to rely more on the presence of soil biota, while *C. diffusa* appears to be more negatively affected by native soil pathogens. Soil microbial communities associated with bunchgrass conditioned soils may be biological aspects of resistance against some species. Other species may rely on soil biota present in native soils, and further condition those soil biota communities in a way which is even more beneficial to exotic plant growth. Soil microbial communities must be viewed in the context of the specific invasion.

Miller, R. F. 2000. Impacts of western juniper on plant community composition and structure. *Journal of Range Management* 53(6):574–585.

Assessed the significance of western juniper dominance on plant community structure and composition in a variety of principal plant associations. No significant relationship was found between juniper canopy cover and low sagebrush. Sagebrush cover decreased as juniper cover increased; however, this was variable across plant community types where big mountain sagebrush was dominant. Juniper strongly impacted aspen overstory canopy cover and density. Understory vegetation response to juniper varied by plant association and was most significant in mountain big sagebrush/Thurber's needlegrass associations and one aspen microsite with 1,000 juniper trees per ha. Plant species diversity indices varied by site and plant association, but in the sagebrush/Thurber's needlegrass association, species diversity indices were reduced in closed stands when compared to woodlands in early developmental stages. Many shrub and tree species (aspen) decline with increasing juniper dominance; however, understory cover of herbaceous vegetation stayed relatively intact for many of the plant associations surveyed, except in arid sites big sagebrush sites. Site characteristics, including the stage of juniper woodland development, should be considered when applying management techniques, especially in arid landscapes dominated by big sagebrush.

Nicolli, M., T.J. Rodhouse, D. Stucki and M. Shinderman. 2020. Rapid invasion by the annual grass *Ventenata dubia* into protected-area low-elevation sagebrush steppe. *Western North American Naturalist*. Accepted – In press.

Reported the discovery of recent infestation and rapid spread of ventenata grass (*Ventenata dubia*) in John Day Fossil Beds National Monument in central Oregon. *Ventenata* was incidentally recorded at

JODA in 2014 during long-term vegetation monitoring surveys. The grass was not originally considered a principal species for monitoring, although the potential for ventenata invasion was noted in 2012 and added to watch-lists in 2014. Ventenata was first recorded in pre-established monitoring plots in 2016. Estimates show a 650% increase in detection over three years of monitoring and across a wide range of environmental conditions. Ventenata is rapidly invading a xeric low elevation steppe ecosystem previously thought to be low-risk for invasion by this species. The invasive annual grass may radically shift vegetation composition at JODA and other low-resistance/resilience ecosystems. This study demonstrates the value of systematic and regular long-term monitoring studies for early detection of problem plant species.

Perkins, L.B., and R.S. Nowak. 2013. Native and non-native grasses generate common types of plant-soil feedbacks by altering soil nutrients and microbial communities. *Oikos* 122(2):199–208.

Examined plant-soil feedbacks in terms of mechanisms and type of feedbacks in 7 grass species (both native and exotic) common to sagebrush steppe. Negative conspecific (same species) feedbacks were common, while both positive and negative heterospecific (different species) feedbacks were rare. Medusahead negatively affected the growth of heterospecifics, but only in clay dominant soils. Bluebunch wheatgrass positively affected growth of heterospecifics, again, in clay soils. Cheatgrass soil conditioning produced neutral effects on subsequent plant growth. Native species tended to condition soils in ways that encourage maintenance of species diversity, while invasive species tended to condition soils in ways that encourage establishment of monocultures. Mechanisms between species differed, and attention should be paid to both conditioning of soil nutrient availability as well as microbial communities. Alterations in both soil microbes and nutrient concentrations by some invasive species may reduce the efficacy of aboveground restoration of native species, necessitating soil amendment in some cases.

Prevéy, J., S. Germino, M. Huntly and J. Inouye. 2010. Exotic plants increase and native plants decrease with loss of foundation species in sagebrush steppe. *Plant Ecology* 207(1): 39–51.

Evaluated the effects of sagebrush removal, with and without the extra soil water made available by exclusion of sagebrush, on both exotic and native plants in sagebrush steppe ecosystems located in southern Idaho. Soil surface temperature did not vary greatly between sheltered and un-sheltered plots during winter and early spring. Shallow soil water was lower in control plots initially but did not differ significantly across treatments in the summer. The only notable difference occurred in the spring as deep-soil water was 2% greater in shrub-removal and control treatments. Plant community composition was similar before treatment, and changed in the shrub removal and rainout-shelter plots after treatment. However, plots with combined shrub removal and rainout shelter did not differ. Cheatgrass cover was 30% greater in shrub removal plots than the control, similar to rainout-shelter plots. Exotic forbs also increased in the shrub removal and rainout-shelter plots. Sagebrush removal increased soil water which in-turn increased resource availability for exotic annual grass and forb invasion. This study highlights the concept removal of sagebrush from shrub-steppe ecosystems can alter plant community resistance to invasion by annual grasses.

Radosevich, S.R., M.M. Stubbs and C.M. Ghera. 2003. Plant invasions-process and patterns. *Weed Science* 51:254–259.

Discusses methods how the science of invasion ecology can be used to study and predict invasions. Elements of the invasion process are broken into introduction, colonization and naturalization. The authors make the point that although generalizations about the invasion process can be drawn, invasion characteristics (each phase of the invasion process) differ between locations. In other words, some ecosystems are more vulnerable to invasion than others based on site characteristics and disturbance regime. The discussion also reiterates findings from previous work that soils, climate (including topographically-mediated climate) and land use are the factors most often associated with invasion success. The authors conclude by emphasizing the importance of models to aid in the process of predicting, preventing and managing species invasions.

Reisner, M. D., J.B. Grace, D.A. Pyke and P.S. Doescher. 2013. Conditions favouring *Bromus tectorum* dominance of endangered sagebrush steppe ecosystems. *Journal of Applied Ecology* 50(4):1039–1049.

Examined abiotic and biotic conditions that limit the magnitude of *B. tectorum* dominance and how shifts in community structure, measured by size and connectivity of gaps between native plants, serve as an indicator of susceptibility to *B. tectorum* dominance and vulnerability to regime shift with fire. Modeled results implied that bunchgrass community structure (abundance and composition) along with biological soil crust played an important role in controlling *B. tectorum* dominance. Bunchgrass abundance limited the invasion of *B. tectorum* by limiting the size and connectivity of gaps between vegetation. Cattle grazing reduces resistance by decreasing bunchgrass abundance while trampling further reduces resistance by reducing biological soil crust. These disturbances also shift bunchgrass composition and increase connecting gaps between perennial plants, further reducing resistance and resilience. It is likely that bunchgrass abundance reduces the magnitude of invasion by reducing water and nutrient availability.

Seipel, T., L. J. Rew, K. T. Taylor, B. D. Maxwell, and E. A. Lehnhoff. 2018. Disturbance type influences plant community resilience and resistance to *Bromus tectorum* invasion in the sagebrush steppe. *Applied Vegetation Science* 21: 385– 394.

The authors evaluated how different disturbances (fire and soil disturbance in fire breaks) influence plant community structure of sagebrush steppe (northern) when cheatgrass is present. Bunchgrass cover and species richness was similar between burned and unburned sites three years post-burn, but sites where soil disturbance occurred exhibited lower bunchgrass cover and species richness. Cheatgrass cover was similar in burned and unburned plots but was substantially higher in sites where soil disturbance occurred. Overall, the data indicated that fire had a less severe impact on site resilience and resistance compared to soil disturbance at this location. The authors pointed out that study locations are generally cooler and moister than sagebrush steppe sites to the south and west, where resilience to fire and other disturbances tends to be lower. This study underscores the importance of soil system integrity on site resilience to disturbance and resistance to species invasions. In cooler and wetter sagebrush steppe sites, fire may be an acceptable management strategy but only under conditions where soil disturbance is minimized or prohibited.

Wallace, J., P. Pavek and T. Prather. 2015. Ecological characteristics of *Ventenata dubia* in the intermountain Pacific Northwest. *Invasive Plant Science and Management* 8(1):57–71.

Evaluated life history traits for ventenata grass at study sites throughout the intermountain Pacific Northwest. *Ventenata* germination was highest after 70 days of incubation when seeds were stored for 90 days. Cold stratification at 5°C negatively influenced aggregate germination. Optimum germination temperature was between 23.3–29.2°C (76–99% germination) with mean germination between 7–13 days. Increased litter positively influenced seedling emergence and survival in comparison to bare surfaces. Mean seedling emergence (50%) occurred between 33 and 94 growing degree days after soil moisture was determined to be above the permanent wilting point. *Ventenata dubia* persistence could be controlled with an application of early post-emergence herbicide in the late fall (dependent upon weather conditions). Litter management techniques such as prescribed burning should also be applied to reduce the benefits litter has on seedling recruitment.

Sagebrush Steppe System Response to Fire

Bates, J.D., R.N. Sharp and K.W. Davies. 2014. Sagebrush steppe recovery after fire varies by development phase of *Juniperus occidentalis* woodland. *International Journal of Wildland Fire* 23(1):117–130.

Compared recovery of mountain big sagebrush (*Artemisia tridentata* ssp. *vaseyana*) steppe following prescribed fire in phase 2 and phase 3 common juniper woodlands in Oregon. Prescribed burning eliminated juniper trees, shrubs and litter in phase 2 and phase 3 woodland plots. Herbaceous cover in the first two years following fire was greater in phase 2 sites. Fires completely eliminated biocrusts with no recovery after nine years of field sampling. Perennial grass levels rebounded in the third year and exceeded pre-burn cover in the sixth year in both sites. Mountain big sagebrush was recorded to be 75–85% below pre-fire levels after the prescribed burn and snowbrush established in both sites but was more dominant in phase 3. Phase 1 and phase 2 juniper woodlands should be considered priority treatment areas as they are the most likely to recover after burning.

Blank, R.R., J.C. Chambers, B.A. Roundy and A. Whittaker. 2007. Nutrient availability in rangeland soils: influence of prescribed burning, herbaceous vegetation removal, overseeding with *Bromus Tectorum*, season, and elevation. *Rangeland Ecology & Management* 60(6):644–655.

Examined the response of soil nutrient bioavailability to herbaceous vegetation removal, prescribed fire, and seeding using anion and cation resin capsules at two sagebrush steppe locations (Nevada and Utah). Herbaceous vegetation removal significantly affected nitrate in both study areas. Nitrophilic species (i.e., cheatgrass) benefit from vegetation removal as the process increases available nitrogen. Soil water availability, temperature, and mineralization rates also increased with herbaceous vegetation removal. Effects of prescribed burning were variable between sites, with increased availability of nitrate in the Nevada sites and increased ortho-P and potassium in both Utah and Nevada locations. Vegetation removal and burning may increase available nitrogen, which increases risk of annual grass invasion.

Boyd, C.S. and K.W. Davies. 2010. Shrub microsite influences post-fire perennial grass establishment. *Rangeland Ecology & Management* 63(2): 248–252

Determined if there was a difference between shrub interspaces and subcanopy microsites on the post-fire success of seeded perennial grasses. Native perennial grasses had reduced density compared to introduced perennial grasses. Post-fire establishment and growth of perennial grasses were favorable in subcanopy microsites opposed to interspaces, indicating that the presence of shrubs influences the progress of revegetation and, subsequently, the location of perennial grasses across a landscape. These findings are consistent with other research that indicates shrub microsites influence soil resource distribution. Limited establishment of native perennial grasses is thought to have been affected by interspecific competition with non-native species in the seed mix in this study. Managers should consider the influence of shrub microsites on seeded perennial grass establishment and growth after wildland fire.

Brooks, M. L. and J.C. Chambers. 2011. Resistance to invasion and resilience to fire in desert shrublands of North America. *Rangeland Ecology & Management* 64(5):431–438.

Examined the concepts of ecological resistance and resilience relating to alien plant invasions and fire in the deserts of North America with a specific focus on resistance to invasions and resilience to fire. The authors also provided management recommendations based on resistance of areas to invasion and resilience to fire. In both hot and cold desert shrublands, resilience to fire tends to increase along elevation and productivity gradients. Species in higher elevations have increased productivity due to more mesic conditions (greater precipitation) which also increases fire frequency. Native shrub-steppe species in higher elevations are more tolerant of fire, and thus more resilient. Native perennial resilience to fire in higher elevation ecosystems is also more resistant to annual grass invasion due to greater probability of recovery and likelihood of native species dominance. Three main areas of focus for managers are to conduct resource assessments and periodic monitoring, develop an understanding of ecological resistance and resilience, and prioritize management activities based on resistance and resilience.

Clark, P.E., C.J. Williams and F.B. Pierson. 2018. Factors affecting efficacy of prescribed fire for western juniper control. *Rangeland Ecology and Management* 71:345–355.

Evaluated factors contributing to effective use of prescribed fire as a tool for western juniper removal. Tree age was a better predictor of mortality than tree height, but in general, younger, smaller trees were more susceptible to fire. Fires burning upslope were more effective than fires burning downslope. Increased juniper mortality was associated with increases in bare ground, however, this also coincided with increased slope, and increased shrub cover. Vegetation type was one of the greatest predictors of tree mortality, as bunchgrass dominated sites experienced less tree mortality than sites dominated by mountain sagebrush. Antelope bitterbrush cover was associated with the greatest juniper mortality of any vegetation type. A lack of ladder fuels, which can be caused by juniper encroachment, may limit the efficacy of prescribed fires. Prescribed fires may then only be an effective tool for juniper removal in young stands at early stages of encroachment.

Condon, L., P.J. Weisberg and J.C. Chambers. 2011. Abiotic and biotic influences on invasion and recovery after fire. *International Journal of Wildland Fire* 20(4):597–604.

Conducted a landscape scale-observational study that examined the distribution and cover of cheatgrass and sagebrush six years after a significant wildfire. Tree canopy cover pre-fire negatively influenced post-fire sagebrush cover. Abiotic factors from at the site and landscape level influenced tree canopy cover pre-fire which subsequently influenced the rate of recovery for sagebrush. Factors which influenced post-fire cheatgrass recovery were direct solar radiation and reduced herbaceous cover. Cheatgrass was most persistent on warm xeric sites and lowest on high-elevation cool sites. Abundance of perennial herbaceous vegetation was a factor in restricted cheatgrass abundance. Efforts that focus on restoring or maintaining native perennial grass and forb populations, especially during the first 2–3 years post-fire, can influence overall system resilience and resistance to exotic species invasion. Successful establishment of desired plant species is dependent on precipitation, so seeding/planting should focus on optimization with seasonal moisture patterns.

Davies, G.M., J. D. Bakker, E. Dettweiler-Robinson, P. W. Dunwiddie, S. A. Hall, J. Downs and J. Evans. 2012. Trajectories of change in sagebrush steppe vegetation communities in relation to multiple wildfires. *Ecological Applications* 22(5):1562–1577.

Examined the extent and direction of changes in vegetation communities by utilizing 'successional trajectories' to determine differences in community resilience to repeat disturbance. Related trajectories to changes in populations of key species and functional groups and developed state-and-transition models that illustrate noted changes. Following in initial fire vegetation community heterogeneity increased in nearby transects but was reduced after the second fire. Modeling results identified four common groups (low, mid-east, mid-west, and high) based on their correspondence to elevation/soil-type gradient. Community groups were significantly different in terms of vegetation community composition. High-elevation transects were noted to have the least response to fire as they did not deviate significantly from their starting state. Modeling determined that fire with subsequent restoration treatment generated two discrete plant community groups with lower elevations dominated by cheatgrass. Disturbance, especially when repeated, initiates decline in shrub abundance. Invasive annual grass emergence can be temporarily mitigated through the use of herbicide following fire, but repeated fire can reduce plant diversity, abundance, seed banks and increase bare ground that creates empty niche space. Species traits influence the trajectory of community change in shrub steppe ecosystems. State-and-transition models that characterize vegetation by shrub/grass or native/invasive dominance can assist with greater visualization of possible community changes in shrub canopy and ground layer structure.

Davies, K. W., J.D. Bates, C.S. Boyd and T.J. Svejcar. 2016. Prefire grazing by cattle increases postfire resistance to exotic annual grass (*Bromus tectorum*) invasion and dominance for decades. *Ecology and Evolution* 6(10): 3356–3366.

Evaluated vegetation community dynamics in shrub-grasslands post-fire on a long-term temporal scale, which were either moderately grazed by cattle or not grazed for +50 years prior to burning. Moderate grazing increased perennial grass community resistance to cheatgrass invasion post-fire. Areas grazed pre-fire had greater perennial bunchgrass densities than ungrazed areas. Moderate grazing reduced cheatgrass densities postfire but did not reduce densities of perennial and annual forbs and native bunchgrasses. Species diversity was also greater in grazed treatments (2+ spp. per

plot). The impacts of disturbances such as grazing and fire are not independent, and interactions must be quantified for appropriate decision making. Disturbances such as grazing and fire should not be seen as binomial but rather understood by the relative intensities of the events.

Davies, K. W., T.J. Svejcar and J.D. Bates. 2009. Interaction of historical and nonhistorical disturbances maintains native plant communities. *Ecological Applications* 19(6):1536–1545.

Investigated the response of sagebrush steppe plant communities to historical disturbance patterns in consideration of current (modern) conditions, and to evaluate the influence of previous disturbance on future disturbances. Both grazing and burning influenced the cover of all plant functional groups. Perennial bunchgrass cover density increased with both disturbance types; however, perennial for biomass production decreased in ungrazed burned treatment sites. Cheatgrass invasion was only notable in ungrazed-burned plots. Importantly, treatments that mimicked historic disruption under modern conditions exacerbated native plant community decline. Light to moderate grazing used as a prescriptive disturbance to reduce litter accumulation can prevent cheatgrass invasion. Whether or not a disturbance mediates or compounds the effects of plant community change depends on the disturbance type, severity, and ecological conditions of the affected area.

Ellsworth, L. and J.B. Kauffman. 2010. Native bunchgrass response to prescribed fire in ungrazed mountain big sagebrush ecosystems. *Fire Ecology* 6(3):86–96.

Examined the effects of prescribed fire in ungrazed mountain big sagebrush ecosystems for three different ecological conditions in Lava Beds National Monument (LBE). **Gillem's Camp:** no significant change in cover of native bunchgrasses occurred following prescribed fires or in the controls; however, spring and fall fires had different effects on Thurber's needlegrass. **Fleener Chimneys:** fire treatments negatively influenced bluebunch wheatgrass but had no significant impact on the density of other native grass species first-year post-fire. Fire-enhanced flowering of two bunchgrasses species one-year post-fall burn (same at Merrill Caves). **Merrill Caves:** fall fires did not significantly affect the density of any of the study species. Native bunchgrasses are seemingly well adapted to fire in the sagebrush ecosystems at LBE. Sites with recorded declines in native bunchgrass density or cover also exhibited increased post-fire flowering, which leads to increased resilience and resistance. Ungrazed systems in varying degrees of degradation that are managed for the restoration of native ecosystem diversity, resilience, and resistance can influence and potentially benefit native grass species survival in post-fire condition

Ellsworth, Lisa M. and J.B. Kauffman. 2013. Seedbank responses to spring and fall prescribed fire in mountain big sagebrush ecosystems of differing ecological condition at Lava Beds National Monument, California. *Journal of Arid Environments* 96:1–8.

Examined the impacts of prescribed fire on mountain big sagebrush ecosystems in varying ecological conditions. Specifically, are seedbanks of native and exotic species altered after fire, and can season of burn create a differential effect on seedbanks? Only a few differences in seed bank response were recorded between fall and spring burns. All plots experienced an increase in native dicots. Native bunchgrasses were not a large component of the germinable seedbank, but germination was highest at Fleener Chimneys. The effects of shrub germination from fire were only recorded at Fleener chimneys. Cheatgrass was the most frequent germinant during the study, especially at Gillem's Camp, which also had the highest exotic dicot germination post-spring burns. Pre-fire site conditions

influence the post-fire plant community, with sites with intact native plant communities being more resilient to future invasion. High severity spring fires had more of an impact than low-severity fall fires, but native plant seedbanks were not greatly impacted from prescribed burning in either season in the mountain big sagebrush ecosystem. Fire can be a useful tool for managers in sagebrush steppe ecosystems, but ecological site factors must be taken into consideration before it is applied. Native shrub dominance and seedbank viability are critical components of a successful prescribed fire management application.

Ellsworth, L. M., D.W. Wroblewski, J.B. Kauffman and S.A. Reis. 2016. Ecosystem resilience is evident 17 years after fire in Wyoming big sagebrush ecosystems. Ecosphere 7(12).

Examined and compared community composition in both burned and unburned Wyoming big sagebrush steppe ecosystems 17 years post-fire, while focusing primarily on the dynamics between native and invasive species and prior (historic) fire regime and control. Prescribed fire generated a mosaic sagebrush community containing mid-late successional patch structure. Differences in cheatgrass abundance were not determined between sample years or treatments. One plot caused the suggestion of increased cheatgrass cover after prescription due to a higher percentage of cover both before and after fire. Forb cover was significantly increased after the fire, but 17-years later, cover showed no differences between burned and control plots. Bunchgrass cover was greater in burned plots 17 years post-fire than control. Medium and tall shrub cover was eliminated in treated sites, but 17-year post-fire colonization of shrubs was visible. Pre-fire site factors likely influence post-fire ecosystem response. Short term patterns of succession and ecosystem response of sagebrush steppe post-fire may not capture long-term community response. Widespread fire suppression may not be ideal in areas based on site characteristics.

Evers, L., B. Miller, and P. Doescher. 2013. Potential effects of disturbance types and environmental variability on sagebrush-steppe community dynamics. Fire Ecology 9(2): 57–79.

Determined how varying disturbance types influence sagebrush steppe ecosystems. The authors focused specifically on whether disturbances, other than fire, regulate sagebrush steppe seral stages, which natural disturbance types have a disproportionate influence on sagebrush steppe ecosystem dynamics, and examined whether the alternate disturbance types influence the frequency of fire. Modeled results determined that the varying disturbance types (singular and in aggregate), other than fire, generated seral stages other than the early seral stage. Additionally, fire rotation, a measure of fire frequency, was altered by other disturbances in sagebrush communities designated as drier. However, fire was determined to be the only notable influence in wetter sagebrush communities. Additionally, the other disturbances identified (pronghorn herbivory, drought, snow mold, voles, insects, and freeze-kill) had more of an impact on drier sites when compared to more productive areas. Certain disturbances, such as pronghorn herbivory and insect outbreaks, were influential over fire rotation and community structure in drier regions, indicating their potential importance in drier portions of the sagebrush steppe.

Hoover, A. N. and M.J. Germino. 2012. A common-garden study of resource-island effects on a native and an exotic annual grass after fire. *Rangeland Ecology & Management* 65(2):160–170.

Determine how bluebunch wheatgrass and cheatgrass abundance differed between coppices and interspaces and identified that soil properties, not other features of microsites, influence the difference in plant growth between burned coppices and interspaces. Coppices supported a greater abundance of bluebunch wheatgrass in both burned and unburned sites than in interspaces. Differences in soil properties (e.g., soil hardness and moisture) were not affected by plant growth. Dry biomass was greater on coppice soils than interspace soils, which suggests that microsite differences influence growth but not the establishment of vegetation. Coppices supported selected grass growth, which is consistent with other studies. Native herbaceous vegetation along with soil water; nutrient availability; seed bank abundance, availability, and emergence; and native perennial grasses can influence resilience of native vegetation communities. Coppices have the potential to support native seed production and dispersal into interspaces, which may reduce cheatgrass abundance. Heterogeneity created by coppice-interspace interactions is important in influencing site resistance and resilience. Management practices (e.g., mowing, burning, and seeding) can alter these systems. Maintaining native vegetation is critical as sites with coppices without native perennials can be quickly overrun by cheatgrass due to nutrient availability.

Innes, R.J. 2019. Fire regimes of Wyoming big sagebrush and basin big sagebrush communities. In: *Fire Effects Information System*, [Online]. U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station, Missoula Fire Sciences Laboratory, MT.

Summarized information pertaining to fire frequency and size in pre-settlement big sagebrush communities, and contrasted that with post-settlement fuel and fire regime changes. Estimates of pre-settlement fire frequency vary greatly, from less than 30 years to over 400, and even over 1,000 years for some locations. While direct evidence of pre-settlement fire regimes is rare, fires in sagebrush steppe were both lightning and human-ignited, and were commonly stand replacing. Fire frequency and post-fire vegetation recovery was largely dependent on site productivity, with longer fire return intervals and post-fire recovery times at warmer, dryer sites. Land use change, woodland expansion, annual grass invasion, shifts in herbivory, and changing climatic conditions all resulted in altered fire regimes. Pre-settlement fire regimes likely existed along a productivity gradient, with more frequent and larger fires occurring in more productive sagebrush communities and after moist years. Less productive sites have experienced the greatest shift in fire regime due to their susceptibility to annual grass invasion, and the subsequent accumulation of continuous fine-fuels. The Columbia Basin has the highest fire recurrence rate over the past 100 years compared with any other sagebrush dominated region, likely due in large part to high risk of conversion to annual grasslands. Fires ignited in and carried by annual grass fuels often spread to adjacent plant communities. Intact, high-quality, sagebrush steppe adjacent to annual grass dominated sites should be prioritized for protection.

Mata-González, R., C.M. Reed-Dustin and T.J. Rodhouse. 2018. Contrasting effects of long-term fire on sagebrush steppe shrubs mediated by topography and plant community. *Rangeland Ecology & Management* 71(3):336–344.

Characterized long-term (15-yr) response of sagebrush and broom snakeweed to variations in topography, fire, and community type. Sagebrush declined post-fire and did not show signs of

recovery 15-years post-fire, with least effects recorded in woodlands and on southern exposures. Sagebrush in unburned plots showed decline after year five and became most notable after year(s) 10 and 15. Fire caused decline in all plots, but more so in woodland plots. Broom snakeweed increased in cover year-five post-fire and continued in brush and woodland plots through the end of the study beyond pre-burn levels. Snakeweed remained stable in unburned plots during the study. These data indicate that the two species respond differently to fire and post-fire environment and that topography and community type influence vegetation recovery rates. Considering species recovery time, site characteristics, and conditions that influence recovery when applying prescribed fire in Wyoming big sagebrush vegetation communities is important.

Miller, R.F., and J.A. Rose. 1999. Fire history and western juniper encroachment in sagebrush steppe. *Journal of Range Management* 52:550–559.

Tested the hypothesis that juniper expansion in the late 1800s and early 1900s coincided with altered grazing regimes from livestock introduction, reduced fire frequency, and optimal climatic conditions for plant growth. Juniper expansion in the study area began between 1875 and 1885, with large, pre-settlement trees accounting for less than 1% of the total population. Fire occurred on average every 7.7 years in the area, and were spatially extensive. Five fires occurred between 1871 and 1897, and they were all smaller fires. Only 2 fire events occurred in the low sagebrush community. Large fires were often preceded by years of optimal vegetation growth, as indicated by tree rings. Little evidence exists to include increased atmospheric CO₂ as a cause of expansion during the periods studied. Juniper expansion was at its peak between 1885 and 1925 during a period of wetter than average conditions, few fires, and intensive livestock grazing. Mean fire return intervals of less than 15 years were able to inhibit juniper encroachment. There is a risk of juniper expansion in areas where livestock grazing and fire suppression limit competition and disturbance to juniper. Juniper treatments should likely attempt to mimic the effects of natural disturbance regimes using local fire return intervals as guides.

Miller, R.F. J.C. Chambers, D.A. Pyke, F.B. Pierson and C.J. Williams. 2013. A review of fire effects on vegetation and soils in the Great Basin Region: response and ecological site characteristics. Fort Collins, CO: United States Department of Agriculture, Forest Service, Rocky Mountain Research Station.

Synthesized the current state of knowledge on fire effects to vegetation and soils in seem-arid ecosystems within the Great Basin region by summarizing literature related to 1. the effects of environmental gradients, ecological site, and vegetation characteristics on resilience to disturbance and resistance to invasive species; and 2. the effects of fire on individual plant species and communities, biological soil crusts, seed banks, soil nutrients, and hydrology; and 3. the role of fire severity, fire versus fire surrogate treatments, and post-fire grazing in determining ecosystem response. The document summarizes multiple studies conducted in the Great Basin concerning wild and prescribed fire and its interactions with biotic and abiotic characteristics across varying sagebrush ecosystems and its influence on resilience and resistance. The concept of site characteristics is often mentioned in terms of whether or not management applications will reduce or enhance community resiliency. The authors recommend using each section as a tool for specific information to inform management decisions based on the varying effects of fire.

Pyke, D.A., S.E. Schaff, A.I. Lindgren, E.W. Schupp, P.S. Doescher, J.C. Chambers, J.S. Burnham and M.M. Huso. 2014. Region-wide ecological responses of arid Wyoming big sagebrush communities to fuel treatments. *Rangeland Ecology and Management* 67(5): 455–467.

Examined the effects of spatial distances before treatment of perennial plants on plant soil surface response after fuel treatment is applied and to evaluate the effects of combined disturbances (including no treatment) on notable plant species or life forms in the study area.

Imazapic treatments had no consistent results, but it did tend to cause lower Sandberg bluegrass cover than any other fuel treatment. Gap measures were not significant covariates before or after treatment. Fire increased perennial plant gaps, more so than any other treatment, and also induced increased cheatgrass cover. Mowing can also increase cheatgrass dominance in similar ways to fire if not applied with consideration. Common pesticides can be used to reduce annual grass cover, but they reduced perennial plant cover as well. Long-term impacts of imazapic to sagebrush steppe communities are unknown.

Rau, B. M., J.C. Chambers, R.R. Blank and D.W. Johnson. 2008. Prescribed fire, soil, and plants: burn effects and interactions in the central Great Basin. *Rangeland Ecology & Management* 61(2):169–181.

Examined soil chemistry, above-ground biomass, and nutrient concentrations of understory grasses and forbs post-spring prescribed burning in a central Great Basin pinyon-juniper woodland. All nutrients besides near-soil-surface potassium, sodium, and zinc ions were similar on both sites before the burn was applied. Burning increased ammonium, nitrate, total inorganic nitrogen, and calcium ions. Many of the nutrients differed by microsite (not including nitrate and ammonium) and were generally greater under shrubs and trees than in interspaces. Perennial grasses and forbs reacted differently after prescribed fire, but Idaho fescue was the only species to show significant microsite effects and microsite x burning interactions. Fire impacted all plant species documented during the study, with an increased effect over time and there were few recorded differences between plant response regarding nutrient uptake, except for in Idaho fescue and silvery lupine. Plants response to burning was variable which is presumed to be attributed to burn tolerance, root characteristics, mycorrhizal associations, and ecophysiological characteristics. Spring burning may present better opportunities to reduce pinyon-juniper persistence and expansion and increase plant biomass for native perennial species.

Rau, B. M., J.C. Chambers, D.A. Pyke, B.A. Roundy, E.W. Schupp, P. Doescher and T.G. Caldwell. 2014. Soil resources influence vegetation and response to fire and fire-surrogate treatments in sagebrush-steppe ecosystems. *Rangeland Ecology & Management* 67(5):506–521.

Studied the variables within Wyoming big sagebrush steppe ecosystems (e.g., vegetation, soil, and abiotic factors) that influence resilience in response to management treatments and resistance to cheatgrass invasion. First-year post-treatment shrub cover decreased in three of the treatments compared to the control and remained low in the second year in three of the treatments. Shrubs in the mow treatment rebounded after three years. Native herbaceous cover increased post-treatment on tebuthiuron and mow plots. Imazapic treatments, imazapic and fire, and tebuthiuron treatments reduced exotic annual grasses but remained lower two years post-treatment on imazapic and

imazapic + fire plots. Treatment caused significant response of all exchangeable soil resin variables as well as influenced wet degree days. Results indicate that fire (wild and prescribed), chemical, and mechanical treatments alter nutrient and soil water availability in sagebrush steppe communities. Increased gap size between perennial herbaceous vegetation and sagebrush can increase cheatgrass persistence due to increased soil moisture availability and nitrate even if fire has not impacted the vegetation community. Lower phosphorus availability may limit invasion from exotic annual grasses but gap size, through modeling, has been determined to be the greatest indicator of whether or not exotic annual grass invasion can occur in sagebrush steppe communities.

Reed-Dustin, C. M., R. Mata-González and T.J. Rodhouse. 2016. Long-term fire effects on native and invasive grasses in protected area sagebrush steppe. *Rangeland Ecology & Management* 69(4):257–264.

Examined the effects of fire, biotic and abiotic factors on native and invasive grass species. Topography influenced cheatgrass cover in each community type, regardless of whether or not a fire occurred. Cheatgrass cover was higher in brush plots as opposed to woodland plots, and higher on south-facing aspects in the brush plots surveyed. Pre-burn and burned cover of cheatgrass was greater on south-facing slopes when compared to north-facing slopes. Time since burn also influenced cheatgrass cover; however, it was contingent on plant community type. Increase in cheatgrass cover was significant in burned brush plots and woodland plots. For *P. spicata*, community type was influenced by topography through time post-burn in burned plots. In contrast to cheatgrass, *P. spicata* cover was greater in woodland plots and on north-facing aspects. Topography influenced *P. spicata* regeneration, wherein cover increased between 1 to 2 years post-burn on north-facing slopes versus 2–5 years on south-facing slopes. *P. secunda* cover was higher on southern exposures and brush plots than woodland plots and southern slopes. Additionally, higher resistance to invasive annual grasses was found on north slopes when compared to south-facing slopes. This work supports other research that indicate native and invasive grass species have different responses to fire and post-fire conditions.

Reis, S.A., L.M. Ellsworth, J.B. Kauffman and D.W. Wroblewski. 2019. Long-term effects of fire on vegetation structure and predicted fire behavior in Wyoming big sagebrush ecosystems. *Ecosystems* 22(2): 257–265.

Characterized shifts in structure and fuel composition with time since last fire of relatively in-tact sagebrush vegetation communities identified as mid-successional over a long temporal scale. Quantified patterns of fuel accumulation and their impact on potential fire behavior. After fire total fuel loads were seven times greater in control plots than burned plots. Herbaceous vegetation was five times higher in burns. Shrub cover was ten times greater in unburned plots, and undershrub litter was 3.75 times higher. Burned plot potential fire behavior decreased in burned plots in all environments. Potential fire behavior was lower in burned sites 17-years post-fire than in the unburned control plots. Low invasive grass and relatively good ecological condition contributed to fire response as they reduced potential for high-intensity fire behavior following prescribed burn. Recovery of Wyoming big sagebrush is highly variable and dependent on topo-edaphic factors.

Spasojevic, M. J., C.A. Bahlai, B.A. Bradley, B.J. Butterfield, M. Tuanmu, S. Sistla, R. Wiederholt and K.N. Suding. 2016. Scaling up the diversity–resilience relationship with trait

databases and remote sensing data: the recovery of productivity after wildfire. *Global Change Biology* 22(4):1421–1432.

Investigated the biodiversity-resilience relationship on a landscape vs. small site scale and functional diversity that exists in woodland and forested ecosystems. The model used to evaluate study hypotheses did fit the data but was only able to explain minor variance in productivity response, and the recovery of productivity was only slightly influenced by species richness. In short, species richness was not a good predictor of resilience of woodland/forest response to fire. Slope was the only variable recorded to directly affect post-fire recovery (rapid recovery on steeper slopes). Functional diversity in traits associated with resistance and fire tolerance were better predictors of vegetation productivity recovery rate after wildfire than functional diversity of seed mass or species richness. Resilience and response to disturbance is affected by many factors, particularly at the site scale. Topography is an important driver of site-specific resilience.

Taylor, M. H., K. Rollins, M. Kobayashi, and R.J. Tausch. 2013. *The economics of fuel management: Wildfire, invasive plants, and the dynamics of sagebrush rangelands in the western United States. Journal of Environmental Management* 126:157–173.

Applied a simulation model that evaluates the economic efficiency of fuel treatments in consideration of two sagebrush steppe ecosystems located in the Great Basin of the western United States. Fuel treatment is considered economically efficient in sagebrush steppe ecosystems only when they are in relatively good ecological health based on costs of fire suppression averted; however, the results do not take into consideration how treatment costs, treatment success rates, wildfire-return intervals, and wildfire suppression cost differ over a variable landscape or ecosystem goods and services maintained from fire suppression. In terms of costs vs. benefit, pre-fire treatment should be applied to relatively intact Wyoming big sagebrush and mountain big sagebrush ecosystems as they have a higher probability of success and reduce future costs of wildfire suppression. Transition from healthier states into more degraded states permanently increases costs due to higher wildfire frequencies and suppression of fire. The results support the widely held belief amongst rangeland managers and ecologists that maintaining ecological health and resiliency on healthy rangeland is the most efficient use of land management resources. It is imperative to understand the actual ecological state of the ecosystem receiving treatment as treatment failure due to a crossed threshold can have costly implications.

Weiner, N.I., E.K. Strand, S.C. Bunting and A. Smith. 2016. *Duff distribution influences fire severity and post-fire vegetation recovery in sagebrush steppe. Ecosystems* 19:1196–1209.

Sought to determine how accumulations of ground fuels under western juniper canopies influence post-fire species response in sagebrush steppe ecosystems. In unburned plots, juniper litter and bare ground composed the greatest mean cover values. Vegetation cover was comprised of varying perennial bunchgrass species. Burned area cover was represented primarily by bareground, ceanothus, and cheatgrass respectively. The most frequently occurring species post-burn was cheatgrass (79% of the quadrats). Pre-fire duff depth had a negative impact on post-fire native perennial canopy cover and positive impacts on annual grass and ceanothus cover. Increased litter and duff were associated with duration of smoldering and associated soil heating, thus increasing the risk of seed mortality. Older junipers were associated with greater depth of litter/duff. Late successional woodlands, which typically have high concentrations of ground fuel, may not be

appropriate areas for prescribed burning as a management tool. Immediate post-fire reseeding may be necessary for recovery of desired perennial bunchgrasses and prevention of annual grass invasion.

West, N., and T.P. Yorks. 2002. Vegetation Responses following Wildfire on Grazed and Ungrazed Sagebrush Semi-Desert. *Journal of Range Management* 55(2):171–181.

Analyzed assumptions about adaptability of state-and-transition and classical (Clementsian) models that describe secondary succession in sagebrush semi-desert ecosystems by examining changes in vegetation cover and bare soil after wildfire in grazed and ungrazed areas. Sagebrush was slow to establish in burned plots within semi-desert ecosystems, especially in comparison to re-establishment in sagebrush steppe systems. Perennial grasses were greatly reduced initially following fire but increased steadily in burned/ungrazed plots, until impacted by the second drought during the study period. In burned and grazed plots perennial grass cover increased during the first five years but experienced fluctuations presumably due to precipitation and grazing. Perennial grass cover in unburned and ungrazed plots changed the least of any growth form across the study. Annual grasses were the most significant cover component on all burned macro-plots until a considerable drought reduced live cover to nearly zero from 1989 to 1993. *Bromus tectorum* was expected to become more prolific, yet perennial grasses were able to recover and become the dominant grass species, particularly in ungrazed macro-plots. Cheatgrass and other annuals were nearly absent during drought, suggesting a precipitation threshold for the species. Long-term datasets allow for diagnosis of vegetation response patterns that may not be apparent from short-term studies.

Sagebrush Steppe Restoration Strategies

Boyd, C.S. and M. Obradovich. 2014. Is pile seeding Wyoming big sagebrush (*Artemisia tridentata* subsp. *Wyomingensis*) an effective alternative to broadcast seeding? *Rangeland Ecology & Management* 67(3): 292–297.

Evaluated post-fire pile seeding of Wyoming big sagebrush relative to natural recovery and broadcast seeding as a tool for increasing sagebrush density at the plant community scale. Described the potential for pile seeding to establish small sagebrush islands. Sagebrush density in pile-seeded plots was substantially higher than in natural recovery plots in 2009. Sagebrush density in 2011 in broadcast seeded plots did not differ from pile-seeded plots but was 16-fold greater than in natural recovery plots. Initially, pile seeding assisted the establishment of sagebrush more than broadcast seeding and natural recovery, but multiyear seedling survival was poor in all treatments. Mulching and piling sagebrush seeds and clustering seedlings may be an effective restoration tool to promote initial sagebrush seedling establishment and growth. Techniques like pile seeding may be more useful for the establishment of sagebrush islands; however, precipitation timing and availability has a significant influence on establishment and interannual survival. Although more labor intensive, transplanting juvenile sagebrush offers higher probability of success in arid and harsh environments.

Brabec, M.M., M.J. Germino, D.J. Shinneman, D.S. Pilliod, S.K. McIlroy, R.S. Arkle. 2015. Challenges of establishing big sagebrush (*Artemisia tridentata*) in rangeland restoration: effects of herbicide, mowing, whole-community seeding, and sagebrush seed sources. *Rangeland Ecology and Management*. 68: 432–435.

Evaluated initial establishment of seeded sagebrush and four populations of small outplants (from different source locations) and small sagebrush outplants in an early seral community where mowing,

herbicide, and seeding of other native plants were applied. Shrubs and forbs seeded in 2012 produced few seedlings across all treatments, with drought hypothesized as a primary cause. Sagebrush did not germinate in any of the sample plots during the study, regardless of seed source. Lower initial survival was recorded from outplants collected outside of the ecoregion whereas the local population had 64% greater survival from individual sagebrush plants. Outplanting may be an important strategy for restoring sagebrush cover in systems that experience frequent drought.

Bradley, B. A. and D.S. Wilcove. 2009. *When invasive plants disappear: transformative restoration possibilities in the western United States resulting from climate change. Restoration Ecology* 17(5):715–721.

Identified novel species best suited to establish under projected climate conditions in areas once invaded by exotic vegetation (i.e., cheatgrass) using bioclimatic envelope modeling. Climate change may create zones where cheatgrass is no longer viable, providing opportunities for restoration of sagebrush steppe and sagebrush shrublands with novel species. If restoration is to occur, efforts are more likely to be successful if novel species have been established before possible new invaders arrive. Although bioclimatic envelope modeling can be used to identify areas where cheatgrass may be less viable, there is uncertainty surrounding viability of novel species, whether or not novel species could become invasive and the time scale during which cheatgrass may become less competitive.

Chambers, J.C. D.A. Pyke, J.D. Maestas, M. Pellant, C.S. Boyd, S.B. Campbell, S. Espinosa, D.W. Havlina, K.E. Mayer, A. Wuenschel. 2014. *Using resistance and resilience concepts to reduce impacts of invasive annual grasses and altered fire regimes on the sagebrush ecosystem and greater sage-grouse: A strategic multi-scale approach. Gen. Tech. Rep. RMRS-GTR-326. Fort Collins, CO: U.S. Department of Agriculture, Forest Service, Rocky Mountain Research Station. 73 p.*

Reviewed the causes and effects of invasive annual grasses and altered fire regimes in the sagebrush steppe and discussed factors which determine resilience to disturbance. The document also summarizes tools available for determining the suitability of areas for treatments related to fuels management, fire operations, post-fire rehab and sage-grouse habitat restoration. Recommends the following steps in an overall framework: 1) identify priority areas of conservation (PACs) based on ecological site descriptions (ESDs) derived from ecological site conditions such as elevation, precipitation, soil type, soil type and attributes (i.e. water holding capacity, moisture availability), slope, aspect, relative "intact-ness" of the native plant community, and distance to possible threat (grazed pastures, roads, hiking trails, invasive sp. source populations, etc.); 2) generate management recommendations and potential applications that enhance resistance and resilience of sites, following a cost-efficient model that places financial resources in areas most likely to recover; 3) pursue adaptive management across broader landscapes and multiple PACs by sharing data and other collected information across jurisdictional boundaries as similar treatments can be applied to high-priority areas to determine how well the application worked in terms of objectives reached.

Chambers, J. C., M.L. Brooks, M.J. Germino, J.D. Maestas, D.I. Board, M.O. Jones and B.W. Allred. 2019. Operationalizing resilience and resistance concepts to address invasive grass-fire cycles. *Frontiers In Ecology And Evolution* 7.

Reviewed scientific knowledge of the influencing factors supporting resistance to invasive annual grasses, resilience to fire, and fire regimes. For purposes of this review, we restrict the summary of this paper to discussions pertaining to cold desert systems. A framework is proposed for prioritizing management intervention for annual grass invasion and associated fire cycles: 1) general resilience indicated by ecosystem attributes and processes; 2) spatial resilience based on landscape composition and configuration; and 3) interactions/differences between spatial and general resilience. For cold deserts, the authors propose several steps in a decision making process: 1) development of appropriate management objectives; 2) develop landscape indicators of general resilience/resistance to invasive grasses (using soil temperature and moisture regime data); 3) develop an understanding of spatial resilience (via distribution of sagebrush cover and/or sensitive species distributions); 4) develop an understanding of fire risk in relation to grass invasion (by intersecting fire risk assessment maps with resilience/resistance information and sagebrush cover maps).

Crist, M.R., J.C. Chambers, S.L. Phillips, K.L. Prentice and L.A. Wiechman. 2019. Science framework for conservation and restoration of the sagebrush biome. Part 2, Management applications : linking the Department of the Interior's integrated rangeland fire management strategy to long-term strategic conservation actions. Gen. Tech. Rep. RMRS-GTR-389. Fort Collins, CO: United States Department of Agriculture, Forest Service, Rocky Mountain Research Station.

The Science Framework establishes the scientific basis for managing sagebrush steppe ecosystems throughout their distribution. The Framework also highlights resource management strategies that focus on ecosystem resilience to disturbance and resistance to invasive annual grasses. Topics covered in Part 2 relevant to NPS lands include adaptive management and monitoring, climate adaptation, wildfire and vegetation management, nonnative invasive plant management, application of National Seed Strategy concepts and livestock grazing management applicable to cold-desert ecosystems. The Framework provides high-level guidance rather than site-specific recommendations, but is completely compatible with a site-specific approach.

Davies, K., J. Bates and C. Boyd. 2019. Post-wildfire seeding to restore native vegetation and limit exotic annuals: an evaluation in juniper-dominated sagebrush steppe. *Restoration Ecology* 27(1):120–127.

Examined the effects of seeding native perennial species following wildfire in sites dominated by western juniper and mountain big sagebrush that may be at risk of post-fire invasion and dominance by invasive annual grasses. Seeded treatments had four times greater perennial grass cover than the controls three years post-fire. Perennial forb cover did not differ among years or between treatments. Annual grass cover increased in the controls over time, and peaked year two post-fire in the seeded treatment and then declined in the third-year post-fire. Annual grass cover was higher in the non-seeded controls when compared to the seeded treatments at the end of the study period. Cover of sagebrush increased in seeded plots but remained consistently low in the unseeded control. Seeded treatments also had higher perennial plant density when compared to the control. Density of non-native annual grasses was also greater in the control when compared to the seeded treatment. Results

support the hypothesis that seeding with perennial grasses is an effective treatment post-fire as the method can increase perennial grass and sagebrush cover as well as density while reducing exotic annual grass and forb establishment in mountain big sagebrush and western juniper communities. Contradicts other studies that indicate seeding with native perennial grasses is ineffective.

Davies, K. W. and J.D. Bates. 2014. Attempting to restore herbaceous understories in Wyoming big sagebrush communities with mowing and seeding. *Restoration Ecology* 22(5): 608–615.

Sought to determine if mowing and seeding large native perennial bunchgrasses in Wyoming big sagebrush plant communities can foster native bunchgrass recovery without increasing exotic annuals. Native perennial bunchgrass density increased in plots following mowing and seeding, but so did cover of invasive annuals. Cover of natives did not increase with any treatment, was generally low and not different from unseeded plots. Biocrust cover declined in mowing and seeding plots compared to control plots. Mowing may not be an effective strategy in Wyoming big sagebrush communities because of the impacts to biocrusts and increased availability of resources (litter) for invasive plant establishment following physical disturbance in these systems. Management strategies in low-resistance/resilience sites should be as low-impact as possible.

Davies, K. W., C.S. Boyd, J.L. Beck, J.D. Bates, T.J. Svejcar, and M.A. Gregg. 2011. Saving the sagebrush sea: An ecosystem conservation plan for big sagebrush plant communities. *Biological Conservation* 144(11):2573–2584.

Summarized existing problems relative to maintaining and restoring the ecological integrity of big sagebrush ecosystems. Characterized key issues as exotic annual grass invasion, heavy grazing, conifer encroachment, ex-urban development, and biodiversity loss (flora and fauna). Recommended actions included preventing undesirable vegetation shifts from occurring, restoring communities invaded by exotic annual grass or encroached on by conifers, reducing and mitigating anthropogenic development. Called for research related to enhancing restoration success, specifically indigenous soil bacterium, fungi, and seedling establishment, and increasing vegetation community diversity is needed. Provided an example approach that could be applied to conserve other ecosystems that would include: 1) identification of primary stressors and risks to the ecosystem; 2) application of conservation practices which are known to be successful; 3) targeting research efforts on stressors which cannot currently be resolved with management practices; and 4) periodic evaluation of stressors, management opportunities and research needs.

Davies, K. W., J.D. Bates and R.F. Miller. 2007. Short-term effects of burning Wyoming big sagebrush steppe in southeast Oregon. *Rangeland Ecology & Management* 60(5):515–522.

Evaluated the effects of fall prescribed burning on Wyoming big sagebrush plant community production, cover, diversity, total soil C, total N, inorganic N, organic matter (OM) and water content. Nitrate and ammonium concentrations in the upper 15 cm of the soil profile were greater in the burned than the control treatment. Carbon, total nitrogen, and soil organic matter were not different between treatments in either year of the study. Soil water content was generally greater in the control (unburned) treatment, but this was also date dependent. Biomass production was greater in the control than the burn, but was less so in the second-year post-burn. Herbaceous vegetation was greater in the control in both years of the study; however, bunchgrass production was greater in the

burned treatment area. Annual grass and annual forb were greater in the burned control in the first year of the study but did not differ between treatments in 2004. In the second post-burn year herbaceous cover was greater in the burned than control treatment, but rabbitbrush cover and tall tussock perennial grass did not vary by treatment. The Shannon diversity index also did not differ between the control and the burned treatment. Livestock forage can be increased with prescribed fall burning in relatively intact sagebrush steppe (*Artemisia tridentata* ssp. *wyomingensis*), however, weed invasion significantly increases with increased soil resource availability. Fall burning should be applied with caution and consideration of alien species invasion.

Davies, K. W., R.L. Sheley and J.D. Bates. 2008. Does fall prescribed burning *Artemisia tridentata* steppe promote invasion or resistance to invasion after a recovery period? *Journal of Arid Environments* 72(6):1076–1085.

Sought to determine whether re-introduction of fire (prescribed) to late seral sagebrush systems (*A. tridentata* ssp. *wyomingensis*) affected the invasion potential of cheatgrass after vegetation community recovery (3-years). Cheatgrass was not able to establish when seeded at 1000 seeds m⁻² rate or less. Establishment, density, and foliar cover of cheatgrass was greater in the unburned control than in the prescribed burn treatment area. Total herbaceous vegetation density, cover, and biomass were greater in the burned treatment when compared to the control treatment; however, total perennial herbaceous density did not differ between the treatments. Soil water content in the upper soil profile (20 cm) was consistent between treatments, but varied as the growing season continued. Soil nitrogen was greater in the control (unburned) treatment. The study concluded that prescribed fall burning increased *A. tridentata* ssp. *wyomingensis*-bunchgrass steppe resistance to cheatgrass invasions when a 3-year recovery period occurred prior to cheatgrass introduction. Greater herbaceous cover in the control may have "blocked" cheatgrass from invasion into the burned treatment. Managers should apply caution when planning to re-introduce disturbance in plant communities due to the risk of exotic plant invasion. Analysis of exotic plant species in the area and their ability to disperse is recommended prior to prescribed disturbance.

Dettweiler-Robinson, E., J.D. Bakker, J.R. Evans, H. Newsome, G.M. Davies, T.A. Wirth, D.A. Pyke, R.T. Easterly, D. Salstrom and P.W. Dunwiddie. 2013. Outplanting Wyoming big sagebrush following wildfire: stock performance and economics. *Rangeland Ecology & Management* 66(6):657–666.

Evaluated the health, survival, and economic costs of outplanting Wyoming big sagebrush as an effective restoration treatment in a post-fire sagebrush steppe ecosystem. The mean survival of sagebrush plantings to Year 3 was 21%, with container stock having the least variation in survival and Stock Type, Amendment, and Planting Year (SAYs) and had reduced mortality in later years. Survival in year one influenced health in year three. The least expensive treatment was Bare Root + Hydrogel (BR +H). Container stock and BR+H had the highest survival and lowest cost, whereas the highest cost treatments (mycorrhizal inoculation) had the lowest survival. Generally, seedling mortality is high in the first years following treatment and typically declines in later years. Managers can gain relatively good predictions on plant survival if monitoring occurs in the first few years after outplanting. Healthy plants in year one can indicate good survival into year three; however, survival also depends on unpredictable climatic factors and site characteristics. Outplanting is a suitable

option for the rapid establishment of shrub-steppe communities as it is the most ecologically and economically effective.

Dilts, T. E., P.J. Weisberg, C.M. Dencker and J.C. Chambers. 2015. Functionally relevant climate variables for arid lands: a climatic water deficit approach for modelling desert shrub distributions. *Journal of Biogeography* 42(10):1986–1997.

Developed functionally relevant climate variables for modeling vegetation distribution in sagebrush steppe. Compared different model's ability to predict vegetation patterns using water deficit variables and precipitation. Quantified climate gradients that control shrub distributions in sagebrush steppe. Found variability between shrub species at sites due to seasonal changes in water balance. Models used performed similarly, but prediction results varied by species. The cumulative water deficit variable was the primary predictor for the water deficit models. The bioclimatic envelope model did not show a defined agreement of which variable influenced species distribution. Species distribution models that use water deficit variables do not perform better than bioclimatic envelope models but predict shrub-steppe species distribution similarly. Water deficit approaches may be easier to interpret as the variables are more functionally relevant. Temperature, which is accounted for in bioclimatic models and not water deficit models, is an important predictor for shrub distribution. Incorporating GIS modeling with spatial data to develop models can help identify important variables influencing vegetation distribution, and can help managers apply techniques for restoration and rehabilitation.

Germino, M., J. Barnard, D. Davidson, M. Arkle, B. Pilliod, E. Fisk and R. Applestein. 2018. Thresholds and hotspots for shrub restoration following a heterogeneous megafire. *Landscape Ecology* 33(7):1177–1194.

Determined relationships, thresholds, and tipping points regarding sagebrush presence from fine-scale sampling across a significant, heterogeneous site which had burned the prior year and to quantify soil surface attributes that are generally obstructed but can affect patterns of recovery for vegetation. Sagebrush established in 50% of the seeded areas. Seeding also led to a 40% greater probability of sagebrush establishment at the lowest elevation ranges, where exotic invasion is the most prevalent. After seeding, the attributes which influenced sagebrush establishment were topographic abiotic features that influenced or changed heatload from fire (e.g., soil water, other soil attributes, and the presence of fertile islands). Modeling indicated that cheatgrass had a negative influence on sagebrush establishment. Sagebrush establishment was positively related to bunchgrass presence. The restoration area was seeded with seeds from the study location. Known influences of seedling establishment first-year post-fire were elevation and physiography. Timing of application and seed source may have influenced establishment due to the use of seeds that were better adapted for the area. Knowing where sagebrush is abundant before wildfire can determine the location of post-fire fertile islands to better support restoration activities. Seeding increases sagebrush presence, mainly when applied to flat slopes in high elevations and areas with low heatloads and greater total water index. Physiographic factors that influence seeding success can be mapped for project areas in a short amount of time. Seeding is most applicable during first-year recovery and can offer starting points for predictions of sagebrush establishment at other sites. Reliance on assessment tools alone is not recommended because they don't account for place-based idiosyncrasies.

Griffith, A. B. 2010. Positive effects of native shrubs on *Bromus tectorum* demography. *Ecology* 91(1):141–154.

Studied the influence of microhabitats generated by the understory of native shrubs big sagebrush and bitterbrush on cheatgrass demography in an area of California located in the hydrographic Great Basin Desert. Intershrub microhabitats differed between sagebrush and bitterbrush, which appears to be due to soil fertility as opposed to soil moisture. Shrub microhabitats had higher cheatgrass density, even double that of intershrub habitats. Microhabitats generated by native shrubs (e.g., sagebrush and bitterbrush) can facilitate cheatgrass populations throughout the Great Basin due to increased germination, survival, and growth. Altered fire regimes in sagebrush steppe may increase cheatgrass populations due to increased shrub abundance. Managers should try to restore rangelands by reducing the amount of shrub cover and increasing native perennial bunchgrasses.

Hardegree, S. P., J.M. Schneider and C.A. Moffet. 2012. Weather variability and adaptive management for rangeland restoration. *Rangelands* 34(6):53–56.

Discussed weather variability and how local weather knowledge can be used in the EBIPM planning process. **1. Goal Setting:** rangelands have highly variable weather, which should be considered when developing restoration goals. **2. Information Collection:** Although information weather sources are plentiful, sparse distribution of weather stations may not accurately represent a site, and PRISM data may contain errors. Using multiple data sources is recommended. **3. Plan Development:** adaptive management requires monitoring plans that adjust and respond to expected weather variability. **4 & 5. Stakeholder Involvement and Adjustment of Plan:** Stakeholders should be made aware of weather-induced variability and uncertainty. State and federal protocols are often too narrow when considering weather variability in restoration and adaptive management. **6 & 7. Plan Implementation and Data Collection:** Remaining conscious of weather is recommended for the plan implementation process. On-site weather data collection may be appropriate for large-scale restoration projects. Vegetation monitoring should also expand to include more information besides biomass and seeding density estimates, such as plant development stages. **8: Evaluate and Update Plan to Maintain Positive Trajectory:** The historical weather ranking generated at the beginning of the planning process should be used to measure successes and failures. However, using historic data should be used within the Authors' recommendations.

Hulet, A., C.S. Boyd, K.W. Davies and T.J. Svejcar. 2015. Prefire (preemptive) management to decrease fire-induced bunchgrass mortality and reduce reliance on postfire seeding. *Rangeland Ecology & Management* 68(6):437–444.

Presented research objectives on the small plot, large plot, and landscape-scale that identified and evaluated the interactions between biotic and abiotic factors that influence fire-based bunchgrass mortality to increase Sagebrush Steppe resilience and resistance. Data from previous studies and preliminary data identified the outline for future research and the development of research objectives throughout this article. Research objectives which are specific to managing fire-sensitive sagebrush were developed and separated by the distinct scales identified. The successful reduction of annual species invasion risk may be determined by management decisions that are made before, during, and after a fire event, as opposed to when a fire is occurring or directly after. Although dependent on weather variability, preemptive management practices may strongly influence native plant community resistance and resilience.

Hulvey, K. B., E.A. Leger, L.M. Porensky, L.M. Roche, K.E. Veblen, A. Fund, J. Shaw and E.S. Gornish. 2017. Restoration islands: a tool for efficiently restoring dryland ecosystems? *Restoration Ecology* 25: S124-S134.

Determined the utility of restoration islands in dryland ecosystems and offered guidelines for their use in restoration. After disturbance, vegetation expands from patches known as resource islands that offer favorable conditions for plant growth. Management that implements restoration islands consider recovery patterns and vegetation in locations determined to have a high probability of recovery success for the initial and surrounding areas. Restoration island can reduce restoration costs, but face challenges in dryland ecosystems due to reduced precipitation, productivity, increased threats from invasive annual grasses, and alterations to the grass-fire cycle. Many strategies can be employed to reduce the before stated issues. Importantly, other dryland ecosystem goals can be supported by implementing restoration islands. Managers should focus on applying treatments to limited areas that are high restoration priority or where the probability of success is high.

Koniak, S., Intermountain Forest Range Experiment Station and United States Forest Service. 1983. Broadcast seeding success in eight pinyon-juniper stands after wildfire. Ogden, UT.: U.S. Dept. of Agriculture, Forest Service, Intermountain Forest and Range Experiment Station.

Analyzed trends in the survival of seeded species after broadcast seeding applications post-burn in seven sites located in Nevada and California. Seeded grasses and perennial species established better on north-facing slopes, with annual grasses found primarily on south- and west-facing aspects. Typically, moisture regimes and reduced temperature variation generate favorable conditions for establishment when compared to south- and west-facing aspects. Site characteristics on north aspects may limit annual grass establishment due to competitive interactions with perennial species in pre-burn areas and reduced seed reserves. However, contrasting factors on south- and west-facing slopes create favorable conditions for annual species establishment but limit perennial species. Areas with adequate precipitation supported the establishment of seeded grasses but were likely limited due to competition with shrubs and annual grasses or propagated areas where site factors reduced establishment potential, especially in post-burn areas with reduced precipitation, except in high-elevation west slopes. Higher elevation west-facing aspects typically had higher cover of all classes of vegetation. When applying seeding as a management technique, consideration of climatic patterns, topography, soil moisture, and timing of seeding is essential, as they may limit or support the establishment of seeded vegetation.

Madsen, M.D., S.L. Petersen, K.J. Fernelius, B.A. Roundy, A.G. Taylor and B.G. Hopkins. 2012. Influence of soil water repellency on seedling emergence and plant survival in a burned semi-arid woodland. *Arid Land Research and Management* 26: 236–249.

Evaluated the influence of hydrophobic soil layers on emergence of bluebunch wheatgrass and Snake River wheatgrass seedlings from burned soils. Results from this greenhouse experiment indicate that hydrophobic soils may inhibit seedling emergence as a function of reduced soil water availability. Seedlings grown in soils to which a wetting agent (alkylpolyglycoside-ethylene oxide/propylene oxide block copolymers) was added demonstrated higher emergence and survival, indicating that wetting agents may improve seeding success in post-burn areas where soils exhibit some degree of water repellency.

Maestas, J. D., S.B. Campbell, J.C. Chambers, M. Pellant and R.F. Miller. 2016. Tapping soil survey information for rapid assessment of sagebrush ecosystem resilience and resistance. *Rangelands* 38(3):120–128.

Described new products and tools recently compiled using existing soil survey data to assist the rapid evaluation of possible resilience and resistance across sagebrush ecosystems. Maps that aggregate soils data from regional scales are useful for the communication of basic ecosystem attributes, biophysical patterns, and differences such as temperature variation across landscapes. This information can be used as a site descriptor to inform decisions, assist rapid regional planning, and make site comparisons for research and management. On local scales, soil moisture subclasses can be used to decipher variability in soil moisture regimes, but including other abiotic and biotic information is important for holistic decision making. Importantly, custom prioritization tools can be developed with these aggregated soils data products based on managers' needs and expertise. Moisture regimes and soil temperature should be considered the first step in the prioritization process and other factors included in the decision-making process. Tools and products like ecological site descriptions (ESDs) and interpretive soils reports that use existing data climatic and soils data can assist managers in future decision making for sagebrush steppe ecosystems at regional and local scales.

Ott, J.E., R.D. Cox, N.L. Shaw, B.A. Newingham, A.C. Ganguli, M. Pellant, B.A. Roundy and D.L. Eggett. 2016. Postfire drill-seeding of Great Basin plants: effects of contrasting drills on seeded and nonseeded species. *Rangeland Ecology and Management* 69:373–385.

Conducted an operational-scale experiment in Wyoming big sagebrush communities to: 1) evaluate the effectiveness of drill-seeding techniques for establishing diverse native seed mixes; 2) compare effects of different drill features on seeded plant establishment; and 3) assess impacts of conventional and minimum-till drills on exotic annuals and residual perennials post-fire. Site, year, treatment and site x year x treatment all had significant impacts on plant establishment. Drill seeding techniques were effective for native plant establishment, though specific results varied by seed size and site-specific conditions. No-till drill techniques were associated with lower cheatgrass cover following seeding. Depending on site conditions (particularly invasive plant cover and precipitation), management objectives that include the suppression of exotic annuals, reestablishment of perennial cover and the restoration of the native plant community might not be achievable in two years post-fire.

Ott, J. E., F.F. Kilkenny, D.D. Summers and T.W. Thompson. 2019. Long-term vegetation recovery and invasive annual suppression in native and introduced postfire seeding treatments. *Rangeland Ecology & Management* 72(4):640–653.

Examined long-term seeded plant persistence and the effects of shifts in species composition of seeded plants on abundance of invasive annual grasses and non-seeded native perennial species. Perennial plant cover from seed mixes dominated after the first year of treatment; however, species composition varied by treatment. Cover was relatively consistent across sites except for the low-diversity native mix at the Jericho study site. Seeded perennial treatments had higher cover in both sites than unseeded controls across the study extent. In contrast, non-seed mix perennial recruitment was highest in the unseeded control plots and was primarily composed of woody species. Annual plant cover was composed mostly of invasive grasses with cheatgrass representing the dominant

species. Annual grass cover was lower than annual forb cover until 2015 when annual grass cover increased in three treatments and was most significant in the unseeded control. Importantly, seed-mix species cover increased in sites where they were not seeded. In the unseeded control, squirreltail, needle-and-thread, western wheatgrass, and Wyoming big sagebrush increased to or beyond the cover of seeded treatments. Species seeded at higher rates in the native high diversity seed-mixes typically increased significantly when compared to the native low diversity mix. Seeded plant density increased over time, suggesting the effects of seeding remain evident long-term. Species dominance of seeded plants suggests that some species are adapted to proliferate in variable site conditions.

Pyke, D.A. 2011. *Restoring and rehabilitating sagebrush habitats*. In Knick, S. T., Connelly, John W., & Cooper Ornithological Society. *Greater sage-grouse : ecology and conservation of a landscape species and its habitats*. Berkeley, Calif.: University of California Press.

Described a process for managing, restoring, or rehabilitating sagebrush ecosystems to achieve desired plant communities for greater sage-grouse habitat. Sagebrush habitat can be enhanced through landscape triage by identifying areas suitable for restoration or rehabilitation. Once sites have been selected, passive or active restoration/rehabilitation should be implemented based on site conditions and potential ability to recover. There are many appropriate management applications to either restore or rehabilitate sagebrush steppe ecosystems; however, choices should be made based on a vegetation communities likelihood of recovery (**landscape triage**), and whether or not passive or active restoration/rehabilitation should be implemented. Once promise of recovery occurs, adaptive management should be applied based on inventory and monitoring in the area to adapt the management techniques for the needs of the current community structure and opportunity to transition into (or maintain) a stable state.

Sheley, R. L., J.M. Mangold and J.L. Anderson. 2006. *Potential for successional theory to guide restoration of invasive-plant-dominated rangeland*. *Ecological Monographs* 76(3):365–379.

Examined the response of vegetation to different restoration treatments applied with consideration of successional management in an invasive species dominated rangeland. Paired methods (i.e., two- and three-way interactions) can influence the trajectory of succession, and thus desired plant community, as a result of plant response to treatment. However, desired and exotic species responded differently to various treatments and the interactions between them. Importantly, almost all of the herbicide treatments increased the abundance of exotic grasses. However, the three-way interaction of no-till, cover crop, and herbicide treatment resulted in lower exotic grass abundance. Successional management, and its intention of influencing plant communities towards a trajectory of desired species, might be attainable in terms of plant establishment; however, richness was not improved in the course of this study. Instead, the results indicate that process-based models can be used for planning and potential predictions of restoration outcomes when managing for invasive species.

Sheley, R., J. James, B. Smith and E. Vasquez. 2010. *Applying ecologically based invasive-plant management*. *Rangeland Ecology and Management* 63(6):605–613.

Synthesized the major components of management decision-making into a logical series of steps for implementation of EBIPM. Amends a successional management framework and provides comprehensive decision tools for EBIPM using the Rangeland Health Assessment that identifies

ecological processes in need of repair, principles for repairing ecological processes that direct vegetation dynamics and incorporate adaptive management procedures to foster the acquisition of new information during management. Recommends consideration of three causes of succession: 1) site availability (disturbance); 2) relative species availability; and 3) relative species performance. Managers should use assessment information to identify the primary causes of succession that favor dominant invasive species. Because altering the "cause" of invasion is central to an EBIPM, the aim is to alter key processes in a particular ecological site to influence to direct vegetation dynamics on a desired trajectory. EBIPM provides a science-based method for developing invasive plant management plans and predicting the outcome and course of treatments.

Sheley, R.L., B.S. Smith and A.J. Svejcar. 2009. Adaptive management for invasive annual grasses: a step-by-step user's guide for implementing EBIPM. Eastern Oregon Agricultural Research Center.

Provides a concise step-by-step method for testing current practices and compare management strategies to develop locally applicable "Best Management Practices (BMP's) while encouraging continued management improvements over time. Specifies steps in the adaptive management process for invasive plant management. States that the adaptive management process is not only essential in areas where stakeholder involvement is warranted, but also critical for the understanding of whether or not treatments have met goals and objectives and what changes should be made to the plan in order to influence a change in the desired direction. The process is iterative, meaning that each time new information is obtained, the plan should be reviewed for adjustments to goals, objectives, treatment strategies, and stakeholder considerations.

Suding, K.N. and R.J. Hobbs. 2009. Threshold models in restoration and conservation: A developing framework. Trends in Ecology and Evolution 24: 271–279.

Suggest a framework for integrating ecological threshold models into ecosystem management and restoration planning. The framework consists of four steps or groupings of components: 1) understanding temporal and spatial patterns of change; 2) identify broad-scale processes and/or drivers that influence resilience and can trigger thresholds; 3) determine if systems have feedback mechanism that may cause rapid change; and 4) test hypotheses about ecosystem function and responses to stimuli via adaptive management and/or organized research.

Thompson, T. W., B.A. Roundy, E. Durant Mcarthur, B.D. Jessop, B. Waldron, and J.N. Davis. 2006. Fire rehabilitation using native and introduced species: a landscape trial. Rangeland Ecology & Management 59(3):237–248.

Compared establishment of native and introduced species sown in four different seed mixes at an operational scale using methods typical of landscape-scale fire rehabilitation projects. Native species will establish in semiarid locations using standard seeding methods and proper seeding rates. Both drill and aerial seeding increased perennial species and reduced annuals in comparison to the unseeded controls. Both native seed mixes had similar results to the ARS and BLM seed mix; however, cost of seeding native plants in the drill seeded plots was high due to higher seeding rates. It's possible that introduced non-native forage grass mixes with a native species component may act as a bridge towards future native species establishment and dominance.

Williams, R.E., B.A. Roundy, A. Hulet, R.F. Miller, R.J. Tausch, J.C. Chambers, J. Matthews, R. Schooley, and D. Eggett. 2017. Pretreatment tree dominance and conifer removal treatments affect plant succession in sagebrush communities. *Rangeland Ecology & Management* 70: 759–773.

Determined how different juniper removal treatments have affected successional trajectories in different sagebrush steppe ecosystems after 3 and 6 years post treatment. The effects of juniper treatments on succession differed depending on pre-treatment vegetation composition. Annual shrubs were a small component of plant communities, both treated and untreated, but cover was slightly higher on burned plots than untreated. Exotic forbs increased with fire, but returned to pre-fire levels by 6 years. Perennial forb cover was positively affected by treatments, but only at sites with initially higher juniper cover. Cheatgrass cover increased with treatments, and 6 years after treatments cheatgrass cover was greater in burned than cut plots with moderate juniper cover. Shrub cover was greater in burned plots than untreated plots by year 6. Big sagebrush, however, did not recover after fire. Tall-grass cover increased by year 6 in all treatments, but was greater in cut plots. Bare ground decreased by year 6 in both burned and cut plots. Fire resulted in decreased woody fuel loads, but increased cheatgrass. Cutting juniper trees maintains fuel load, but alters fuel structure, and mastication of juniper especially can reduce fire severity. Mechanical treatments allow for existing shrubs to persist after treatment, and while some shrub components established readily after fire, big sagebrush did not. Prescribed fire should only be used for juniper treatment on cool, moist sites with low risk of cheatgrass invasive, and only if a loss of sagebrush at the site is acceptable. Mechanical treatment of juniper can be successful, but may need to be coupled with annual grass control and revegetation methods in cases of extensive (Phase III) juniper encroachment.

General Sagebrush Steppe Vegetation Condition

Allen, E.A. and R.S. Norwak. 2008. Effect of pinyon-juniper tree cover on the soil seedbank. *Rangeland Ecology & Management* 61(1):63–73

Quantified seed bank and plant community alterations resulting from mountain big sagebrush community conversion into pinyon-juniper woodlands. Total native plant cover and diversity for all categories recorded decreased significantly as woodland cover increased. As tree litter and tree microsites increased, shrub microsites decreased. Increasing tree cover had varying effects on individual species cover, but the cover of both Sandberg bluegrass and cheatgrass was relatively consistent in all classes of tree-cover. The increase in woodland cover did not significantly affect total seedbank density or diversity. Seedbank density for sagebrush decreased with increasing woodland cover. Many of the species determined in the seedbank were not reflected in the mature vegetation community, and the mature vegetation did not necessarily represent the species composition of the seedbank. Significant alterations in seedbank density for the most abundant species identified were not detected with increasing tree cover and were located in all tree-cover classes defined. Importantly, managers should be aware that cheatgrass cover is positively correlated with its seedbank density, and that fire, although limiting to cheatgrass seed survival, likely won't prevent future invasion. Additionally, some mature principal species may not be represented in seedbanks, reducing the likelihood of natural recruitment.

Bunting, S.C., J.L. Kingery, E. Strand. 1999. Effects of succession on species richness of the western juniper woodland/sagebrush steppe mosaic. In: Monsen, Stephen B.; Stevens, Richard. comps. Proceedings: ecology and management of pinyon-juniper communities within the Interior West; 1997 September 15–18; Provo, UT. Proceedings RMRS-P-9. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station. p. 76–81

Focused on the encroachment influence of western juniper across a landscape-scale on plant species richness and diversity. The authors found that woodland expansion reduced both herbaceous plant and shrub cover, but significant changes to species richness across gradients of succession were not detected in this study. Notably, the lowest average species richness was determined in stands dominated by young juniper. Generally, early to mid-seral communities better supported perennial species when compared to late-seral communities. Increased quantities of annual species were determined in mature juniper woodlands as a result of low perennial species cover. Alterations to plant species diversity within the varying woodland stages were thought to have occurred due to the influence of woodland succession on species abundance. The authors determined that the presence of all woodland structural stages best supported vascular plant richness and diversity, further supporting the incorporation of disturbance in landscape management.

Caicco, S.L., J.M. Scott, B. Butterfield and B. Csuti. 1995. A GAP analysis of the management status of the vegetation of Idaho, U.S.A. Conservation Biology 9(3):498–511.

Assessed and summarized the conservation status of the major land-cover types in Idaho. Analysis indicated that approximately 26.3% of Idaho's vegetation is classified as shrub steppe and/or grassland. The authors note the particular lack of information regarding ecological status of shrub-steppe rangelands, particularly big sagebrush communities that have experienced historic overgrazing and/or fire. Lack of information regarding understory conditions may result in over-estimation of the degree to which intact big sagebrush communities are actually protected. Given the course nature of GAP analyses, managers should not rely on them as decision tools for prioritizing landscape protection. Instead, more localized and finer-grained analysis, like those produced using systematic vegetation monitoring, are a necessary component of sustainable vegetation management programs.

Chambers, J.C. and M.J. Wisdom. 2009. Priority research and management issues for the imperiled Great Basin of the western United States. Restoration Ecology 17(5):707–714.

Provided a summary of the research and management difficulties persisting in the Great Basin and provided recommendations of the scientific information necessary for relevant oversight in the region. Factors such as increasing development, prior and current land-use conversion, climate change, invasive species spread, and alterations fire regimes are noted as some of the primary threats to the region. Additionally, the aggregated effects of these factors result in broad-scale conversions of vegetation communities, loss of watershed function, and native species loss, further altering ecosystem structure and function across the region. The authors identified multiple science information needs for the area such as large-scale monitoring and assessment of regional ecosystem conditions and potential disturbance susceptibility; the inclusion of science-based information on the identified threats and their aggregated effects; the ability to predict and model possible landscape alterations and their incorporation in management decisions; and novel management tools that can assist in decision-making, preparation, and implementation. Additionally, the collaboration between

researchers and management, as well as policy concerns, should be addressed to better support and maintain ecosystems within the Great Basin.

Davies, K.W., J.D. Bates and R.F. Miller. 2006. Vegetation characteristics across part of the Wyoming big sagebrush alliance. *Rangeland Ecology & Management* 59(6): 567–575.

Determined the extent of intact, late-seral, Wyoming big sagebrush vegetation attributes, defined the plant associations for the sagebrush alliance within the study area, and compared the vegetation attributes in sample sites to defined cover classes for the greater sage-grouse. Cover of herbaceous species varied across the sampling area, with approximately 50% of the herbaceous cover being that of bunchgrasses. A majority of sites contained sagebrush, albeit at differing values of cover (6–20%). Five dominant plant associations, with varying functional group cover values, were identified within the 170 sites sampled in the study area. Placing the alliances associated with Wyoming big sagebrush into groups was stated as important, as management activities can be adjusted to accommodate the needs each association. The ability of the sample sites to meet the recommended sage-grouse habitat vegetation cover guidelines varied, indicating that the guidelines were not generated for application across all types of sagebrush habitats, like the Wyoming big sagebrush alliance. Identifying the different plant associations present in this sagebrush alliance can assist in the development of best management practices for those distinct associations.

Epanchin-Niell, R., J. Englin and D. Nalle. 2009. Investing in rangeland restoration in the Arid West, USA: countering the effects of an invasive weed on the long-term fire cycle. *Journal of Environmental Management* 91(2):370–379.

Applied a Markov model of vegetation dynamics for the sagebrush steppe ecosystem to predict vegetation change and weigh management costs under different intensities and types of post-fire revegetation. The model predicted a partial conversion of sagebrush steppe ecosystems to cheatgrass monoculture within a 100-year time scale (similar to current conditions); however, the model overpredicted the current extent of native vegetation and cheatgrass monoculture, but under predicted the current extent of shrubland-cheatgrass vegetation. The findings were consistent with the expected difference between current and historic vegetation dynamics as a result of variability in livestock grazing intensity. Overall, the model is better suited to predict current and future conditions as opposed to historic vegetation dynamics. Taking no revegetation actions was found to be the least effective and most costly method for slowing cheatgrass invasion. Revegetation with nonnative species (i.e., crested wheatgrass) was determined to be as ineffective as applying no restoration action when determining native vegetation maintenance. Cheatgrass dominance was controlled by revegetation with native species and crested wheatgrass equally. Post-fire revegetation reduces cheatgrass dominance and long-term management costs.

Miller, R.F., S. Knick, D. Pyke, C. Meinke, S. Hansen, M. Wisdom, and A. Hild. 2011. Characteristics of sagebrush habitats and limitations to long-term conservation. Pages 204–249 in S.T. Knick and J.W. Connelly, editors. *Greater sage-grouse: ecology and conservation of a landscape species and its habitats*. University of California Press, Berkeley, California, USA.

Described the distribution of sagebrush and its alliances and plant associations in the sage-grouse conservation area and discussed potential disturbances and stressors that are predicted to affect future

sagebrush habitat conservation. The authors determined that the likelihood of cheatgrass presence was moderate to high when mapping the probability of cheatgrass abundance across floristic provinces (nearly half the mapped area). Disturbance regimes have been altered in much of the SGCA, shifting natural communities outside of historic variation into new steady states. Changes in plant community structure can occur over both long- and short-time scales and impair a community's natural resilience and resistance to novel and additive disruptions. Decreased moisture availability and increasing temperatures negatively impact sagebrush steppe vegetation communities and reduce habitat suitability. Additionally, invasive annual grasses that are better suited for new disturbance regimes can replace sagebrush steppe ecosystems due to their resource exploitation capabilities. Increased annual species dominance paired with changes to historic disturbance regimes have increased fire severity, influenced loss of perennial seeds and their subsequent seed banks, and reduced resilience to variable weather conditions and stochastic climate patterns.

Mitchell, R. M., J.D. Bakker, J.B. Vincent, and G.M. Davies. 2017. Relative importance of abiotic, biotic, and disturbance drivers of plant community structure in the sagebrush steppe. Ecological Applications 27(3): 756–768.

Sought to determine how abiotic, biotic, and disturbance drivers influence the structure of plant communities in sagebrush steppe ecosystems. The authors determined that community-level metrics, especially species richness, are affected by abiotic drivers such as moisture availability, more so than soil quality. However, abiotic effects were not influential on native and exotic grass cover. Plant community structure was influenced primarily by military-related disturbances. Areas disturbed by military training had altered relative abundance of native grasses with an increased relative abundance of invasive species. However, the disturbance type did not significantly affect native forbs. Fire had the second most pronounced effect on plant community structure, especially in consideration of shrubs, followed by livestock grazing and maintenance and roads, which showed little effect. Furthermore, the biotic driver initial plant community had robust utility in determining contemporary plant community structure despite data collected 14-years prior to analysis; however, it was a poor predictor of plant species richness, indicating potential control on smaller spatial scales. The findings indicate that the initial plant community has a significant influence on plant species community composition followed by abiotic and disturbance-related drivers. Yet, it is essential to recognize how these drivers interact to influence community-level metrics.

Ripplinger, J., J. Franklin and T.C. Edwards. 2015. Legacy effects of no-analogue disturbances alter plant community diversity and composition in semi-arid sagebrush steppe. Journal of Vegetation Science 26: 923–933.

Examined the role managed disturbances play in sagebrush steppe plant community composition and how species composition changes with time following disturbance using a 50-year dataset from Utah. Managed disturbances evaluated included three treatments designed to reduce shrub cover: chemical treatments, prescribed fire and mechanical removal. While there were site and treatment-based differences in species composition, the authors stress that the long-term effects of managed disturbances were present across all sites 50 years after treatment application. Vegetation communities at all sites different from undisturbed reference communities. Native forbs and non-native grasses increased in all treatment sites compared to untreated reference areas. The authors

hypothesized that increases in non-native grass cover may have occurred as a result of the treatments themselves, such that equipment used during the treatment process may have served as vectors of seed spread. The results of this study indicate that predictions of return to pre-disturbance reference conditions may be inaccurate for some sagebrush steppe ecosystems, and that observed conditions in many locations are likely a legacy expression of no-analogue vegetation treatments conducted in the past.

Roberts, C., & J.A. Jones. 2000. Soil patchiness in juniper-sagebrush-grass communities of central Oregon. *Plant and Soil* 223: 47–61.

Examined the influence of soil resource island and bare patch size, spacing and properties (soil moisture, pH, nitrogen, soil arthropods and VAM) on vegetation conditions in sagebrush-steppe invaded by western juniper compared to sites where juniper was absent in an isolated protected area in Central Oregon. Similar to previous work on soil resource islands in sagebrush grass communities, this study documented resource patchiness which increased in areas where shrubs invaded grasslands. Where juniper was present sites exhibited increased bare area, reduced grass and sagebrush size, increased spacing between grass and sagebrush plants, reduced arthropod biomass, spatially-variable soil moisture and altered nitrogen cycle phases compared to sites where juniper was absent. These results indicate that juniper either responds to or causes changes in resource island structure and composition in sagebrush steppe communities, which has implications for the relative invisibility of these systems. Of particular note are the changes in vegetation gap size and reduced vigor of sagebrush and bunchgrass species, which are likely signs of reduced community resistance to invasion. Managers should consider juniper removal and/or management strategies in sites where similar vegetation responses are apparent following juniper invasion.

Rodhouse, T. J., K.M. Irvine, R.L. Sheley, B.S. Smith, S. Hoh, D.M. Esposito and R. Mata-Gonzalez. 2014. Predicting foundation bunchgrass species abundances: model-assisted decision-making in protected-area sagebrush steppe. *Ecosphere* 5(9):1–16.

Sought to determine the patterns of foundational species abundances over space and time to assist in decision-making guidance of protected areas by identifying key environmental influences on abundance patterns of bluebunch wheatgrass, Thurber's needlegrass, and Sandberg bluegrass. 13% of the area was estimated to be annual grass mono-dominant (75% or more) and bluebunch wheatgrass was the only perennial grass to be estimated at over 25% in any of the plots. Topography was the most dominant predictor of bunchgrass and annual invasive grass abundance. Medusahead is predicted to be most likely found on flat ground. Higher elevation north facing slopes exerted a strong influence on wheatgrass probabilities but not needlegrass abundance. Annual grass cover strongly influenced native perennial grass cover (negative association). Fire had a very strong influence on both cheatgrass and medusahead abundance due to their ability to exploit post-fire resources/conditions and invade areas which were previously intact if bluebunch wheatgrass mortality was high. Only 25% of the total area was determined to be priority 1 ($\geq 25\%$ bluebunch wheatgrass cover). Topography was deemed the strongest "buffer" to disturbance such as grazing, fire, and annual grass invasion.

Schlaepfer, D.R., W.K. Lauenroth and J.B. Bradford. 2014. Natural regeneration processes in big sagebrush (*Artemisia tridentata*). *Rangeland Ecology & Management* 67(4): 344–357.

Presents a synthesis of available knowledge regarding natural big sagebrush regeneration, focusing on characteristics associated with big sagebrush seed production, germination, and establishment. Knowledge gaps identified in this review include big sagebrush response to biotic factor interactions and varying disturbance events, responses to predicted changes in atmospheric inputs (e.g. CO₂ and nitrogen) and climate change.

Schlesinger, W., J. Raikes, A. Hartley and A. Cross. 1996. On the spatial pattern of soil nutrients in desert ecosystems. *Ecology* 77(2): 364–374.

Evaluated spatial distribution of soil nutrients and the degree to which shrub invasion of Chihuahuan Desert grasslands is influenced by soil nutrient patches under shrubs. Results indicated that available nitrogen distribution in uninvaded grasslands exhibited a clumped distribution wherein most nitrogen was located within close proximity to native bunchgrasses. Given the spatial distribution of individual grasses in these systems, broad-scale nitrogen distribution can be described as somewhat homogeneous in areas with substantial grass cover. In areas where shrubs were more dominant, the spatial pattern of available nitrogen shifted to a relatively larger area around shrubs but little nutrient value in larger gaps between shrubs. The authors hypothesized that these shifts in nitrogen availability may allow for long-term shrub persistence as low available nitrogen in bare patches would essentially limit recolonization by native grasses. From a management perspective, activities that result in physical changes to the structure of intact bunchgrass communities should be avoided, and grassland restoration activities will likely require shrub control in addition to nutrient amendments to ensure adequate grass establishment.

Stoms, D., F. Davis, K. Driese, K. Cassidy and M. Murray. 1998. Gap analysis of the vegetation of the Intermountain Semi-Desert Ecoregion. *Great Basin Naturalist* 58(3):199–216.

Presented results from a multistate gap analysis of plant communities located in the Intermountain Semi-Desert (ISD) ecoregion. Fifty-seven percent of the forty-eight land-cover classes mapped were dominated by big sagebrush (*A. tridentata* sp.), agriculture, and big sagebrush/low sagebrush, respectively. Field surveys conducted by the USFS showed overall agreement. A majority of the ecoregion is publicly owned and managed by the BLM, with significant allowance for extracted use (96% of the ecoregion). Much of the area is managed under priority 3 and 4 status, with equal proportions of each. A relatively small percentage of sagebrush alliances and other essential plant communities (i.e., bunchgrasses) were found to be represented under status 1 and 2 lands where biodiversity conservation is of high priority.

Ecological Resilience and Resistance Concepts and Protected Area Management

Chambers J.C., C.R. Allen and S.A. Cushman. 2019. Operationalizing ecological resilience concepts for managing species and ecosystems at risk. *Front. Ecol. Evol.* 7:241.

Provides a summary of ecological resilience concepts and applies them to management contexts, using an example from the sagebrush ecosystems. The authors promote a resilience-based framework in order to focus management where it will result in the most effective ecological outcomes. Six key components of a resilience-based framework are reviewed, including: managing for adaptive capacity; selecting an appropriate spatial extent and grain; understanding factors that influence

ecological resilience; understanding landscape context and spatial patterns of resilience; understanding pattern and process interactions and their variability; and understanding relationships among ecological and spatial resilience and the capacity to support habitats and species.

Chapin III, F.S., A.L. Lovcraft, E.S. Zavaleta, J. Nelson, M.D. Robards, G.P. Kofinas, S.F. Trainor, G.D. Peterson, H.P. Huntington and R.L. Naylor. 2006. Policy strategies to address sustainability of Alaskan boreal forests in response to a directionally changing climate. *Proceedings of the National Academy of Sciences of the United States* 103(45):16637–16643.

Discussed integrated strategies concerning sustainability by acknowledging the interconnections between global- and local-scale dynamics driven by the interactions humans have with their environment, and in particular, areas of resilience, adaptability, and vulnerability using Alaska's boreal forests as a case study. Ecological change in Alaska can be viewed, in part, as a function of climate change. Ecologically, changes in the hydrologic cycle affect slow variable categories (e.g. disturbance regimes and soil resources) and impact supporting services, causing reduced tree growth, increased fire severity and extent, insect outbreaks, and soil drying. The disturbances stated above have additional consequences, such as increasing the types and amount of disturbances in ecosystems. There is an opportunity to develop an integrated policy framework for protected area management to address the interacting drivers and consequences of climate change and ecological response using four distinct policy strategies: foster human adaptability, reduce vulnerability, enhance resilience, and enhance transformability.

Coffin, D.P., W.K. Lauenroth, I.C. Burke. 1996. Recovery of vegetation in a semiarid grassland 53 years after disturbance. *Ecological Applications* 6:538–555.

Addressed whether the composition of plant species at a site can be used as an indicator of recovery, whether the patterns of vegetation recovery follow a traditional (Clemenstian) or modified succession model, and if there is a relationship between species recovery and distance to undisturbed vegetation. Some vegetation recovery followed either the traditional or modified model of succession; the predicted recovery of vegetation in many of the fields did not fit into either model. Indicator selection based on multiple species for vegetation recovery proved difficult due to the production of alternate conclusions ranging from recovered to not recovered. Factors relating to management and other land-use practices, local climate, and soils not surveyed in the study may have attributed to the variability in vegetation recovery. Blue grama grass, a slow to recover species, was found in all plots sampled, indicating faster recovery than previously acknowledged. Full recovery of the community to pre-disturbance vegetation was not detected in any of the old fields; however, cover and density of certain species indicated recovery of those associations. The authors determined that four distinct classifications of fields could be identified based on blue grama grass cover and the distance from unplowed areas. For the shortgrass systems surveyed, understanding how blue grama grass recovers on old fields is important as it is the species most tolerant of disturbances and stressors like drought and grazing and generally determines long-term system stability. However, more research needs to be conducted on factors that contribute to the variability in vegetation recovery.

Cramer, V.A., R.J. Hobbs, and R.J. Standish. 2008. What's new about old fields? *Land abandonment and ecosystem assembly. Trends in Ecology & Evolution* 23:104–112.

Presented a generalized framework concerning the assemblage of vegetation communities on abandoned fields based on interacting factors such as land-use legacies, climate, soils, and individual species traits. The authors state that the interaction between the intensity of land-use legacies and the intrinsic vegetation and soil properties of a site generally determines a site's restoration ability based on the biotic or abiotic thresholds crossed. As land-use intensity increases, the likelihood of a community assembling to a native state diminishes. Areas that have experienced reduced agricultural land conversion, and contain large tracts of native vegetation communities, are more likely to recover naturally and less likely to be impacted by novel invasions; however, this effect changes along a gradient of land-use intensity and climate gradients. As such, old fields that have experienced significant alterations to nutrient and water cycles from land-use activities are less likely to recover to a natural plant community and have probably transitioned into an alternate ecological state. These areas will require intensive restoration efforts. Instead of focusing on restoration to a natural state, goals that focus on the provision of ecosystem services, and an increase of biodiversity and habitat will be the most achievable.

Cole, D.N., L. Yung, E.S.Zavaleta, G.H. Aplet, F.S. Chaplin III, D.M. Graber, E.S. Higgs, R.J. Hobbs, P.B. Landres, C.I. Millar, D.J. Parsons, J.M. Randall, N.L. Stephenson, K.A. Tonnessen, P.S. White and S. Woodley. 2008. Naturalness and beyond: Protected area stewardship in an era of global environmental change. *The George Wright Forum* 25(1):36–56.

Examined the various meanings of naturalness and why it is increasingly problematic as a central goal for protected area management. Detailed the case for and against human intervention in ecosystem processes and explored how naturalness might be redefined or reinterpreted, and how concepts of ecological integrity and resilience might supplement or replace it. Managing for the human-generated concept of naturalness as it is currently defined is not necessarily appropriate as 'naturalness' implies stagnancy. Ecosystems are dynamic, and desired conditions should not be based on historical reference. Instead, managing for ecological integrity, the ability for an ecosystem to perform proper function, or resilience, the ability for an ecosystem to absorb disturbance may be more appropriate with future climatic uncertainty. However, this is dependent on the management goals and objectives of a given park. Parks that integrate management activities that promote resilience or restoration of ecological integrity may avoid future undesirable consequences.

D'Antonio, C. and M. Thomsen. 2004. Ecological resistance in theory and practice. *Weed Technology* 18:1572–1577.

Defined ecological resistance, and addressed whether or not the drivers of resistance can be interpreted as well as applied in a controlled manner to manage invasive species. Ecosystem resistance is the ability of an ecosystem to resist change as a result of site characteristics.

Understanding the factors influencing resistance can help managers develop appropriate strategies to encourage plant community resistance. Sources of resistance can be influenced by plant community composition and plant species diversity, as they can inhibit invasive species germination. Species phenology and life history influence ability to compete with invasive plants. Competitive resistance is influenced by abiotic factors, making restoration dependent on site characteristics over time and space. Restoring resistance can be challenging, as factors that encourage resistance in one area may

not affect resistance in another or over time and space. Resistance has the greatest utility in ecosystems where the phenology, distribution, and life histories of native species vary from invaders. Furthermore, efforts to establish resistance may have harmful effects on ecosystems if restoration does not acknowledge patterns such as historic disturbance regimes.

Ellison, A. M., M.S. Bank, B.D. Clinton, E.A. Colburn, K. Elliott, C.R. Ford, D.R. Foster, B.D. Kloeppel, J.D. Knoepp, G.M. Lovett, J. Mohan, D.A. Orwig, N.L. Rodenhouse, W.V. Sobczak, K.A. Stinson, J.K. Stone, C.M. Swan, J. Thompson, B. Von Holle and J.R. Webster. 2005. Loss of foundation species: consequences for the structure and dynamics of forested ecosystems. *Frontiers in Ecology and the Environment* 3: 479–486.

Identified issues concerning the loss of foundation species in ecosystems. Foundation species are described as species that influence and stabilize community dynamics, populations, as well as productivity and ecosystems processes. In forested ecosystems, certain tree species are identified as foundation species due to their impact on forest structure and microclimate development. However, many of these tree species are in decline due to factors such as over-harvesting, high-impact forestry practices, intentional removal, and invasive pests and pathogens. As foundation species become less abundant across the landscape, many of the processes they regulate decline, and their influence on structure diminishes. The pattern and intensity of foundation species loss also influence the rate and severity of ecosystem alteration; however, these systems are described as fragile and can transition to alternate stable states with minimal disturbance. Management is encouraged to use a novel suite of research applications to help identify foundation species as well as monitor potential future impacts on their persistence.

Esposito, D. M., T.J. Rodhouse, R. Mata-González, R. and M. Hovland. 2019. Differential species responses to aspects of resistance to invasion in two Columbia Plateau-protected areas. *Rangeland Ecology & Management* 72(5):773–782.

Evaluated characteristics associated with plant species resilience by using a large, spatially extensive vegetation monitoring set from two protected areas containing sagebrush steppe ecosystems. For both John Day Fossil Beds (JODA) and Craters of the Moon (CRMO), resistance to invasion was determined to be higher in areas with higher moisture availability mediated by local-scale topographical features (steep north-facing slopes). Nevertheless, the topographic correlates were different between parks. In JODA, which had greater variability in topography, slope, and aspect were the most related variables to invasion. The key determinates in CRMO were proximity to disturbance and elevation. Patterns of resistance in JODA are represented by variations in topography where intact vegetation communities are located on steep north-facing slopes but may be threatened by invasives due to changing fire regimes and precipitation patterns. Elevation is the largest determinant of resistance at CRMO but is influenced by proximity to disturbance, and variability of precipitation may hinder its capacity. To apply resistance-based management, place-based characteristics that determine resistance, as well as resilience, should be established for more effective treatment applications.

Foster, C. N., C.F. Sato, D.B. Lindenmeyr, and P.S. 2016. Integrating theory into disturbance interaction experiments to better inform ecosystem management. *Global Change Biology* 22(4):1325–1335.

Analyzed empirical literature's integration of recent theoretical developments on disturbance interactions and its effect on management implications. Identified gaps between theoretical and experimental studies, and the effects this has on the ability to inform management decisions. This document aimed at guiding research that provides an understanding of managing multiple types of stressors. Testing ideas that bridge gaps between theory and experimental studies is key when looking at different types of interactions in an ecological context. Developing an understanding of empirical studies' execution is important for understanding solutions. Studies focusing on specific management problems but fail to integrate relevant theory may be limited within broader management implications. Research should focus on integrating theoretical literature and ecological interaction within the landscape. Testing fundamental relationships and interactions between pathways in theoretical modeling is important; explicitly, identify interacting pathways and ensuring research is conducted in the correct spatial and temporal scale. Management should replicate regression-based designs where replicas are across a gradient. This would provide better detection of nonlinear effects.

Franklin, J.F., D.B. Lindenmayer, J.A. MacMahon, A. McKee, J. Magnusson, D.A. Perry, R. Waide, and D.R. Foster. 2000. Threads of continuity: ecosystem disturbances, biological legacies and ecosystem recovery. *Conservation Biology in Practice* 1: 8–16.

Recently, large disturbances such as Hurricanes Hugo and Andrew, the Yellowstone Fires, and the eruption of Mount Saint Helens have provided researchers with an appreciation for disturbance complexity and the process of ecosystem recovery. The authors compare disturbances to "editors" in that they alter select ecosystem components, while others are left unimpaired, and assist in the regeneration of the ecosystem; however, different types and severities of disturbance influence the quantity of remaining biotic components. These remaining biotic elements affect the trajectory of secondary succession. Biological legacies, or biotic elements that endure after a disturbance (e.g., organic materials, environmental patterns, and organisms) are important for ecosystem recovery. Other legacies are structural, such as woody debris, logs, animal carcasses, and dead trees. The third legacy type is *biologically-generated spatial patterns* and is essential for the distribution of soil resources. Essentially, legacies, and the multiple roles they play, act as links to the prior and developing ecosystem. Human-caused disturbances are typically uniform, and the biological legacies left are less abundant and have reduced diversity and spatial heterogeneity when compared to natural disturbances. Managers should consider the implementation of the biological legacy concept to meet management goals.

Gunderson, L. (2000). Ecological Resilience-In Theory and Application. *Annual Review of Ecology and Systematics* 31:425–425.

Resilience has two definitions: engineering resilience and ecological resilience. Adaptive capacity is the ability for an ecosystem to remain in a stable state as changes to processes and characteristics occur. There are many ecosystems with alternative stable states and the drivers of their transitions. Resilience is linked to successional phases and functions at different capacities in the four stages of the adaptive cycle. Humans alter resilience through attempts to control and manage ecosystem

processes and functions, causing a resource crisis due to unwanted ecosystem state transitions. There are three management alternatives post-system change that help the system to return on its own accord, restore the system to a preferred status, or accept the changes as irreversible. Management activities that aim to restore resilience by focusing on keystone processes across multiple scales using the adaptive management framework and social resilience can help reform ecosystems.

Hobbs, R. J., E. Higgs, and J. A. Harris. 2009. *Novel ecosystems: implications for conservation and restoration. Trends in Ecology & Evolution 24:599–605.*

Land-use alterations and climate change have contributed to the shifting of ecosystems from past structure and function to represent new states, and have many names such as no-analog, novel, and emerging systems. Some amount of change is standard in ecosystems; however, the accelerated rate in which change occurs resulting from human-related progressions of non-native species and advancing climate change is pushing systems into novel states. The authors identified some of the potential consequences of novel ecosystems caused by changes to biotic and abiotic attributes. Importantly, the further away an ecosystem is from historical biotic composition and abiotic conditions, the closer it is to a novel state, wherein meaningful restoration becomes more difficult to apply, due to the crossing of restoration thresholds. It is important to continue research on novel ecosystems to identify, classify, and determine their management.

Meddens, A.J.H., C.A. Kolden, J.A. Lutz, A.M.S. Smith, C.A. Cansler, J.T. Abatzoglou, G.W. Meigs, W.M. Downing, and M.A. Krawchuk. 2018. *Fire refugia: what are they, and why do they matter for global change? BioScience (68)12:944–954.*

To define and identify the varying aspects of fire refugia by addressing three overarching questions: what are fire refugia, what theoretical frameworks underlie the ecological function of fire refugia, and how can fire refugia support ecosystem resilience under global change? Fire refugia are described as minimally affected, or unburned patches where diversity can retreat to, persist in, and potentially expand from. Fire refugia's ecological function is dependent on the mobility, fire sensitivity, and reproductive age of the animal and vegetation communities within them; the variation between the burned matrix and fire refugia; and the successional trajectories of adjacent burned areas post-fire. Fire refugia can provide areas where species that have not adapted to new disturbance regimes can seek refuge, migrate through, or adapt in place. The persistence of climate change, current land and fire management practices, and anthropogenic ecosystem alteration threatens the maintenance of fire refugia. Establishing the four refugia dichotomies identified in the paper clarifies the characteristics of fire refugia and aids in their identification and classification, further informing researchers on opportunities for future study areas that investigate the function, formation, and conservation of fire refugia. Managers can use this information for decision-making in terms of fire management strategies.

Walker, B., Kinzig, A., & Langridge, J. 1999. *Original articles: Plant attribute diversity, resilience, and ecosystem function: the nature and significance of dominant and minor species. Ecosystems 2(2):95–113.*

Developed a classification system for plant functional types and to determine functional attribute similarities concerning dominant and minor species in grazed sites. In communities that were grazed lightly, there was limited functional similarity between dominant species. Minor species in the

communities that were lightly grazed increased under heavy grazing conditions. Ecological resiliency and the subsequent structure and function of the plant communities studied are influenced by the interaction between functional diversity and redundancy. When considering restoration of native plant communities and resiliency management, it is important to incorporate species that are both functionally diverse and similar, albeit on different scales, to maintain ecological balance.

Biocrust Ecology and Influence in Rangeland Ecosystems

Bainard, L., P. Brown and M. Upadhyaya. 2009. Inhibitory effect of tall hedge mustard (*Sisymbrium loeselii*) allelochemicals on rangeland plants and arbuscular mycorrhizal fungi. *Weed Science* 57(4):386–393.

Sought to understand allelopathic potential of tall hedge mustard by assessing the effect of phytochemicals on germination, radicle growth, AMF spore germination of *Glomus intradices* and AMF inoculum potential of field soil. Spotted knapweed and bluebunch wheatgrass plants grown in tall hedge mustard conditioned soils had lower plant biomass and mycorrhizal colonization than plants grown in soils not conditioned by tall hedge mustard. Seed germination and radicle growth of spotted knapweed, bluebunch wheatgrass and Idaho fescue were reduced when treated with a tall hedge mustard extract. Spore germination of *Glomus intradices* was also reduced when exposed to tall hedge mustard extract. Tall hedge mustard and other *Sisymbrium* species capable of producing glucosinates condition soil microbial communities in ways that negatively affect heterospecific plant germination and growth. These effects are likely long lasting (i.e., soil legacies), especially in mustard monocultures, and would require restoration of the AMF community during restoration.

Bowker, M.A. 2007. Biological Soil Crust Rehabilitation in Theory and Practice: An Underexploited Opportunity. *Restoration Ecology*, 15:13–23.

Reviewed the ecological contributions of biological soil crusts as well as methods and efficacy of restoring biological soil crusts in degraded landscapes. Biological soil crusts contribute to ecosystem function by reducing soil erosion, increasing length of soil moisture availability, influencing soil biota diversity, and increasing nitrogen availability. Methods of restoration include passive restoration, where natural colonization of biocrusts is encouraged through soil stabilization or resource amendment techniques, or active restoration where sites are inoculated with biocrust spores, or transplants of surface soil containing biocrusts. At some sites combinations of passive and active restoration may be required. In arid sites especially, losses of biocrusts may initiate a transition to a degraded state and loss of ecosystem functions. Biocrusts should be monitored and protected as biological factors of resilience and resistance. Restoration of degraded landscapes will likely benefit from biocrust restoration and the functions they provide, especially in more arid systems.

Chiquoine, L.P., S.R. Abella and M.A. Bowker. 2016. Rapidly restoring biological soil crusts and ecosystem functions in a severely disturbed desert ecosystem. *Ecological Applications* 26(4):1260–72.

Determined the effects of multiple restoration methods, including soil amendment, shrub planting, inoculation and soil surface transplants on restoration of biological soil crusts in an area with mechanically disturbed soil. Eighteen months post-treatment, biocrust cover had increased in inoculated plots to levels associated with pre-disturbance conditions, although lichens (especially *Collema*) dominated, with moss communities re-establishing to a lesser degree within the time

period. Cyanobacteria recovery was associated with inoculation, and to a lesser degree top-soil transplants. Cyanobacteria density increased in inoculated plots by 20% when also receiving top-soil transplants. Increased biocrust cover was also associated with increases in soil chlorophyll a, ammonium, and stability. While inoculation and soil transplants had a significant effect on biocrust recovery over an 18-month period, plots that lacked these treatments did not experience biocrust recovery. Biocrust recovery also had a significant effect on soil functional characteristics. Biological soil crusts are a component of intact and resilient sites in semi-arid systems, and restoration of biocrust cover and function can occur over relatively short time spans using materials gathered locally.

Eldridge, D. J., R. Rosentreter and M. Pellant. 2004. Recovery of biological soil crusts following wildfire in Idaho. *Journal of Range Management* 57(1):89–96.

Determined the relationship between the recovery of the various attributes of the vascular plant community in Wyoming big sagebrush steppe and the biological soil crust community. Soil properties were highly variable in all sites and increased when seeded. Soil variability was attributed to shrub interspaces and disturbed-undisturbed patches. Post-fire plant community changes likely influenced biological crust recovery. Cheatgrass dominated burned-unseeded plots post-fire, but the burned-seeded and control plots had relatively few instances of cheatgrass. Lichen species richness and abundance were greatest on unburned plots, followed by burned-seeded. Moss species showed a similar trend. The burned-seeded plots had greatest species richness. The short moss group had consistently high cover across all treatments and increased in response to the degree of disturbance. The dominant tall moss, *Tortula ruralis*, is generally confined to sub-canopy microsites. Many of the other mosses recorded had prolific cover in some of the shrub interspaces. Annual grass cover likely decreased due to the combined effect of increased germination of small mosses resulting from increased bare soil and seeded perennial grass cover. Disturbances like fire and grazing can degrade biocrusts. Managers attempting to enhance the native plant community post-fire should consider treatments that pair seeding with biocrust inoculation. Biocrusts development is associated with reduced annual grass cover as biocrust species, particularly lichens, occupy plant interspaces, reducing resource availability for non-native annuals.

Harper, K. T. and J. Belnap. 2001. The influence of biological soil crusts on mineral uptake by associated vascular plants. *Journal of Arid Environments* 47: 347–357.

Examined novel relationships between cyano-bacteria-Collema crusts and mineral content of desert plants and present a synthesis of literature regarding the influence of biological soil crusts on desert plant mineral content. Results from this study support previous work indicating that soil crusts have both positive and negative effects on mineral concentrations in plant tissues. The presence of soil crusts was correlated with lower plant ion concentrations of Fe, Mn, Na, P and Zn in certain conditions. The authors hypothesized that these effects may result in competition between soil organisms and plants, particularly annuals, for the most limiting nutrients. In many cases, however, plant ion concentrations were higher in plants growing from soils supporting crusts. From a resilience/resistance perspective, soil crusts likely increase resistance in systems by increasing the availability of scarce nutrients for mature perennial plants while decreasing available nutrients in vegetation gaps. Disturbances that influence soil crusts should therefore be avoided, and in some

cases vegetation restoration projects may require restoration of soil crusts to ensure successful establishment in improved ecological resistance.

Hovland, M., R. Mata-González, R.P. Schreiner and T.J. Rodhouse. 2019. Fungal facilitation in rangelands: do arbuscular mycorrhizal fungi mediate resilience and resistance in sagebrush steppe? *Rangeland Ecology & Management* 72(4):678–691.

Developed a conceptual framework that enhances understanding of arbuscular mycorrhizal fungi (AMF) in sagebrush steppe ecosystems and deciphers whether or not AMF plays a role in the mitigation of exotic species invasion. Using a conceptual framework generated by tiered assessments such as mycorrhizal host status, mycorrhizal benefits, and AMF community composition, to determine the role of mycorrhizae effects on annual grass invasion may assist managers with choosing effective restoration techniques, which increases resilience and resistance. AMF can mediate environmental stressors to sagebrush ecosystems, such as drought, soil structure, and function. AMF can also mediate competition between native and invasive plants. AMFs ability to reduce competition also depends on site-specific characteristics as the responsiveness of key sagebrush ecosystem species has proven unpredictable. Tailoring the AMF restoration approach to the impaired site concerning exotic invasive species and the native ecosystem is recommended. Plant community structure should be well understood before application and commensurate with management goals. It is thought that AMF restoration will be most impactful on small scales, which have been identified as restoration islands, high priority links, and remnant vegetation communities.

Peterson, E. 2013. Regional-scale relationship among biological soil crusts, invasive annual grasses, and disturbance. *Ecological Processes* 2(1):1–8.

Sought to determine how disturbance-biocrust-annual grass relationships manifest at a regional scale. Biocrust cover demonstrated a negative association with annual grass cover; however, the correlation was low. Odds of increased annual grass cover are higher if the biocrust cover is low.

Disturbance due to cattle grazing was associated with reduced biocrust cover. Locations that have high biocrust cover also have low annual grass cover, and biocrust cover can be used as a predictor of annual grass cover in models that incorporate other ecological variables. This study validates that disturbance can also be used as a good predictor of biocrust cover in models that incorporate ecological variables. Biocrusts should be considered by managers as a paired restoration tool.

Resistance of restored areas may be reduced if the soil surface niche is left unoccupied by biocrusts. Currently, protection of areas which contain biocrusts is considered one of the only tools for managing biocrusts. Disturbance severity and its impact on biocrusts should be analyzed as some types of disturbance can be tolerated.

Williams, J.D., J.P. Dobrowolski, N.E. West and D.A. Gillette. 1995. Microphytic crust influence on wind erosion. *Transactions of the American Society of Agricultural Engineering* 38:131–137.

Examined the impacts of microphytic crusts on soil stability in a desert ecosystem. Compared wind velocity thresholds for soil movement in treatments with intact soil crusts (control), sites where soil crusts were chemically killed and sites where crusts were mechanically removed (scalped). Scalped treatments were more susceptible to wind erosion than either chemically treated or control sites. Soil crusts reduce soil erosion potential by binding soil particles, and are thus an important component of

ecological site integrity. In rangeland areas where soil crusts are present, managers should restrict land uses that may physically damage these crusts. Additionally, restoration activities should include provisions for establishing soil crusts as an important component of ecosystem integrity.

Appendix B. Geodatabase Table of Contents

A geodatabase is provided as a companion to this report to support spatially-explicit plans for park prioritization of steppe landscapes and is available at (<https://irma.nps.gov/Datastore/Reference/Profile/2271774>).

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Table B-1. Geodatabase Table of Contents.

Theme	Feature class or raster name	Description	Source(s), modified for project
Boundaries	JODA_BND_ParkUnitBoundaries_py	JODA park unit boundaries	Selection from "National Park Service – Park Service Boundaries" shapefile accessed from https://public-nps.opendata.arcgis.com/datasets/b1598d3df2c047ef88251016af5b0f1e_0
	JODA_BND_PLSS_py	Public Land Survey System within JODA project area	Derived from: Bell, J. and D. Hinson. 2010. Natural resource condition assessment: John Day Fossil Beds National Monument. Natural Resource Report NPS/UCBN/NRR—2010/174. National Park Service, Fort Collins, Colorado.
	JODA_BND_ProjectArea_py	JODA project areas created by placing a two kilometer buffer around the watershed basins surrounding the park units	Derived from: Bell, J. and D. Hinson. 2010. Natural resource condition assessment: John Day Fossil Beds National Monument. Natural Resource Report NPS/UCBN/NRR—2010/174. National Park Service, Fort Collins, Colorado.
Fire	JODA_FIRE_Boundaries_py	JODA prescription and wildfire polygons	John Day Fossil Beds National Monument, National Park Service shapefiles AND GeoMac.gov, US Historic Fire Perimeters, https://rmgsc.cr.usgs.gov/outgoing/GeoMAC/historic_fire_data/us_historic_fire_perims_dd83_METADATA.html
	JODA_FIRE_HancockComplex2011OctoberPoints_pt	Post-fire burn severity survey plots	Tom Rodhouse, Ph.D., Ecologist, UCBN, National Park Service
Geology	JODA_GEOL_Soils_py	Includes ecological site descriptions, soil temperature and moisture regimes	National Park Service SRI-Soil Survey Geographic (SSURGO) for John Day Fossil Beds National Monument, Oregon.
Land Use	JODA_BND_Ownership_py	General land ownership within the three management units of JODA	Derived from: Bell, J. and D. Hinson. 2010. Natural resource condition assessment: John Day Fossil Beds National Monument. Natural Resource Report NPS/UCBN/NRR—2010/174. National Park Service, Fort Collins, Colorado.

Theme	Feature class or raster name	Description	Source(s), modified for project
Resistance & Resilience	JODA_ECO_BradfordEtAl_py	Current and future potential resilience and resistance @ 10km resolution based on SSURGO/STATSGO soils information and climate change projections (eg RCP 4.5 and 8.5 CMIP5).	Bradford et al. 2019. Climate-driven shifts in soil temperature and moisture regimes suggest opportunities to enhance assessments of dryland resilience and resistance. <i>Frontiers in Ecology and Evolution</i> 7:358.
Transportation	JODA_TRANS_All_Trails_In	JODA trails	John Day Fossil Beds National Monument shapefiles (from field collected data and partial digitization using NAIP imagery) and BLM OR GTRN Publication Trails Line (gtrn_pub_trails_arc, published 2018-06-12) were merged and edited to create this feature class.
	JODA_TRANS_highways_In	Highways within and between Clarno, Painted Hills and Sheep Rock units of JODA	Oregon Department of Transportation highways_arc obtained from the Oregon Spatial Data Library, clipped to the area of interest.
	JODA_TRANS_roads_In	Roads within and around Clarno, Painted Hills and Sheep Rock units of JODA	Bureau of Land Management (BLM) GTRN_PUB_ROADS_ARC, clipped to the area of interest and edited using ESRI basemap imagery.
Vegetation	JODA_VEG_2011_2019_PlotsSurveyed_pt	NPS Upper Columbia Basin Network vital signs monitoring plot locations surveyed during 2011–2019.	Locations were generated via randomization following the monitoring program protocol, Yeo et al. 2009 (see: https://irma.nps.gov/DataStore/Reference/Profile/662446).
	JODA_VEG_SamplingFrame_2019_py	NPS Upper Columbia Basin Network vital signs monitoring sample frames for 2019.	Sample frames were generated following the monitoring program protocol, Yeo et al. 2009 (see: https://irma.nps.gov/DataStore/Reference/Profile/662446).
	JODA_VEG_Vegetation_py	Vegetation polygons in JODA	2011. Vegetation Inventory Project John Day Fossil Beds National Monument, accessed from the Integrated Resource Management Applications data portal at https://irma.nps.gov/DataStore/Reference/Profile/2188808 .
Vegetation Raster	JODA_VEG_GAP_NTE_2011_ra	GAP National Terrestrial Ecosystems land cover map for JODA project area	U.S. Geological Survey Gap Analysis Program http://gapanalysis.usgs.gov

Theme	Feature class or raster name	Description	Source(s), modified for project
Water Resources	JODA_HYDRO_basins_py	Watershed and subwatershed hydrologic unit boundaries	Derived from: Bell, J. and D. Hinson. 2010. Natural resource condition assessment: John Day Fossil Beds National Monument. Natural Resource Report NPS/UCBN/NRR—2010/174. National Park Service, Fort Collins, Colorado.
	JODA_HYDRO_streams_py	Primary streams within JODA project areas	Derived from: Bell, J. and D. Hinson. 2010. Natural resource condition assessment: John Day Fossil Beds National Monument. Natural Resource Report NPS/UCBN/NRR—2010/174. National Park Service, Fort Collins, Colorado.
	JODA_HYDRO_waterbodies_py	Water bodies (lakes, ponds, wetlands, streams and other hydrographic features) within JODA project areas	Derived from: Bell, J. and D. Hinson. 2010. Natural resource condition assessment: John Day Fossil Beds National Monument. Natural Resource Report NPS/UCBN/NRR—2010/174. National Park Service, Fort Collins, Colorado.
Difference Normalized Burn Index (dNBR) rasters	JODA_FIRE_dnbr1999_WindyPt_Rx_ra	Fire severity raster for the JODA 9/7/1999 Windy Point prescribed fire in the Sheep Rock Unit	LANDSAT data downloaded from earthexplorer.usgs.gov, processed in Arc Map, and clipped by buffered (30m) fire boundary (source: NPS and LANDFIRE www.landfire.gov). LANDSAT image dates: 31 July 1999 and 17 September 1999.
	JODA_FIRE_dnbr2001_Picture_Rx_ra	Fire severity raster for the JODA 10/2/2001 Picture prescribed fire in the Sheep Rock Unit	LANDSAT data downloaded from earthexplorer.usgs.gov, processed in Arc Map, and clipped by buffered (30m) fire boundary (source: NPS and LANDFIRE www.landfire.gov). LANDSAT image dates: 22 September 2001 and 24 October 2001.
	JODA_FIRE_dnbr2002_MiddleMtn_Rx_ra	Fire severity raster for the Middle Mtn prescribed fire on 9/24/2002 in the Sheep Rock Unit of JODA	LANDSAT data downloaded from earthexplorer.usgs.gov, processed in Arc Map, and clipped by buffered (30m) fire boundary (source: NPS and LANDFIRE www.landfire.gov). LANDSAT image dates: 9 September 2002 and 11 October 2002.
	JODA_FIRE_dnbr2002_SandMtn_Rx_ra	Fire severity raster for the 9/20/2002 Sand Mountain prescribed fire in the Painted Hills Unit of JODA	LANDSAT data downloaded from earthexplorer.usgs.gov, processed in Arc Map, and clipped by buffered (30m) fire boundary (source: NPS and LANDFIRE www.landfire.gov). LANDSAT image dates: 9 September 2002 and 25 September 2002.

Theme	Feature class or raster name	Description	Source(s), modified for project
	JODA_FIRE_dnbr2004_RockCr_Rx_ra	Fire severity raster for 9/5/2004 Rock Creek prescribed fire in the Sheep Rock Unit of JODA	LANDSAT data downloaded from earthexplorer.usgs.gov, processed in Arc Map, and clipped by buffered (30m) fire boundary (source: NPS and LANDFIRE www.landfire.gov). LANDSAT image dates: 29 August 2004 and 30 September 2004.
	JODA_FIRE_dnbr2005_BransonS_Rx_ra	Fire severity raster for the 9/1/2005 Branson-South prescribed fire in the Sheep Rock Unit of JODA	LANDSAT data downloaded from earthexplorer.usgs.gov, processed in Arc Map, and clipped by buffered (30m) fire boundary (source: NPS and LANDFIRE www.landfire.gov). LANDSAT image dates: 16 August 2005 and 2 July 2006. NOTE the large time difference between images and interpret results with caution.
	JODA_FIRE_dnbr2005_BransonN_Rx_ra	Fire severity raster for the 9/14/2007 Branson-North prescribed fire in the Sheep Rock Unit of JODA	LANDSAT data downloaded from earthexplorer.usgs.gov, processed in Arc Map, and clipped by buffered (30m) fire boundary (source: NPS and LANDFIRE www.landfire.gov). LANDSAT image dates: 7 September 2007 and 7 July 2008. NOTE the large time difference between images and interpret results with caution.
	JODA_FIRE_dnbr2011_HancockComplex_wf_ra	Fire severity raster for the 2011 Hancock Complex wildfire in the Clarno Unit of JODA	LANDSAT data downloaded from earthexplorer.usgs.gov, processed in Arc Map, and clipped by buffered (30m) fire boundary (source: NPS and LANDFIRE www.landfire.gov). LANDSAT image dates: 17 August 2011 and 9 September 2011.
	JODA_FIRE_dnbr2015_BlueBasin_wf_ra	Fire severity raster for the 2015 Blue Basin wildfire in the Clarno Unit of JODA	LANDSAT data downloaded from earthexplorer.usgs.gov, processed in Arc Map, and clipped by buffered (30m) fire boundary (source: NPS and LANDFIRE www.landfire.gov). LANDSAT image dates: 25 June 2015 and 12 August 2015.
	JODA_FIRE_dnbr2015_SugarLoaf_wf_ra	Fire severity raster for the 2015 Sugar Loaf wildfire in the Clarno Unit of JODA	LANDSAT data downloaded from earthexplorer.usgs.gov, processed in Arc Map, and clipped by buffered (30m) fire boundary (source: NPS and LANDFIRE www.landfire.gov). LANDSAT image dates: 25 June 2015 and 12 August 2015.

Theme	Feature class or raster name	Description	Source(s), modified for project
Surface Rasters	JODA_TOPO_Aspect_ProjectArea_ra	Aspect raster created from 10m DEM	DEM retrieved from ArcGIS REST Services Directory from the Oregon Geospatial Enterprise Office: https://navigator.state.or.us/arcgis/rest/services/Framework/Elevation_DEM_10m/ImageServer and processed in ESRI ArcMap.
	JODA_TOPO_DEM_10m_ProjectArea_ra	Digital Elevation Model (DEM)	DEM retrieved from ArcGIS REST Services Directory from the Oregon Geospatial Enterprise Office: https://navigator.state.or.us/arcgis/rest/services/Framework/Elevation_DEM_10m/ImageServer and processed in ESRI ArcMap.
	JODA_TOPO_SCOSA_Project Area_ra	SCOSA raster created from 10m DEM-derived surfaces (Aspect and Slope)	DEM retrieved from ArcGIS REST Services Directory from the Oregon Geospatial Enterprise Office: https://navigator.state.or.us/arcgis/rest/services/Framework/Elevation_DEM_10m/ImageServer and processed in ESRI ArcMap.
	JODA_TOPO_Slope_ProjectArea_ra	Slope raster created from 10m DEM	DEM retrieved from ArcGIS REST Services Directory from the Oregon Geospatial Enterprise Office: https://navigator.state.or.us/arcgis/rest/services/Framework/Elevation_DEM_10m/ImageServer and processed in ESRI ArcMap.

Appendix C. Fire Management Plan Update Recommendations for John Day Fossil Beds National Monument.

The purpose of these revisions is to provide the scientific basis for updates to the June 2004 Wildland Fire Management Plan (FMP) for the Monument. Suggested revisions reflect contemporary scientific understanding circa 2019. Recommendations are based on current understanding of the fire ecology of North American sagebrush steppe ecosystems, and vegetation community responses to fire within the Monument itself. Conclusions drawn here rely on the concepts of resistance to invasion and resilience to disturbance that are well established and increasingly applied to inform understanding of the risks prescribed and wildland fires present for increasing exotic annual grass invasion. The exotic annual grasses present at the Monument have increased the risk of ignition and spread of wildfire due to the flammability, density, and continuity of annual grass litter. There is also an increased risk of post-fire invasion by annual grasses into previously uninvaded sites due to the amount of annual grass seed present in the soil. The active annual grass-fire cycles now established in all Monument uplands require management priorities to shift to fire prevention, post-fire mitigation of annual grass re-establishment via pre-emergent herbicide application, and the use of mechanical and chemical methods of invasive plant treatment rather than use of prescribed burns that was used by the Monument historically and advocated in the 2004 FMP.

What follows are recommended changes to specific sections of JODA Wildland Fire Management Plan that will better reflect current scientific knowledge and best protect significant natural resources within the Monument.

Objectives

1. Remove prescribed burning as an invasive species management tool.
2. Update policy to reflect current within-agency drivers of fire management decisions.
3. Provide reasoning for removal of prescribed burning as an invasive species management tool.
4. Update vegetation and soils sections to include results from contemporary NPS vital signs and fire effects monitoring and to integrate resistance and resilience concepts into the plan.
5. Suggest strategic fire suppression activity and protection of sites harboring intact native vegetation.
6. Update fire monitoring and research sections to reflect current understanding

Suggested Actions

1. Remove prescribed burning as an invasive species management tool.

Provided is a list of sections where prescribed burning is mentioned in the text. Removal or alteration of content is suggested. Proposed replacement content for some of these sections are available later in this document.

- Section I. A. (pg 7) Prescribed fire may be used to reduce hazardous fuels; restore the natural ecosystem processes; reduce debris resulting from management practices; maintain the historic

practices and viewshed; expose or reduce encroaching native and non-native vegetative species; and/or further the knowledge of fire effects on the ecosystem through research.

- Section I. A. (pg 7) Development of an approved fire management plan will facilitate the goal of using prescribed fires in portions of John Day Fossil Beds National Monument for resource benefits.
- Section I A. (pg 10) Prescribed fires . . . may be used to achieve agency land or resource management objectives as defined in the fire management plans. Prescribed fires will be conducted only when the following conditions are met: a.) Conducted by qualified personnel under written prescriptions. b.) Monitored to assure they remain within prescription.
- Section II. B. 1. (pg 11) The utilization of fire as a management tool will aid in accomplishing these objectives by reducing the hazardous fuel accumulations and resultant potential for large wildfires that could threaten these resources, while returning the natural process of fire to the ecosystems of the Monument.
- Section III. A. (pg 18) Lightning caused wildfires on the Monument are not a major concern, except where they have the potential to threaten lives, NPS facilities, or historic buildings because they are a natural phenomenon in the ecology of the area.
- Section III. C. 2. (pg 20) Prescribed fires will be used to meet stated resource objectives as described in this GMP. (Entire section)
- Section IV. D. (pg 47) Prescribed Fire (Entire section)

2. Update policy

Remove policy quotes that encourage the use of prescribed fire.

- Section I A. (pg 10) Prescribed fires . . . may be used to achieve agency land or resource management objectives as defined in the fire management plans. Prescribed fires will be conducted only when the following conditions are met: a.) Conducted by qualified personnel under written prescriptions. b.) Monitored to assure they remain within prescription.
- Section II. B. 1. (pg 11) The utilization of fire as a management tool will aid in accomplishing these objectives by reducing the hazardous fuel accumulations and resultant potential for large wildfires that could threaten these resources, while returning the natural process of fire to the ecosystems of the Monument.

Incorporate current NPS policy and culture concerning fire in the parks.

- Section II. A. (pg 9) NPS Management Policies Concerning Fire Management

Rationale

While past NPS policy (1988) has advocated for a hands-off approach to fire management, it has become increasingly recognized in the current era of rapid environmental change that active management of parks and protected areas is required (Chapin et al. 2006, Cole et al. 2008, Hobbs et al. 2009). For example, NPS Director's Order 100 (which was rescinded in 2017 but yet still provides sound contemporary resource management guidelines) specified that the agency should manage park resources with an emphasis on resilience. More specifically, DO 100prescribed the following:

“To achieve the stewardship goal and set priorities for conservation, restoration, and protection of resources, the NPS will emphasize resilience, connectivity at land/seascape scales, and life-cycle stewardship as guiding strategies for resource management. Application of these strategies in resource management will be informed by scientific and scholarly research and traditional ecological knowledge.”

Increasing active stewardship (i.e., not relying on natural disturbance) is particularly relevant for wildland fire management in NPS units with sagebrush steppe vegetation, due largely to annual grass invasion. The Monument, which has a history of grazing, exotic plant invasion, and wildfires, and is considered to be inherently a low resilience (Wyoming big sagebrush) landscape (Miller et al. 2013, Chambers et al. 2014), should be considered a model setting for the implementation of this strategy.

3. Provide reasoning for removal of prescribed burning as an invasive plant management option.

- Section III. C. 2. (pg 20)

Replace with:

Prescribed fires will **NO LONGER** be used to meet stated resource objectives as described in this GMP.

Prescribed burns are no longer recommended at the Monument. Long-term monitoring data and recent studies conducted within the park clearly demonstrate that fire within the Monument too often results in loss of native plant communities and dominance by exotic annual grasses. At the time of the 2004 revision of the FMP, future prescribed burns were absent only from the Clarno Unit of the Monument, due to the recent wildfires and extensive invasion of medusahead at that location. Since that time, both wild and prescribed fires have continued to alter the landscape at JODA. Research continues to support the connection between fires and increased annual grass cover. Long-term fire effects monitoring conducted at the Monument revealed persistent shifts from diverse sagebrush steppe-plant communities, to communities dominated by annual grasses (Reed-Dustin et al. 2016) and weedy sub-shrubs (Mata-Gonzalez et al. 2018). Notably, big sagebrush is still absent from plots burned 15 years prior (Mata-Gonzalez et al. 2018). Vegetation monitoring conducted by the UCBN vital signs monitoring program has revealed a steady increase in annual grass cover in all units of the Monument (Figure C-1). Predictive models drawing on UCBN monitoring data have also shown that only ~25% of the upland vegetation in the Monument supports intact stands of native bunchgrass (Rodhouse et al. 2014). Not only has cheatgrass and medusahead expanded and increased in density, but a new exotic annual grass, *Ventenata dubia* (ventenata) has established itself (first discovered in 2014), and increased in cover by approximately 650% in only three years (Nicolli et al. 2020).

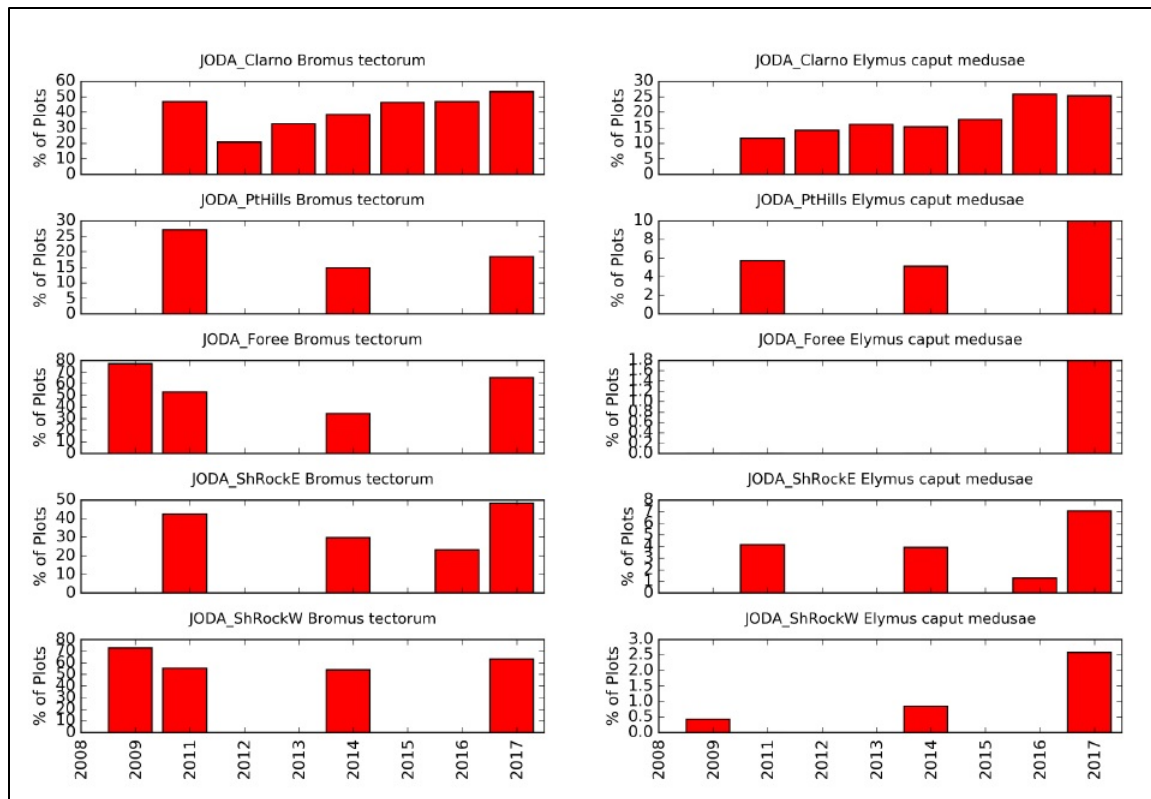


Figure C-1. Graphs showing percentage of monitoring plots where cover of *Bromus tectorum* (cheatgrass) and *Elymus caput-medusae* (medusahead) exceeded 25%. Data available is from 2008–2017, and locations are different units of the John Day Fossil Beds National Monument. The continuous data set from the Clarno Unit reflects post-fire monitoring efforts.

4. Update vegetation and soils sections to include current monitoring data and resistance and resilience concepts. Elaborate on cheatgrass ecology, and include medusahead and ventenata as biotic drivers of state transitions.
 - Section II. B. 2. e. (pg 14) *Vegetation*

Replace with:

The dominant native plant communities in the Monument include big sagebrush/bunchgrass, western juniper/big sagebrush, and bunchgrass-dominated steppe communities. Other communities, such as willow-dominated riparian and mountain mahogany communities also occur. Exotic annual grass communities dominate at lower elevations and on south-facing slopes (Rodhouse et al. 2014, Esposito et al. 2019). These annual grass communities are comprised of cheatgrass [and other exotic bromes such as *Bromus japonica* (Japanese brome)], medusahead, and ventenata. A description of the effect of fire on plant communities within the Monument is located in this document (Section III. D. 5. d. – *Vegetation Changes Due to Fire and Fire Suppression*), however, it should be noted that annual grasses benefit from the presence of fire in the Monument, and, according to monitoring efforts, are steadily increasing in density and distribution (Figures C-1, C-2).

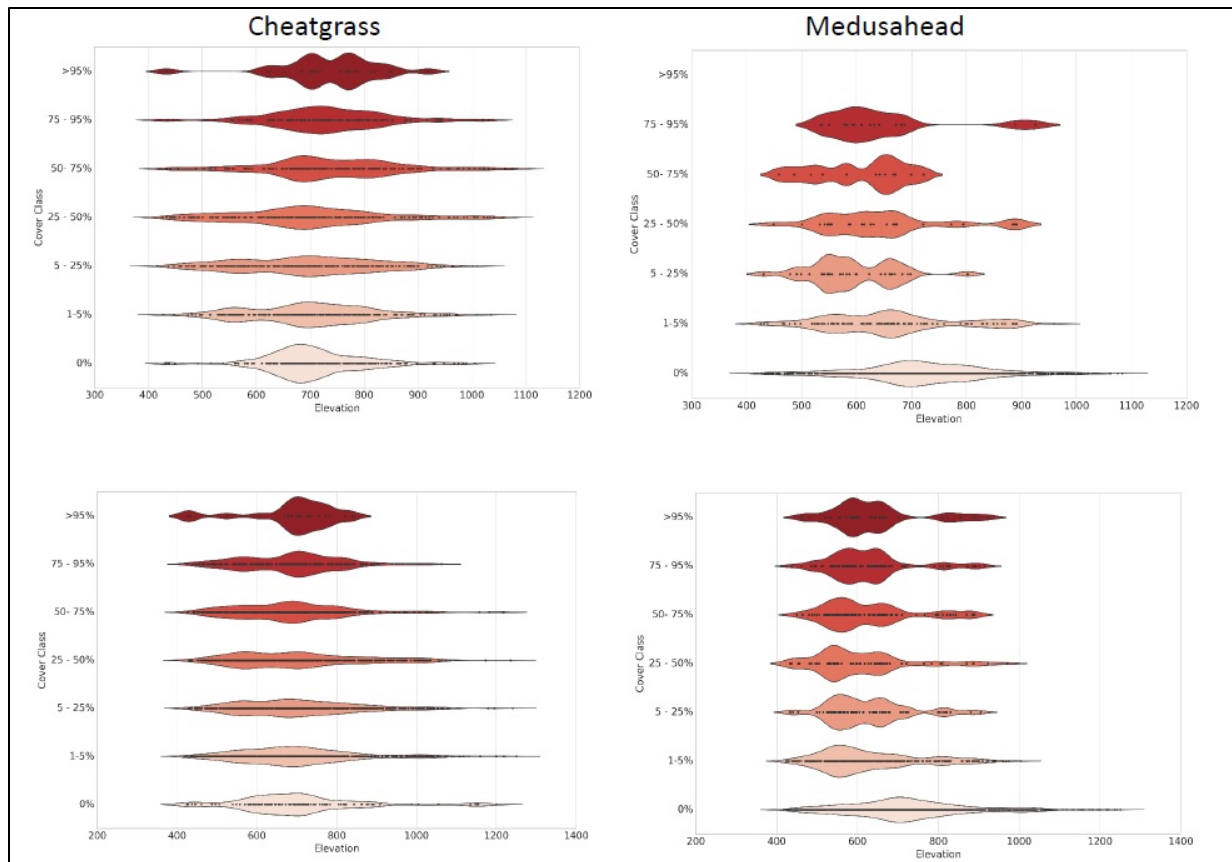


Figure C-2. Bean plots comparing cheatgrass and medusahead cover by elevation between survey years 2008–2012 and survey years 2013–2017. While elevation is considered an abiotic aspect of resistance and resilience at this park, more recent surveys have found greater cover of both annual grasses at higher elevations, revealing upslope expansion.

While resistance to exotic plant invasion does not appear to increase with increased distance from Monument boundaries (Esposito et al. 2019), certain invasive plant populations may be more prevalent along highways and waterways. Roadside weed populations commonly include annual grasses, but also annual forbs such as *Koschia scoparia*, *Salsola tragus* (Russian thistle), *Onopordum acanthium* (Scotch thistle), and *Sysimbrium altissimum* (tumble-mustard), with reed canary grass forming dense monocultures in riparian areas.

In addition to prioritizing intact native plant communities for protection, there may be individual plant populations worth monitoring and protecting at the Monument. While no federally-listed plant species occur in the Monument, the state of Oregon lists arrow-leaf thelypody (*Thelypodium eucosmum*) and South John Day milkvetch (*Astragalus diaphanous* var. *diurnus*) as threatened and Henderson ricegrass (*Achnatherum hendersonii*) and Jugermann’s monkeyflower (*Mimulus jungermannoides*) as candidate plant species (Hoh et al. 2015). Locally endemic plants found within the Monument include Henderson ricegrass, as well as John Day chaenactis (*Chaenactis nevii*), yellowhair paintbrush (*Castilleja xanthotricha*), fuzzytongue penstemon (*Penstemon eriantherus* var. *argillosus*), and snowball cactus or hedgehog cactus (*Pediocactus nigrispinus*) (Beuchling 2008).

An inventory of plant communities was completed in 1976 at John Day Fossil Beds NM (Youtie and Winward 1977), updated by Sapsis (1992), and once again during the Natural Resources Conservation Service Soil Surveys in the late 1990's (2001 Draft Report). A complete vegetation inventory and vegetation map was produced for the Monument by the UCBN vital signs monitoring program during the inventory phase of the program (Erixson et al. 2011). An inventory of all natural resources conditions was also completed by the UCBN in 2010 (Bell and Hinson 2010). More recent UCBN monitoring-related documents published in the NPS Natural Resource Data Series (e.g., Nicolli 2019, Smith et al. 2017, Esposito and Rodhouse 2015) detail findings from vegetation surveys. Furthermore, a model-based synthesis of upland condition for prioritization of areas for protection following the Ecologically-Based Invasive Plant Management (EBIPM) decision-support toolkit that utilized UCBN monitoring data was produced by Rodhouse et al. (2014) with a corresponding park plan (Hoh et al. 2015). All of these documents are available from the NPS data store <https://irma.nps.gov>) and from the UCBN website (which mirrors the data store).

- Section II. B. 2. f. (pg 15)

Replace the paragraph beginning “*The soils of the monument . . .*” with:

The soils of the Monument range from deeper loams and clays along the riparian areas; to shallow rocky bluffs; to the exposed paleosols (most of which are nearly devoid of vegetation) typical of the Painted Hills Unit. In general, the aridic soil moisture and mesic soil temperatures of the Monument lend to site invasibility by annual grasses. Soils are composed of ashy, gravelly, and stoney loam, with a clayey sub-surface, although there are also examples of exposed paleosols. The clay soils of the Monument facilitate the establishment of medusahead grass. Slow permeability and high run-off potential are especially common of clay soils dominated by annual grasses, while intact bunchgrass communities tend to persist in soils with less clay, and more organic matter.

Cloudburst storms following summer wildland fires pose one of the greatest threats to the soil resource because large amounts of soil may be temporarily exposed. Typically, the best stands of native plant communities are found at higher elevations or on north slopes due to better moisture regimes. These recover from disturbance quickly and are the most likely to be protected from soil erosion by vegetation.

- Section III. D. 5. d. (pg 28) Vegetation Changes due to Fire and Fire Suppression

Replace with:

The arrival of exotic invasive annuals such as cheatgrass (*Bromus tectorum*) and medusahead (*Taeniatherum caput-medusae*) in the last century has led to the conversion of extensive acreages to fire-tolerant monocultures throughout the Intermountain West, Great Basin and southwestern United States. Reduced bio-diversity and increased fine fuel loads at annual grass invaded sites promotes more frequent and expansive fires, and decreases resistance to invasion and resilience to disturbance, promoting post-fire reinvasion by annual grasses (i.e., annual grass-fire cycle). Cheatgrass has become ubiquitous in the Monument due to this fire cycle, exacerbated by historic livestock grazing. Medusahead is also expanding rapidly and contributes to the fire cycle because it builds a dense layer

of flammable thatch. Both of these exotic grasses are annuals, and selective herbicide treatments have become available to slow their invasion. Imazapic is a popular pre-emergent herbicide that can be applied to an area that has been affected by fire in order to reduce the initial establishment of annual grasses, but is only part of a post-fire management scheme that would include seeding of native grasses and reapplication of herbicide the following year. Aminopyralid is a pre-emergent herbicide that is currently not as widely used as Imazapic, but shows promise suppressing both medusahead and ventenata (*Ventenata dubia*).

A number of other weeds found in the Monument's uplands may also benefit from reduced competition for resources and increased nutrient availability resulting from wildland fires. These include, but are not limited to Dalmatian toadflax, Russian knapweed, yellow starthistle, and scotch thistle. Suppression of fire and burned area emergency response utilizing herbicide and seeding will be necessary on nearly all of the lands of the Monument. A more detailed approach to managing invasive annual grasses can be found within the Ecologically Based Invasive Plant Management plan (Hoh et al. 2015) and Burned Area Emergency Response plan for the Monument.

5. Suggest strategic suppression activity and protection of sites harboring intact native vegetation. Include as a natural resource to be protected from detrimental impact due to wildfire (see Wildfire Management Goal #2 on page 18).
 - Section II. B. 1 (pg 11) The utilization of fire as a management tool will aid in accomplishing these objectives by reducing the hazardous fuel accumulations and resultant potential for large wildfires that could threaten these resources, while returning the natural process of fire to the ecosystems of the Monument.

Rationale

The suppression of fire will likely aid in accomplishing these objectives. Fires will exacerbate conversion to annual grasslands and exposure of steep slopes to more bare ground and higher rates of erosion, potentially exposing fossil resources and geological formations to degradation.

- Section III. A. (pg 18) Lightning caused wildfires on the Monument are not a major concern, except where they have the potential to threaten lives, NPS facilities, or historic buildings because they are a natural phenomenon in the ecology of the area.

Rationale

We advocate for the elimination of prescribed fire and strategic suppression of all wildfires in the Monument. We suggest that natural resource management goals that relate removal of western juniper be accomplished, where warranted, with manual mechanical thinning. This and other vegetation management activities, including application of herbicide should be done strategically as advocated for by Rodhouse et al. 2014 and as planned by Hoh et al. 2015, as part of the implementation of EBIPM in the Monument.

Further, we recommend strategic fuel treatments in areas infested with exotic species to create fire breaks surrounding priority native vegetation. The proposed approach follows methods utilized on the Sawtooth National Forest and soon to be implemented at Hagerman Fossil Beds National

Monument (Gilbert Moreno, personal communication). Treatments consist of fall application of Imazapic to 100-foot wide buffers around intact native vegetation patches. Treatments are repeated the following spring, with the addition of glyphosate. Success of both chemical applications is enhanced by moisture, so timing application of Imazapic to coincide with precipitation events is important. This treatment will result in bare soil areas for 2–3 years following application, after which the areas can be seeded with desirable species to rebuild site resistance and reduce spread of exotic species into high priority vegetation zones.

- Section III. C. 2. (pg 20) *Wildland Fire Suppression*

6. Update fire monitoring information, including current methods and future plans

- Section VI. (pg 62) Monitoring and Evaluation

Replace with:

The NPS Fire Effects Monitoring Program and the NPS Inventory & Monitoring Program (via the NPS Upper Columbia Basin Network) Reed-Dustin et al. 2016, Mata-Gonzalez et al. 2018, Esposito et al. 2019 are closely monitoring the uplands of the park both prior to and after fire. Recent post-fire monitoring has been conducted at the Clarno Unit of the Monument since a 2011 wildfire, and at the Blue Basin portion of the Sheep Rock Unit since a 2015 wildfire. Analyses of vegetation changes following older fires have been completed by Rodhouse et al. (2014), Reed-Dustin et al. (2016), Mata-Gonzalez et al. (2018), Esposito et al. (2019).

- Section VII. A. (pg 64) Previous and Ongoing Fire Research Conducted at JODA

Replace with:

Fire monitoring and data collection by a regional NPS Fire Effects team has been ongoing since 1999 when the first prescribed burn was planned and completed at the Monument. In 2014, the analysis of this 15-year fire effects data set resulted in two published papers on the response of grasses (Reed-Dustin et al. 2016) and shrubs (Mata-Gonzalez et al. 2018) to prescribed fire. Broader assessments of vegetation in burned and unburned portions of the Monument have been included in the analyses of Rodhouse et al. (2014) and Esposito et al. (2019). Analyses of more recent wildfires (e.g., 2011 in Clarno and 2014 in Sheep Rock) is ongoing. Prior to these studies, a study of fire effects on native bunchgrass was conducted in a small portion of the Sheep Rock Unit by (Kauffman, et al. (1997). Kauffman et al. (1997) concluded that native bunchgrass in the Monument responded favorably to fire and advocated broadly for the use of prescribed fire for fuels reduction and weed management. This report is now considered outdated and has been superseded by the more recent studies and supporting scientific understanding. There is overwhelming evidence that fires have exacerbated the weed situation in the Monument and have not succeeded in enhancing desired native plant communities. Given the spatial extent of current exotic annual grass invasion, associated seed bank and presence of an annual grass fire-cycle in the Monument, prescribed burning and let-it-burn wildfire management strategies are no longer supported.

Appendix D. Recommendations for Burned Area Emergency Response Planning at John Day Fossil Beds National Monument.

The purpose of this information is to propose content for inclusion into future burned area assessment and planning documents at JODA. Recommendations provided here are based on information derived from the peer-reviewed literature summarized in this document and are consistent with existing Department of Interior guidance documents. More specifically, this content is designed to complement guidance provided by the 2006 Interagency Burned Area Emergency Response Handbook and the USDA Science Framework for Conservation and Restoration of the Sagebrush Biome (Crist et al. 2019). Successful implementation of these recommendations is reliant on incorporation of the existing EBIPM plan for JODA (Hoh et al. 2015) into integrated fire and vegetation management planning.

Proposed Objectives for Future Burned Area Assessments

1. Evaluate potential for non-native plant expansion and encroachment into native plant communities within fire perimeter.
2. Provide management recommendations to treat areas of existing exotic annual grass invasion adjacent to the burned area perimeter and prevent expansion into the burned area.
3. Provide management recommendations to protect remnant native vegetation and enhance recovery in burned areas unlikely to recover naturally from fire damage.

Issues

Remnant healthy populations of bluebunch wheatgrass (*Pseudoroggenria spicata*), predominantly on north facing slopes, have burned and are at high risk of invasion by annual invasive grasses.

Cheatgrass (*Bromus tectorum*) dominates much of the sagebrush steppe landscape within the park. Medusahead (*Elymus caput-medusae*) is less dominant, but is spreading rapidly. Both are winter annuals and significantly increase fire activity. Both have the ability to outcompete native grasses in a post fire environment.

Due to past management practices many species of invasive weeds are present. Thirteen well established exotic plant species are of particular management concern.

Cover of Wyoming big sagebrush (*Artemisia tridentata wyomingensis*) is low and many areas that once supported big sagebrush have burned previously and sometimes repeatedly, both from the increased fire cycle and from prescribed fire to control juniper. Big sagebrush recovery is not evident in many (if not all) post-fire vegetation communities in the Monument.

Sagebrush steppe is one of the most threatened ecosystems in the Intermountain West. As a result, JODA is an important repository of sagebrush steppe habitat and regionally significant vegetation propagules. Remaining steppe habitats within the Monument must be prioritized for protection.

Steep terrain and access for treatment limits management opportunities.

Background

Natural and Developed Setting

John Day Fossil Beds National Monument (JODA) is in the John Day River Valley and Basin, a subunit of the Columbia Plateau region in north central Oregon. The landscape is heavily influenced by the John Day River and its associated geography. Large alluvial fans and flats morph into hills, some very steep, and ridges consisting of bedrock, basalt, sediment and badland exposures. JODA's elevations range from 1,300 to 4,578 feet. The weather also varies and is unpredictable. The area in and around the Monument is characterized by a semiarid plateau/continental climate, averaging approximately 14 inches of precipitation annually, including 15 inches of snow. Temperatures range from an average maximum of 91.2 F in July to an average minimum of 21.6F in January (Bell and Hinson 2010).

Steppe Vegetation

JODA is separated into three geographically distinct Units; the Sheep Rock Unit (8916 acres), the Clarno Unit (1969 acres), and the Painted Hills Unit (3129 acres). Together the Units comprise 14,056 acres and support upland plant communities classified as "intermontane sagebrush steppe" (Bell and Hinson 2010). Vegetation communities of the intermontane sagebrush steppe within the Monument consist of a mixture of forbs, shrubs, and dryland grasses, with western juniper (*Juniperus occidentalis*) present as scattered open savannah in the uplands (Bell and Hinson 2010). A 2010 natural resources condition assessment (Bell and Hinson 2010), supported by a concurrent comprehensive vegetation inventory (Erixson et al. 2011) identified that the most widespread upland plant associations in the Monument were those dominated by western juniper, big sagebrush, and bluebunch wheatgrass. The most common (>2600 acres) map class within JODA was an herbaceous vegetation complex dominated by bluebunch wheatgrass and Sandberg bluegrass (*Poa secunda*). The subspecies of big sagebrush that is found in the Monument is predominantly Wyoming big sagebrush (*A. t. wyomingensis*). In deeper soils (e.g., flat valley bottoms) basin big sagebrush (*A. t. tridentata*) is common. Both of these overstory big sagebrush subspecies are associated with inherently low-resilient and low-resistant sagebrush steppe because they grow in dry (low productivity) ecoregions. Big sagebrush and bluebunch wheatgrass are foundation species for steppe communities found in the Monument, and can be used as indicators for overall site integrity, and potential resilience and resistance (Sheley et al. 2006, Chambers and Wisdom 2009, Miller et al. 2013, Chambers et al. 2014, Chambers et al. 2019).

Contemporary conditions of Monument steppe plant communities are severely degraded from recent wildfires and annual grass invasion. Cheatgrass is particularly ubiquitous throughout the Monument. For example, NPS vital signs monitoring teams rarely encounter cheatgrass-free sites, and the percentage of large-sample randomly-located monitoring plots with no cheatgrass is routinely ~95%. More worrisome is the rapid rates of increase by medusahead rye (*Taeniatherum caput-medusae*) and ventenata grass (*V. dubia*) in the Monument. Several analyses of both the NPS fire effects monitoring and NPS vital signs monitoring data have demonstrated a clear increase in annual grass invasion as a

result of fire in recent decades (Rodhouse et al. 2014, Reed-Dustin et al. 2016, Mata-Gonzalez et al. 2018, Esposito et al. 2019, Nicolli et al. 2020).

Land Use history

The proximity of available water coupled with a relatively mild climate led to a plethora of human use in the region. Predominant land uses in the basin include agriculture, timber production, and recreation. Due to past and present land use, coupled with the introduction of invasive plant species, much of the uplands have been converted to annualized grasslands dominated by cheatgrass (*Bromus tectorum*), medusahead (*Elymus caput-medusae*) and other non-native grasses. Subsequent fires, both prescribed and natural ignition, have exacerbated the problem. Medusahead expansion within the Monument is a significant concern and has been a motivation for introducing Ecologically Based Invasive Plant Management (EBIPM) to JODA (Hoh et al. 2015).

Ecologically Based Invasive Plant Management

A comprehensive EBIPM plan for JODA, written collaboratively by the Upper Columbia Basin Inventory and Monitoring Network, the Agricultural Research Service, and JODA staff, was completed in 2015. This vegetation management plan is based on ecological principals and I&M monitoring, and strives to stimulate vegetation dynamics toward native species. Land areas have been grouped into one of three categories of invasive plant infestation (Figure D-1):

Priority 1: no/light infestation

Priority 2: moderate infestation with some desired plants

Priority 3: high infestation without desired species

Priority 1 Areas: Prevention

This portion of the plan is for areas in the Monument that are in good condition with a high percentage of native plants.

Vision: No new weed infestations.

Goal: Stop/Slow the spread of invasive species to currently un-infested areas.

Specific Objectives: Stop any new invasive weeds from becoming established in the Monument. Eradicate yellow starthistle, knapweeds, kochia, Dalmatian toadflax, whitetop, and ventenata from the Monument. Slow cheatgrass and medusahead from advancing to new areas. Enhance protection of ecologically intact plant communities

Priority 2 Areas: Control

An integrated plan has been developed to control invasive plants to eliminate competition to native plants so they can recover in an area, possibly without further restoration efforts.

Priority 3 Areas: Require revegetation

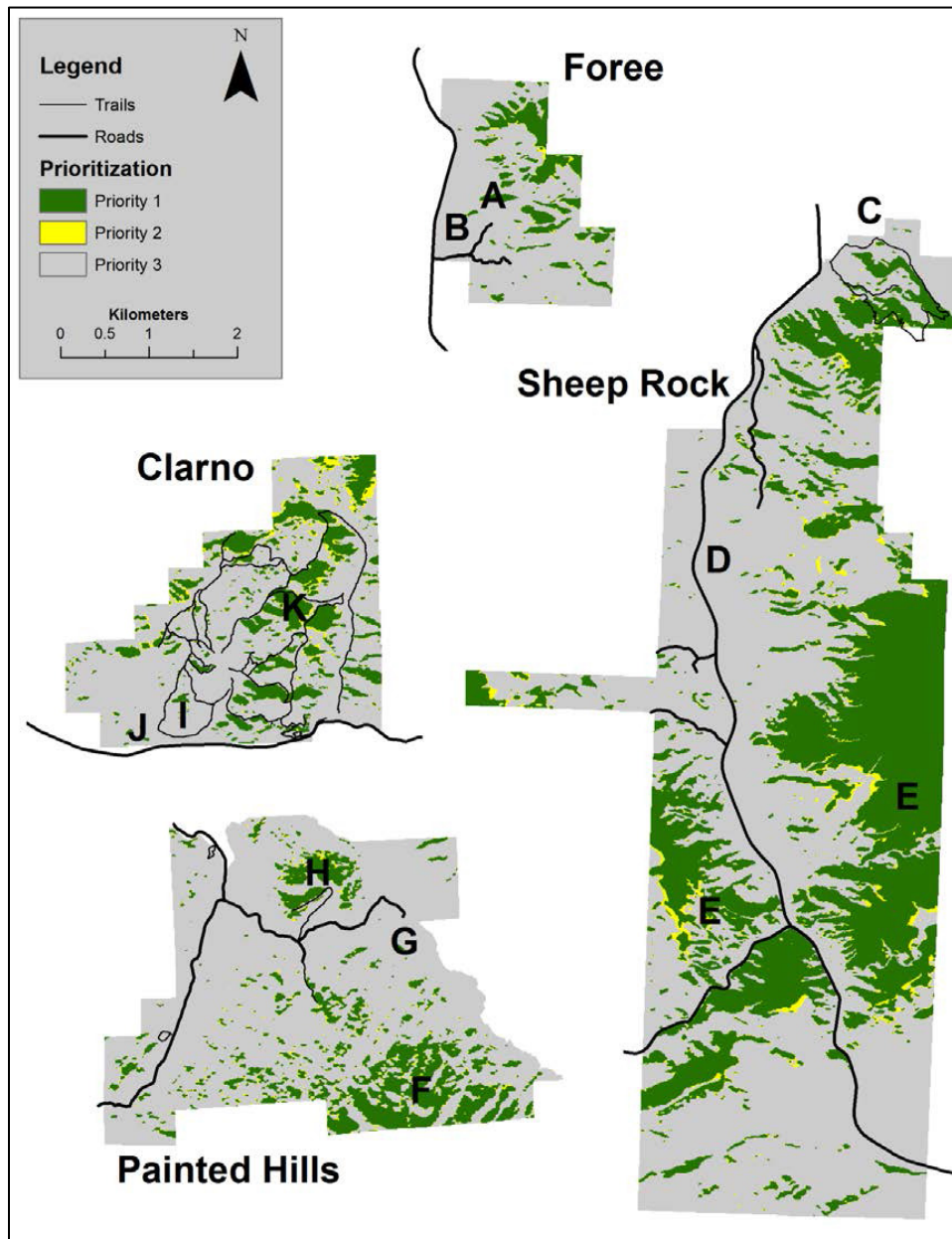


Figure D-1. Priority areas outlined in EBIPM plan. Priority 1 and 2 areas occur in the northern Sheep Rock unit (C) where both fires occurred. Location C: Middle Mountain/Blue Basin – The north slopes of Middle Mountain near Blue Basin contain several areas with high percentages of native bunchgrasses. The 3-mile loop trail at Blue Basin provides access to some of these areas, which are threatened by Dalmatian toadflax and common mullein (Hoh et al. 2015).

Another planning document, JODA's General Management Plan, states that the desired condition of JODA should be restored as nearly as possible to the conditions it would be in today had natural ecological processes not been altered. Vegetation should be reminiscent of pre-European settlement

and the natural fire regime should be restored. The presence of nonnative species should be minimized to the extent possible. (NPS-JODA 2008)

Findings to Prioritize in Future Burned Area Assessments

1. Emphasize impacts to foundation species, and in particular big sagebrush and bluebunch wheatgrass.
2. Describe impacts to and response of other indicator bunchgrasses [e.g. Sandberg's bluegrass (*Poa secunda*), Idaho fescue (*Festuca idahoensis*) and Thurber's needlegrass, *Achnatherum thurberiana*].
3. Describe evidence of annual invasive grass expansion into the burned area, as well as the extent of annual exotic grass invasion in areas adjacent to the burned area perimeter.
4. Emphasize proximity of intact sagebrush/bunchgrass steppe to burned area as a key component of specific restoration strategies.

Recommended Actions

V-1 Early detection and spot treatment of prioritized noxious weeds

Detection surveys of non-native target species should be conducted concurrently with the eradication of target species in areas with high infestation potential (see Figures D-2–D-5) and/or in areas previously identified as priority 1 in the 2015 EBIPM (Figure D-1 above) for three years post-fire. Management of target species should occur twice annually to cover varying weed phenologies and treatment windows. This will deplete weed propagules and allow natural recruitment of native species without competition from invasives. Treatment should include a combination of chemical and mechanical methods, specified in the JODA Integrated Pest Management Plan and will be conducted by JODA staff.

V-2 Targeted broadcast herbicide application for high priority restoration sites and prevention of escalated fire cycle regime.

Populations of annual exotic grasses are expected to increase exponentially in the newly exposed ground without management intervention. These grasses are known to increase fire return intervals and to inhibit recovery of native bunchgrasses. Priority management areas were previously established in the EBIPM. Because BAR provides only a 3 year window for restoration, and restoration of Priority 3 areas is a much longer undertaking, therefore only Priority areas 1 & 2 are recommended for this treatment.

Imazapic is a popular pre-emergent herbicide that can be applied to an area that has been affected by fire in order to reduce the initial establishment of annual grasses, but is only part of a post-fire management scheme that would include seeding with a diverse mix of native grasses and reapplication of herbicide the following year. Aminopyralid is a pre-emergent herbicide that is currently not as widely used as Imazapic, but shows promise suppressing both medusahead and ventenata (*Ventenata dubia*).

Imazapic kills plants by inhibiting the production of branched chain amino acids which are necessary for protein synthesis and cell growth. Imazapic is relatively non-toxic to terrestrial and aquatic

mammals, birds, and amphibians. It has an average half- life of 120 days in soil. It is not mutagenic or teratogenic and would not be expected to have any adverse effect on big game and none game species when used as labeled. It is considered to be nontoxic to mammals, birds, fish, and aquatic invertebrates. If ingested by mammals, Imazapic is rapidly excreted in the urine and feces and does not bio-accumulate in animals. In addition, the acute toxicity and irritation studies conducted with Plateau show this product to be non-toxic and non-irritating. Imazapic is non- toxic to fish and aquatic vertebrates with a 96 hour LD50 value greater than 100 mg/L (comparable to the toxicity of caffeine). (Tu 2001)

Given the ubiquitous presence of exotic annual grasses and associated seedbank within the Monument, herbicide treatments the first year following fire are unlikely to effectively prevent invasion in burned areas. Further, establishment of native plants in low-productivity sites following burns tends to be slow, and immature native bunchgrass species are particularly susceptible to competition from invasive annual grasses (Humphrey and Schupp 2004). As a result, seeding treatments and out-planting containerized native plant stock are necessary to establish desired plant communities in burned areas. Using containerized or out-planted mature native plants for restoration projects may provide greater resistance to annual grass invasion as they demonstrate superior competitive ability with exotic species and improved survival compared to seeded treatments (McGlone et al. 2012, Dettweiler-Robinson et al. 2013, Humphrey and Schupp 2004). Where ecological site descriptions dictate, including mature bottlebrush squirreltail plants in restoration projects will increase resistance to invasion and can assist with sagebrush recruitment (Booth et al. 2003).

Seeding with site adapted propagules rather than seed obtained from generalized sources may increase the effectiveness of restoration treatments (Germino et al. 2018, Brabec et al. 2019), and is consistent with NPS policies regarding restoration practices.

Seeding with a diverse native seed mix can improve long-term resistance to invasion and reduce complications associated with establishment of non-native plants introduced via seed mixes (Ott et al. 2019, Davies et al. 2019).

Based on these and other data, and timing delays inherent in government operations, the prescription for this treatment is:

- Treat Priority Areas 1&2 within fire perimeter and a buffer zone of 200 feet around these areas (into Priority 3 areas) and along vectors (road, trails, parking) to reduce propagule movement into burned areas. Avoid treatment on slope over 40 degrees for safety purposes => 223 Acres.
- 7 oz/acre Imazapic (Plateau or equivalent)
- 16 oz/acre Glyphosate
- Surfactant
- Delivery in 20 gal water/acre

- Timing of herbicide treatment: early spring--post snow but prior to native green up. If the site is heavily disturbed or infested with exotic species, consider a fall application of Imazapic followed by a spring treatment of Imazapic and glyphosate.
- Aerial or drill seed using a native bunchgrass/forb seed mix specified to the most common ecological sites in the burned area. Seeding should occur in late fall (preferred) or early spring.
- Consider out-planting with mature native plants where possible (nursery stock or transplants from nearby areas). Out-planting should focus on foundation species which can compete well with invasives (e.g. needlegrass and bluebunch wheatgrass) or which are difficult to establish via seed (e.g. big sagebrush). Out-planting islands of fertility can be created throughout burned areas as available stock allows.

Treatment will be contracted with oversight provided by JODA staff.

V-3 Seed or Out-plant Islands of big sage into burned areas.

Big sagebrush (*Artemisia tridentata*) does not generally re-sprout post fire; successive fires in this area of JODA have reduced or eliminated populations to small areas. Establishment of big sagebrush species via aerial seeding has produced variable results in field experiments (see Knutson et al. 2014, Boyd and Obradovich 2014, Ott et al. 2016, Davies et al. 2019, and Ott et al. 2019), though seeded areas typically experience greater sagebrush cover than unseeded control areas. Drill seeding may increase establishment of big sagebrush species (Thompson et al. 2006, Ott et al. 2016). A viable alternative may be to out-plant nursery stock big sagebrush seedlings, which have a higher probability of establishment and long-term survival (Dettweiler-Robinson et al. 2013).

Recommended Approach:

Create islands of big sage and foundation bunchgrass by combining out-planted sagebrush seedlings and mature bunchgrasses with seeding.

Islands should either be clustered in close proximity (i.e. 10–15 meters) to other islands or established adjacent to unburned areas of intact native vegetation to ensure propagule exchange and pollination (Hulvey et al. 2017).

Locate islands strategically based on site attributes, particularly topography. North-facing slopes in priority 1 areas present the greatest opportunity for successful establishment and persistence. Island creation may be necessary in some burned areas with lower potential, but these should be established after the most strategic locations have been addressed (Hulvey et al. 2017).



Landscape Prioritization - Sheep Rock

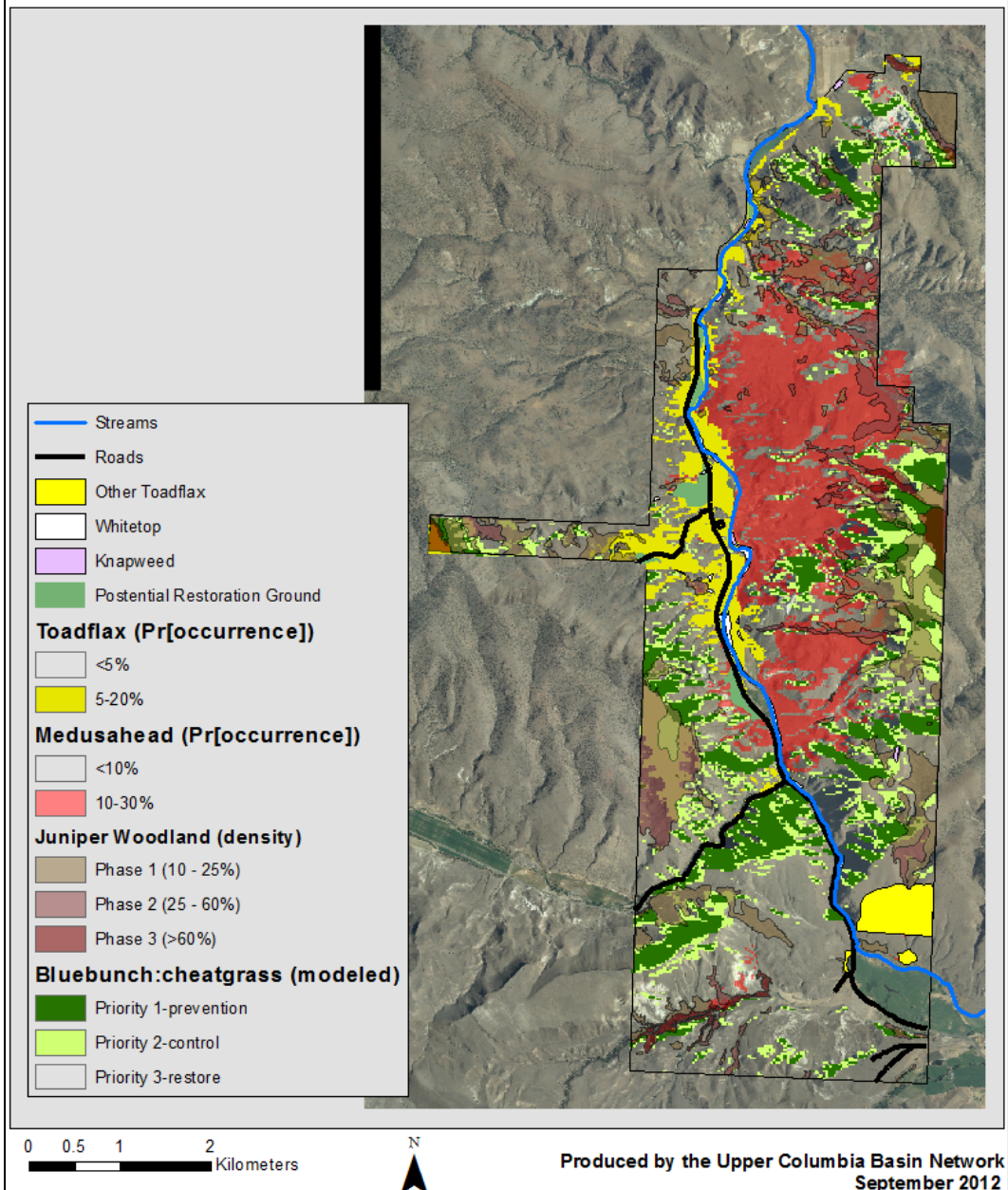


Figure D-2. Landscape prioritization map identifying predicted probabilities for weed species occurrence in the Sheep Rock Unit of John Day Fossil Beds. Reproduced from Hoh et al. 2015.

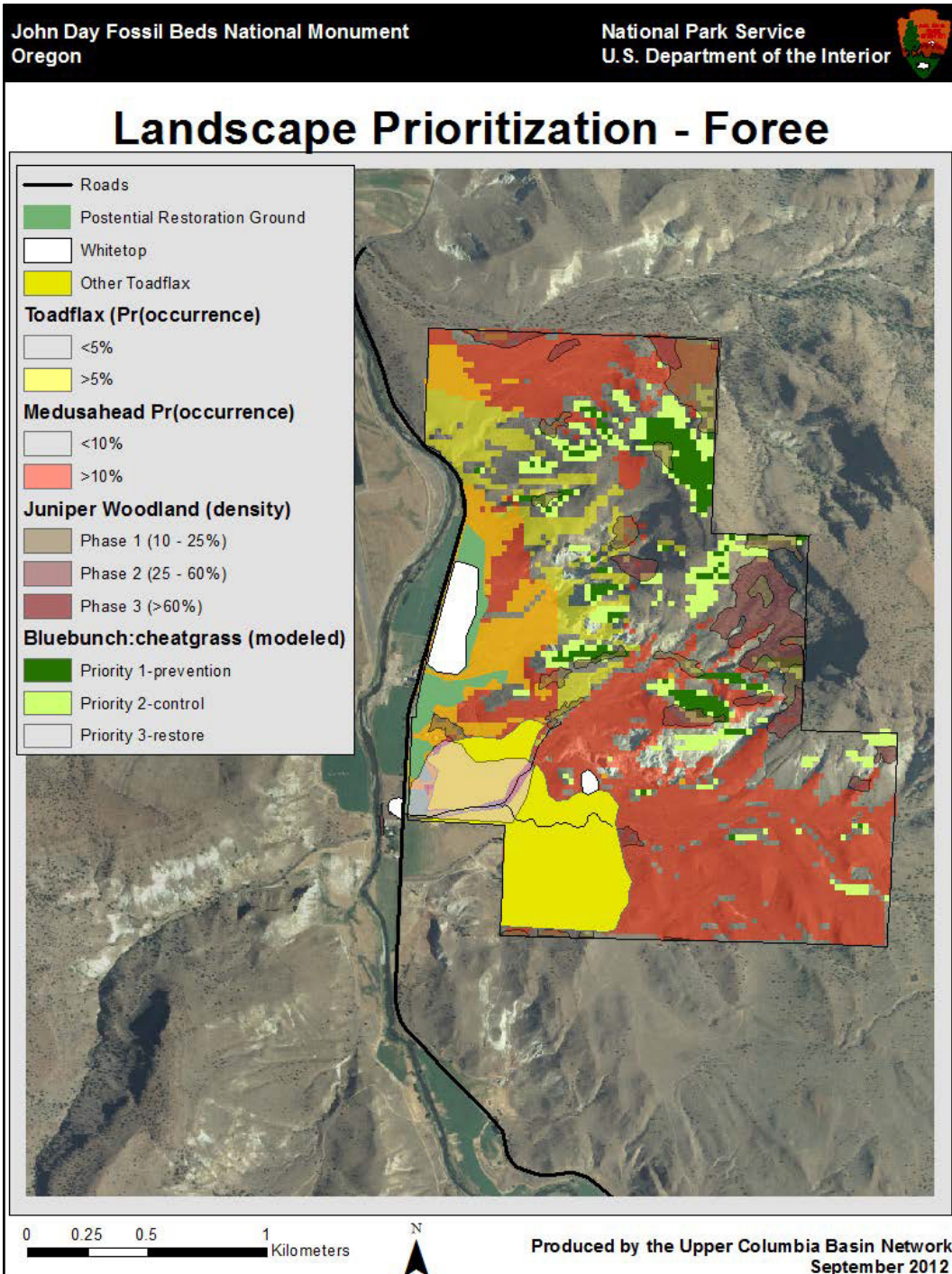


Figure D-3. Landscape prioritization map identifying predicted probability of weed species occurrence in the Foree Unit of John Day Fossil Beds. Reproduced from Hoh et al. 2015.



Landscape Prioritization - Painted Hills

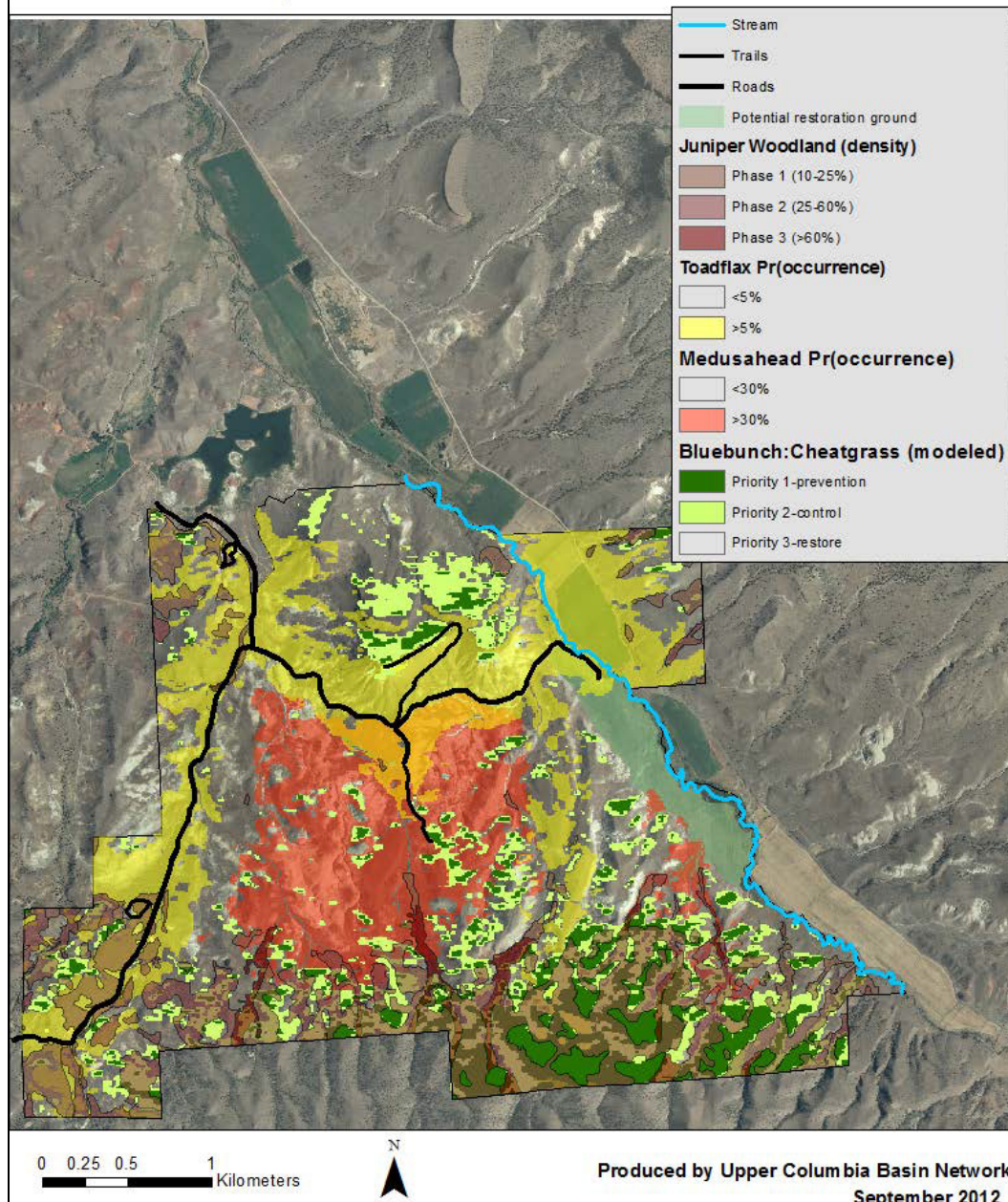


Figure D-4. Landscape prioritization map identifying predicted probability of weed species occurrence in the Painted Hills Unit of John Day Fossil Beds. Reproduced from Hoh et al. 2015.



Landscape Prioritization- Clarno

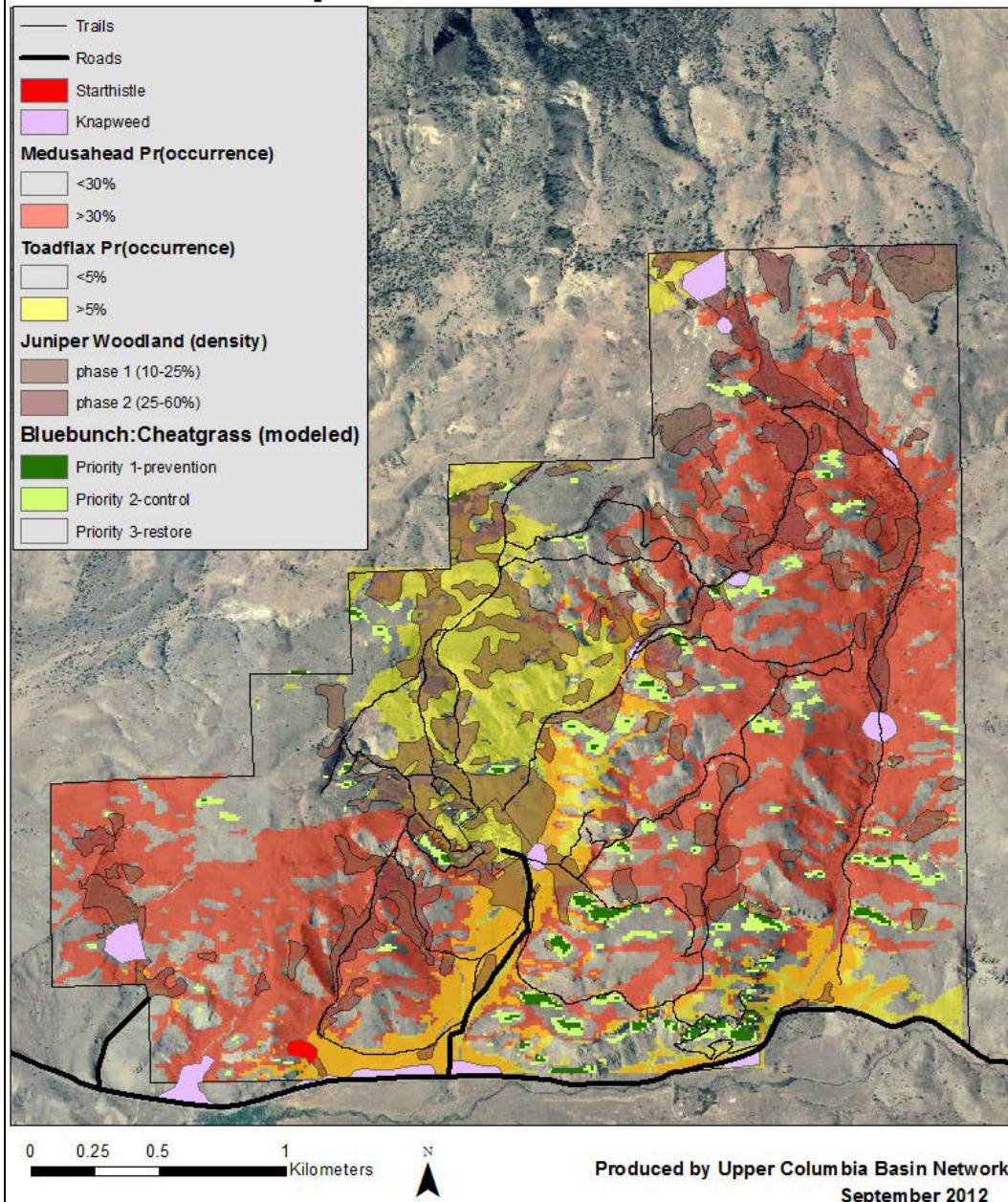


Figure D-5. Landscape prioritization map identifying predicted probability of weed species occurrence in the Clarno Unit of John Day Fossil Beds. Reproduced from Hoh et al. 2015.

Appendix E. Ecologically-based Invasive Plant Management.

EBIPM practices are a critical component of managing for resilience and resistance and for successful implementation of the actions recommended in this synthesis. A complete EBIPM plan for John Day Fossil Beds was completed in 2015, and is available at <https://irma.nps.gov/DataStore/DownloadFile/517337>.

Appendix F. Recommendations for Sagebrush Steppe Interpretive Information for John Day Fossil Beds National Monument.

Information provided here is intended to provide an example of interpretive material that can be derived from this synthesis document. It is the intention of the authors to work with Monument interpretive staff to identify information of interest for development of high-value interpretive materials for use at JODA. Sagebrush steppe grasslands at JODA represent a unique ecological transition between the shrubland dominated Great Basin to the south and the grasslands of the Columbia Plateau. This synthesis provides an opportunity for Monument interpretive staff to highlight the importance of sagebrush steppe ecosystems generally, and in particular those systems contained within Monument boundaries.

Defining the Place

While best known for its fossil resources, John Day Fossil Beds National Monument also contains important remnants of sagebrush steppe ecosystems. Sagebrush steppe is the term used to describe the extensive shrub and grass-dominated rangelands that cover much of the western United States (Figure F-1). To the casual observer, there may appear to be an unlimited amount of sagebrush steppe in the American West, but critical changes in plant communities within this vast region have led to it being referred to as one of the most imperiled ecosystems in North America.

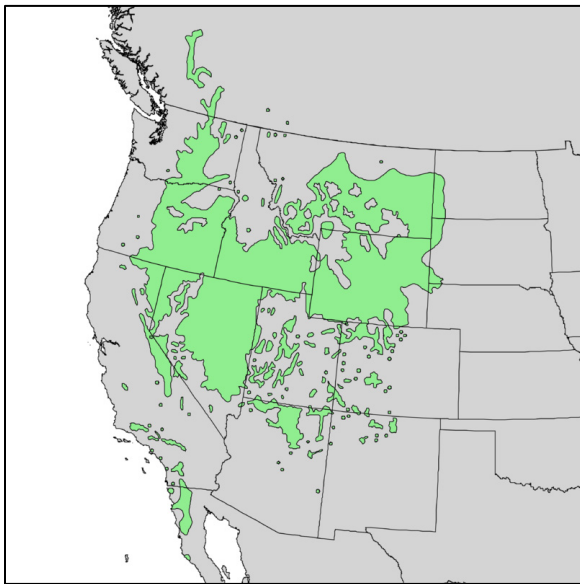


Figure F-1. Generalized map of sagebrush species distribution in the western United States. Reproduced from <http://esp.cr.usgs.gov/data/little/>.

Steppe ecosystems within the Monument are unique because of the abundance and production of native bunchgrasses here. Unlike sod-forming grasses, bunchgrass species grow in clumps with bare soil gaps in between plants. Bunchgrass species (like bluebunch wheatgrass) found in the Monument

are often referred to as “foundation” species because of their importance for maintaining ecosystem health and resisting invasion by non-native plants. These very grasses were likely a key reason pioneer ranchers homesteaded in the region.



Figure F-2. Healthy bluebunch wheatgrass community in the John Day Fossil Beds National Monument. Reproduced from Hoh et al. 2015.



Figure F-3. Site infested by cheatgrass and medusahead in the John Day Fossil Beds. Reproduced from Hoh et al.

Why are Sagebrush Steppe Ecosystems Imperiled?

Sagebrush steppe ecosystems typically exist in areas that receive limited precipitation, much of which falls in winter when many plant species are dormant. In the summer, daytime temperatures can

be quite warm and rainfall events are uncommon. Additionally, soils in areas occupied by sagebrush steppe tend to be low productivity, especially at lower elevations. When combined, these limiting factors contribute to low ecological resilience in some sagebrush steppe ecosystems. Ecological resilience refers to how well a plant community responds to disturbance events. Ecosystems with low resilience can be easily disturbed and difficult to restore. Historic grazing by sheep and cattle, disruption of natural fire cycles and invasion by non-native annual grasses have resulted in widespread changes to sagebrush steppe ecosystems. At John Day Fossil Beds, historic sheep grazing and cultivation practices degraded native bunchgrass communities, such that many areas are now dominated by exotic invasive annual grass species (e.g. cheatgrass). When sites become dominated by exotic annual grasses, wildfires become more frequent and burn larger areas. Burned areas are then susceptible to further invasion by more exotic annuals, leading to an annual grass fire cycle.

Why is Sagebrush Steppe Important?

While sagebrush steppe ecosystems may appear quite desolate, an estimated 300–400 vertebrate species utilize these ecosystems as habitat, many of which occur nowhere else. Species that were once common, most notably the greater sage grouse, are now declining with the loss and degradation of healthy sagebrush steppe habitat. Sagebrush steppe ecosystems also provide great value to humans, including provision of natural resources (wildlife, water, energy resources, minerals, etc.) and outstanding recreation opportunities.

What Can You Do?

Remaining sagebrush steppe ecosystems in the Monument are a natural resource repository of national significance. The primary threat to these systems today is the spread of exotic annual grasses. Seeds from exotic species are easily spread by humans, particularly if you walk through an infested area. Learn how to recognize common exotic annual species like cheatgrass, and be careful to avoid walking through areas where cheatgrass and other invasives are present in order to minimize spread to other areas.

Appendix G. Seeding Recommendations for Ecological Sites Classified as JD North 9–12” PZ in John Day Fossil Beds National Monument.

The seeding recommendations presented here are based on information derived from the ecological site description and associated Historic Climax Plant Community (HCPC) for the JD North 9–12” PZ ecological site. Seeding recommendations were developed using species identified in the ecological site HCPC (below) and on findings from relevant research on restoration strategies and ecological resilience for big sagebrush plant communities. More specifically, species identified for the seed mix presented below meet one or more of the following three conditions:

1. The species has been identified as a foundation species or potential foundation species, which have strong influence on ecosystem resilience or resistance (e.g. bluebunch wheatgrass and basin big sagebrush).
2. The species has demonstrated ability to compete successfully with exotic annual grasses, cheatgrass in particular.
3. The species has similar life-history traits to cheatgrass, with specific emphasis on early season growth characteristics.

The overall objective of this guide is to provide protected area managers with a rapid-response and/or restoration strategy that establishes key foundation species and associated ecological resilience/resistance for the ecological site and to provide a strong ecological base for longer-term, succession-based restoration as resources allow.

HCPC Description and Composition (verbatim from the NRCS Ecological Site Description for JD North 9–12’ PZ):

Dominated by bluebunch wheatgrass and Idaho fescue. This plant community evolved with limited grazing by large herbivores and with fire frequency of every 5 to 10 years. About 5% of the plant composition is made up of forbs and 8% of shrubs. Bluebunch wheatgrass increases with clay surface. Idaho fescue increases on due north steep slopes with silty surface.

Table G-1. Historic Climax Plant Community (HCPC) for JD North 9–12” PZ derived from the Natural Resource Conservation Service Ecological Site Description.

Group	Common Name	Symbol	Scientific Name	Annual Production
Grass/Grasslike (1)	bluebunch wheatgrass	PSSPS	<i>Pseudoroegneria spicata</i> ssp. <i>spicata</i>	720–960
	Idaho fescue	FEID	<i>Festuca idahoensis</i>	60–240
	Thurber's needlegrass	ACTH7	<i>Achnatherum thurberianum</i>	60–120
Grass/Grasslike (1) Total	–	–	–	840–1320
Grass/Grasslike (2)	Sandberg bluegrass	POSE	<i>Poa secunda</i>	20–40
Grass/Grasslike (2) Total	–	–	–	20–40
Forb (3)	common yarrow	ACMI2	<i>Achillea millefolium</i>	1–3
	Onion	ALLIU	<i>Allium</i>	1–3
	Pussytoes	ANTEN	<i>Antennaria</i>	1–3
	Milkvetch	ASTRA	<i>Astragalus</i>	1–3
	blepharipappus	BLEPH2	<i>Blepharipappus</i>	1–3
	mariposa lily	CALOC	<i>Calochortus</i>	1–3
	Indian paintbrush	CASTI2	<i>Castilleja</i>	1–3
	prairie clover	DALEA	<i>Dalea</i>	1–3
	Fleabane	ERIGE2	<i>Erigeron</i>	1–3
	Buckwheat	ERIOG	<i>Eriogonum</i>	1–3
	Desertparsley	LOMAT	<i>Lomatium</i>	1–3
	Locoweed	OXYTR	<i>Oxytropis</i>	1–3
	Phlox	PHLOX	<i>Phlox</i>	1–3
Forb (3) Total	–	–	–	20–60
Shrub/Vine (4)	basin big sagebrush	ARTRT	<i>Artemisia tridentata</i> ssp. <i>tridentata</i>	24–96
	Rabbitbrush	CHRY9	<i>Chrysothamnus</i>	5–10
	broom snakeweed	GUSA2	<i>Gutierrezia sarothrae</i>	5–10
	shadscale saltbush	ATCO	<i>Atriplex confertifolia</i>	1–5
Shrub/Vine (4) Total	–	–	–	35–121

Recommended Foundation Species Mix

Species listed in Table G-2 meet at least two conditions specified above and/or are considered foundation species for the site. Proportional seeding rates were derived using a seed mix calculator developed by Benson et al. (2011) for shrub steppe ecosystems in eastern Washington. Input values for seed composition (relative percentage of the total plant community composition) were derived from the HCPC for this ecological site.

For example, the HCPC for JD North 9–12” PZ indicates that bluebunch wheatgrass is expected to account for 720–960 lbs. per acre of the 1200 lbs. per acre representative value for the site. Taking

the midpoint of the high and low production values for bluebunch wheatgrass (840 lbs. per acre) and dividing by the representative value for total production at the site (1200 lbs. per acre), the target seed composition for bluebunch wheatgrass should be 70%.

Important seeding characteristics (seedling vitality, seed purity and germination rate) required by the calculator are not readily available for several of the species listed below (Thurber's needlegrass and desert parsley), so values were estimated from similar species for which data were available.

According to Benson et al. (2011), grass seed mixes applied at nine lbs. pure live seed (PLS) per acre via drill seeding techniques have been successful at sagebrush sites throughout the Columbia Basin.

The seed mix calculator indicates this particular seed mix is recommended to be applied at 13 bulk lbs. per acre. Late fall or late winter seeding is recommended, though early spring seeding is possible depending on soil conditions (Benson et al. 2011).

Table G-2. Recommended seeding rates for foundation species for ecological site JD North 9–12" PZ at John Day Fossil Beds National Monument, OR.

Common Name	Species Code	Proportional Seeding Rate ¹	Bulk lbs./acre
Bluebunch wheatgrass	PSSPS	82%	10.2
Thurber's needlegrass	ACTH7	8%	1.0
Idaho fescue	FEID	4%	.50
Sandberg's bluegrass	POSE	1%	.10
Common yarrow	ACMI2	>1%	>.10
Desert parsley	LOMAT	4%	.60
Basin big sage	ARTRT	1%	.50

¹ Source: Seed Mix Calculator from Benson, J. E., R.T. Tveten, M. G. Asher and P.W. Dunwiddie. 2011. Shrub-Steppe and Grassland Restoration Manual for the Columbia River Basin. Washington State Department of Fish and Wildlife, Olympia, WA.

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