NISC
NATIONAL INVASIVE SPECIES COUNCIL

U.S. DEPARTMENT OF THE INTERIOR · OFFICE OF THE SECRETARY
1849 C STREET NW · WASHINGTON, DC 20240

Wildland Fire and Invasive Species Published Research

Through the partnership between the National Invasive Species Council (NISC) and the Wildland Fire Leadership Council (WFLC), research coordination has been identified as a key theme underpinning work to advance integration of invasive species and wildland fire efforts. The NISC/WFLC task team has thereby looked at issues related to identifying and promoting key research questions, as well as supporting information sharing and coordination on agency priorities.

One element of this work includes reviewing the scientific literature to understand the scope of work to date as well as key gaps. Most of the existing research from 2000 to the present explores the relationship between invasive plants, particularly grass species, and wildfire risk, fire regimes, impacts to native plant communities, and loss of wildlife habitats. The following sections briefly summarize the work that has been completed (Appendix I displays the abstracts and citations for each topic).

- Climate Change and Modeling
- Invasive Annual Grasses Management
- Plant Community Structure
- Vegetation Mapping and Modeling
- Fine Fuels Management, Wildfire, and Invasives
- Post-Fire Invasion and Restoration
- Genetic Studies
- Social Issues
- Grazing Management

NISC staff searched Google Scholar, USGS publications warehouse, USFS TreeSearch, and AGRICOLA using keywords “invasive species”, “invasive species and fire”, “invasive species and wildfire” from 2000 to 2024. Agency and literature synthesis projects are also included in Appendix II under the topics of Climate Change, Restoration, and Fire Management and Invasive Species.

This is a living document that will be updated over time. If you have additions or comments please contact: Stanley W. Burgiel, Ph.D., Executive Director, National Invasive Species Council (NISC); Email: stanley_burgiel@ios.doi.gov

Summary of Topics

Climate Change

Seventeen articles were published directly correlating invasive species to climate change or how climate change is impacting fine fuel accumulation and wildfire frequency in combination with invasive species (the grass-fire cycle). The topic of climate change and invasive species has been a focus of research from 2011 to the present, although one article from 1992 (D’Antonio and Vitousek) was at the forefront of the questions regarding global change and the grass-fire cycle. They recognized “biological invasions into

wholly new regions are a consequence of a far reaching but underappreciated component of global environmental change, the human-caused breakdown of biogeographic barriers to species dispersal" throughout the world. Concluding "the effects of alien grasses on ecosystem function (fire, nutrient loss, altered local microclimate, prevention of succession) are significant on the local scale and becoming increasingly important on regional and global scales." Subsequently, long-term research has continued throughout the following decades.

The sagebrush biome became the focus of much research concerning climate change and the grass-fire cycle. Currently we are losing 1.3 million acres of sagebrush habitat to invasive grasses that degrade natural plant community functions and increasing fire frequencies. As cheatgrass has fully integrated into the interstitial spaces of the sagebrush community, fire can more rapidly spread and travel across the landscape. Cheatgrass not only provides a fuel source that has not been present before, but during this droughty period of climate change, it is outcompeting native plant species that normally return after wildfires. Quietly following cheatgrass invasions, two "new" invasive grass species are beginning to invade the sagebrush biome as well (ventenata and medusahead). Researchers are measuring the influences of CO_2, precipitation, soil moisture, plant moisture, abiotic and biotic conditions at temporal and spatial scales to predict the rate of spread of invasive grasses using suitability models, climate models, and probability models. While management implications are a concern, the need for continued monitoring and research still exists to answer questions on what locations invasive grass species will occupy next given the changing climate.

Invasive Annual Grasses Management

Understanding the basic physiology of invasive annual grasses (IAG) remains a question for researchers to explore. Our searches resulted in fourteen publications that focused on the management of AIG in regard to wildfire management and fine fuels reductions. Managers are limited by time and budgets so they need tools that will deplete AIG propagules at meaningful scales with positive results. Research has focused on cheatgrass, ventenata, medusahead, and other AIG (mostly specific to islands) to determine application rates, timing, and prioritization of treatments for effectiveness. Researchers are also considering impacts of AIG on livestock forage quality, wildlife habitat, and native plant communities. Incorporating AIG management into decision-making tools is identified as a future need by many researchers and managers, as is long-term monitoring of treatment effectiveness. More information is also needed on island AIG and their impacts on natural and anthropogenic communities, though researchers globally also recognize that invasive grasses are a major threat to native and agricultural plant communities.

Plant Community Structure

Understanding how plant community structure functions is an important component of maintaining native plant communities as well as restoring plant communities. Plant community structure not only includes plant species but the soil, precipitation, aspect, elevation, and topography of where plant species are found. By understanding plant community structure, ecological preservation and restoration will become more successful. Data and analysis from these studies will be used to enhance computer model projections for expansion probabilities and habitat suitability. Researchers have explored forest, shrubland, and grassland ecosystems in light of invasive species, climate change and wildfire frequency changes. Our literature search found 25 publications from 2014 – 2024 that address how invasive species are changing plant community structures across the globe, however, most of the research was conducted in the sagebrush biome, Hawaiian Islands, or Northwestern U.S.

Vegetation Mapping and Modeling

Remote sensing technologies and satellite archives help scientists monitor terrestrial vegetation globally (18 publications from 2016-2024). Whether satellite-derived products like the Rangeland Analysis Platform (RAP) can fulfill pre-fire information needs and be used to parametrize models of fire recovery to inform postfire management of IAGs is a key question.

Spatial patterns, successional stages, and biotic and abiotic factors all need more research to build the best model for predicting suitability, whether for new invasions or spread. Some if not most, modeling efforts have a direct link to climate change when modeling the potential of invasive plant species spread, especially if the research is connected to wildfire as well. But there are still needs for basic biological information about invasive species that limit what models can predict.

Models in this area include LANDFIRE, Rangeland Analysis Platform (RAP), INHABIT, and project specific models that researchers used to develop Treatment Response Groups (TRGs), Species Distribution Models (SDMs), or Decision Support Tools (DSTs) using remote sensing.

Fine Fuels Management, Wildfire, and Invasive Species

While there is much discussion and research around fine fuels management and wildfire reduction, 50 publications from 2000-2024 were found during the literature search when fuels management and wildfire were combined with invasive species management. Most research focuses on invasive annual grasses such as cheatgrass (*Bromus tectorum*), Buffelgrass (*Cenchrus cilliaris*), and Ventenata (*Ventenata dubia*); however, globally there are many more species to consider. (Knowledge of flammability and intensity of other invasive species has been identified as a data gap in present research and management knowledge.)

In the absence of starting experimental fires, researchers use fire models (such as LANDFIRE, FARSITE, BeHAVE Plus, MODIS, LandSAT-7) and machine learning to determine if invasive species change fire behavior by being an additional fuel source that may increase frequency and intensities of wildfires. Locations of studies covered grasslands, forest edges, sagebrush communities, islands, and specific wildlife habitats where invasive species are widespread or becoming more common. Specific locations such as fuelbreak lines, PODs, or the WUI have also been studied in terms of how invasive species may enter these spaces more frequently and the unintentional opportunity they provide for invasive species establishment. Most researcher are considering larger landscape scale studies as more appropriate for determining the impacts of invasive species on wildfires and where to focus management actions. Climate change is another factor researchers are considering when studying the invasive species-fire cycle since the future of newly disturbed areas is not going to be the same as it was before.

Post-Fire Invasion and Restoration

Post fire restoration and disturbed native habitat restoration remains as great of a challenge as wildfire when considering invasive species introduction and spread. As mentioned in the “Fine Fuels Management, Wildfire, and Invasive Species” section, the climate is changing rapidly enough, such that post-fire environment and restoration strategies may not mirror their previous conditions. Our reviews looked at 31 publications from 2009-2024 to summarize the most recent published works on post-fire invasion and restoration. Species specific research includes invasive annual grasses such as medusahead, ventenata, and cheatgrass, but overall restoration techniques reviewed plant communities as a whole. While researchers evaluated the post-fire environment, altered states of the natural environment due to fire regime changes,

climate change, non-historical use, drought, and additional disturbances (e.g., salvage logging, herbicide applications) were also considered for restoration challenges.

Researchers looked at various restoration techniques from timing, seed mixes, equipment, soil amendments, fertilizer, straw/mulch, etc. across a wide array of landscapes. This research has generated future research needs for developing deep rooted perennial grasses, biological controls, and a better understanding of what seeds and species to plant in the future highlighting feasibility considerations such as social, budgetary, and environmental concerns. Most of the published research focuses on shrublands. However, forested areas, rangelands, agricultural lands, and islands need investigative research and monitoring to fully understand the restoration processes of these areas.

Restoration after a wildfire is not only important to native plant communities but the wildlife that live in them, protected species, and ecosystem services. Therefore, several studies link wildlife habitat importance to plant restoration activities. These studies also include the need for long-term monitoring and conservation planning.

Genetic Studies

The topic of genetic studies for invasives plant species in the context of wildland fire resulted in three publications written in 2017, 2020, and 2024. As stated by Wang et al. (2024), understanding why some, but not other, plant communities are vulnerable to invasive species is essential for predicting and managing biological invasions. Using genetics, researchers can identify adaptive traits directly linked to breeding systems and compare the genetic markers between populations. Genetic studies have reviewed cheatgrass and ventenata, but any invasive species could be better understood using genetic analysis.

Social Issues

Social dynamics and educational efforts are key components to invasive species and wildfire management. Working on public lands, partnering with non-governmental organizations, universities, and local municipalities requires a connection to the land and the common goals to be achieved. Even within Federal agencies, top-down and bottom-up conversations are imperative to solution focused land management. The NISC publications lists includes five papers (2022-2024) that surveyed affected land groups (e.g., agricultural community) and land managers regarding the impacts of wildfire and invasives species, how funding and resource sharing across jurisdictional boundaries can improve land management efficiencies, how land managers are adapting to and using new research and climate change, and how institutional changes (e.g., objectives, authorizations, and capacities) are limiting land management.

Grazing Management and Rangelands

Globally and throughout the western US, researchers are looking for new ways to incorporate grazing and rangeland management into invasive species, wildland fire, and restoration management strategies. Combining grazing techniques with strategies to manage wildfires and invasive species plays a crucial role in maintaining healthy rangeland ecosystems. Seven research articles (2008-2024) explore how vegetation and fuel treatments can increase annual production if implemented with common goals. By integrating these techniques and strategies, land managers can promote sustainable agriculture, protect ecosystems, and reduce the risks associated with wildfires and invasive species. Integrating climate change adds another level of complexity by changing the effective grazing season for fine fuels reduction, which may require supplemental feeding. Given the unknowns of climate change, there are also unforeseeable consequences and possibly undesirable risks that will need to be considered.

Appendix I: Research Papers Topics

Climate Change and Modeling

Anthropogenic climate change is hypothesized to modify the spread of invasive annual grasses across the deserts of the western United States. The influence of climate change on future invasions depends on both climate suitability that defines a potential species range and the mechanisms that facilitate invasions and contractions. **Climate Change in Western US Deserts: Potential for Increased Wildfire and Invasive Annual Grasses** John T. Abatzoglou and Crystal A. Kolden

For nearly a century, invasive annual grasses have increasingly impacted terrestrial ecosystems across the western United States. Weather variability associated with climate change and increased atmospheric carbon dioxide (CO2) are making even more difficult the challenges of managing invasive annual grasses. As part of a special issue on climate change impacts on soil and water conservation, the topic of invasive annual grasses is being addressed by scientists at the USDA Agricultural Research Service to emphasize the need for additional research and future studies that build on current knowledge and account for (extreme) changes in abiotic and biotic conditions. **Invasive annual grasses—Re envisioning approaches in a changing climate.** D. Archer, D. Toledo, D.M. Blumenthal, J. Derner, C. Boyd, K. Davies, E. Hamerlynck, R. Sheley, P. Clark, S. Hardegree, F. Pierson, C. Clements, B. Newingham, B. Rector, J. Gaskin, C.L. Wonkka, K. Jensen, T. Monaco, L.T. Vermeire, and S.L. Young

Mountain environments are currently among the ecosystems least invaded by non-native species; however, mountains are increasingly under threat of non-native plant invasion. The slow pace of exotic plant invasions in mountain ecosystems is likely due to a combination of low anthropogenic disturbances, low propagule supply, and extreme/steep environmental gradients. The importance of any one of these factors is debated and likely ecosystem dependent. We evaluated the importance of various correlates of plant invasions in the Wallowa Mountain Range of northeastern Oregon and explored whether non-native species distributions differed from native species along an elevation gradient. **Non-Native Plant Invasion along Elevation and Canopy Closure Gradients in a Middle Rocky Mountain Ecosystem.** Joshua P. Averett, Bruce McCune, Catherine G. Parks, Bridgett J. Naylor, Tim DelCurto, Ricardo Mata-González

Multiple species of annual grasses are invading sagebrush-steppe communities throughout the western United States. Most research has focused on dominant species such as Bromus tectorum (cheatgrass), yet other, less studied annual grasses such as Taeniatherum caput-medusae (medusahead) and Ventenata dubia (ventenata) are spreading rapidly. Future precipitation regimes are expected to have less frequent but more intense rain events, which may affect soil moisture availability and favor these 'newer' invasives over cheatgrass. We conducted a full factorial, growth chamber study examining the effects of two watering regimes (small/frequent, large/infrequent rain pulses) across nine soil types on the growth of cheatgrass, medusahead and ventenata. We tested a hypothesis that medusahead or ventenata would have greater growth than cheatgrass with larger/infrequent rain events. **The effects of precipitation and soil type on three invasive annual grasses in the western United States.** Sheel Bansal, Jeremy J. James, Roger L. Sheley

Assessing landscape patterns in climate vulnerability, as well as resilience and resistance to drought, disturbance, and invasive species, requires appropriate metrics of relevant environmental conditions. In

dryland systems of western North America, soil temperature and moisture regimes have been widely utilized as an indicator of resilience to disturbance and resistance to invasive plant species by providing integrative indicators of long-term site aridity, which relates to ecosystem recovery potential and climatic suitability to invaders. However, the impact of climate change on these regimes, and the suitability of the indicator for estimating resistance and resilience in the context of climate change have not been assessed. Here we utilized a daily time-step, process-based, ecosystem water balance model to characterize current and future patterns in soil temperature and moisture conditions in dryland areas of western North America and evaluate the impact of these changes on estimation of resilience and resistance. **Climate-Driven Shifts in Soil Temperature and Moisture Regimes Suggest Opportunities to Enhance Assessments of Dryland Resilience and Resistance.** John B. Bradford, Daniel R. Schlaepfer, William K. Lauenroth, Kyle A. Palmquist, Jeanne C. Chambers, Jeremy D. Maestas and Steven B. Campbell

Although natural resource managers are concerned about climate change, many are unable to adequately incorporate climate change science into their adaptation strategies or management plans and are not always aware of or do not always employ the most current scientific knowledge. One of the most prominent natural resource management agencies in the United States is the Bureau of Land Management (BLM), which is tasked with managing over 248 million acres of public lands for multiple, often conflicting, uses. Climate change will affect the sustainability of many of these land uses and could further increase conflicts between them. **Impacts of climate change on multiple use management of Bureau of Land Management land in the Intermountain West, USA.** Elaine M. Brice, Brett A. Miller, Hongchai Zhang, Kirsten Goldstein, Scott N. Zimmer, Guenchik J. Grosklos, Patrick Belmont, Courtney G. Flint, Jennifer E. Givens, Peter B. Adler, Mark W. Brunson, and Jordan W. Smith

Iconic sagebrush ecosystems of the American West are threatened by larger and more frequent wildfires that can kill sagebrush and facilitate invasion by annual grasses, creating a cycle that alters sagebrush ecosystem recovery post disturbance. Thwarting this accelerated grass–fire cycle is at the forefront of current national conservation efforts, yet its impacts on wildlife populations inhabiting these ecosystems have not been quantified rigorously. Within a Bayesian framework, we modeled 30 y of wildfire and climatic effects on population rates of change of a sagebrush-obligate species, the greater sage-grouse, across the Great Basin of western North America. **Wildfire, climate, and invasive grass interactions negatively impact an indicator species by reshaping sagebrush ecosystems.** Peter S. Coates, Mark A. Ricca, Brian G. Prochazka, Matthew L. Brooks, Kevin E. Doherty, Travis Kroger, Erik J. Blomberg, Christian A. Hagen, and Michael L. Casazza

Contemporary pressures on sagebrush steppe from climate change, exotic species, wildfire, and land use change threaten rangeland species such as the greater sage-grouse (Centrocercus urophasianus). To effectively manage sagebrush steppe landscapes for long-term goals, managers need information about the potential impacts of climate change, disturbances, and management activities. We integrated information from a dynamic global vegetation model, a sage-grouse habitat climate envelope model, and a state-and-transition simulation model to project broad-scale vegetation dynamics and potential sage-grouse habitat across 23.5 million acres in southeastern Oregon. **Climate change and land management impact rangeland condition and sage-grouse habitat in southeastern Oregon.** Megan K. Creutzburg, Emilie B. Henderson and David R. Conklin

Biological invasions into wholly new regions are a consequence of a far reaching but underappreciated component of global environmental change, the human-caused breakdown of biogeographic barriers to species dispersal. Human activity moves species from place to place both accidentally and deliberately- and it does so at rates that are without precedent in the last tens of millions of years. As a result, taxa that evolved in isolation from each other are being forced into contact in an instant of evolutionary time. **Biological invasions by exotic grasses, the Grass/Fire Cycle, and Global Change**. (Published 1992). Carla M. D'Antonio and Peter M. Vitousek

In this chapter, we explain how the adaptive traits, genetic variability, and physiology of certain invasive species provide them with the competitive ability to grow, reproduce, and spread successfully under conditions of climate change. **Effects of Climate Change on Invasive Species.** Deborah M. Finch, Jack L. Butler, Justin B. Runyon, Christopher J. Fettig, Francis F. Kilkenny, Shibu Jose, Susan J. Frankel, Samuel A. Cushman, Richard C. Cobb, Jefrey S. Dukes, Jefrey A. Hicke, and Sybill K. Amelon

Wildfire is a major proximate cause of historical and ongoing losses of intact big sagebrush (Artemisia tridentata Nutt.) plant communities and declines in sagebrush obligate wildlife species. In recent decades, fire return intervals have shortened, and area burned has increased in some areas, and habitat degradation is occurring where post-fire re-establishment of sagebrush is hindered by invasive annual grasses. In coming decades, the changing climate may accelerate these wildfires and invasive feedbacks, although projecting future wildfire dynamics requires a better understanding of long-term wildfire drivers across the big sagebrush region. Here, we integrated wildfire observations with climate and vegetation data to derive a statistical model for the entire big sagebrush region that represents how annual wildfire probability is influenced by climate and fine fuel characteristics. **Wildfire probability estimated from recent climate and fine fuels across the big sagebrush region.** Martin C. Holdrege, Daniel R. Schlaepfer, Kyle A. Palmquist, Michele Crist, Kevin E. Doherty, William K. Lauenroth, Thomas E. Remington, Karin Riley, Karen C. Short, John C. Tull, Lief A. Wiechman and John B. Bradford

Anthropogenic climate change has increased the frequency of drought, wildfire, and invasions of non-native species. Although high-severity fires linked to drought can inhibit recovery of native vegetation in forested ecosystems, it remains unclear how drought impacts the recovery of other plant communities following wildfire. We leveraged an existing rainfall manipulation experiment to test the hypothesis that reduced precipitation, fuel load, and fire severity convert plant community composition from native shrubs to invasive grasses in a Southern California coastal sage scrub system. **Long-term drought promotes invasive species by reducing wildfire severity.** Sarah Kimball, Jessica Rath, Julie E. Coffey, Moises R. Perea-Vega, Matthew Walsh, Nicole M. Fiore, Priscilla M. Ta, Katharina T. Schmidt, Michael L. Goulden, Steven D. Allison

Exotic plant invasions alter ecosystem properties and threaten ecosystem functions globally. Interannual climate variability (ICV) influences both plant community composition (PCC) and soil properties, and interactions between ICV and PCC may influence nitrogen (N) and carbon (C) pools. We asked how ICV and non-native annual grass invasion covary to influence soil and plant N and C in a semiarid shrubland undergoing widespread ecosystem transformation due to invasions and altered fire regimes. **Interannual climate variability mediates changes in carbon and nitrogen pools caused by annual grass invasion in a**

semiarid shrubland. Adam L. Mahood, Rachel O. Jones, David I. Board, Jennifer K. Balch, Jeanne C. Chambers

An increasing number of invasive plant species are spreading in the Pacific Northwest (PNW), an area of unique natural areas, economic value, and increasing human population. Predicting the potential habitat suitability for invasive plant species that are not yet established in the region is crucial for developing preventative management strategies. To this end, this study developed habitat suitability models for four invasive plant species, two terrestrial species: *Geranium lucidumand, Pilosella officinarum*; and two aquatic species: *Butomus umbellatus and Pontederia crassipes*. The researcher initially considered 33 bioclimatic variables, 10 land cover types, and a human influence index as current model predictor variables with location records for each species drawn from the introduced range (North America). I projected each species' current habitat suitability in the PNW region using ensemble modelling of six algorithms to 2050 and 2080, under 3 potential future climate scenarios. **EFFECTS OF CLIMATE CHANGE ON THE HABITAT SUITABILITY OF 4 RELATIVELY NEW INVASIVE PLANT SPECIES IN THE PACIFIC NORTHWEST.** Emma Nikkel

We review science-based adaptation strategies for western North American (wNA) forests that include restoring active fire regimes and fostering resilient structure and composition of forested landscapes. As part of the review, we address common questions associated with climate adaptation and realignment treatments that run counter to a broad consensus in the literature. These include the following: (1) Are the effects of fire exclusion overstated? If so, are treatments unwarranted and even counterproductive? (2) Is forest thinning alone sufficient to mitigate wildfire hazard? (3) Can forest thinning and prescribed burning solve the problem? (4) Should active forest management, including forest thinning, be concentrated in the wildland urban interface (WUI)? (5) Can wildfires on their own do the work of fuel treatments? (6) Is the primary objective of fuel reduction treatments to assist in future firefighting response and containment? (7) Do fuel treatments work under extreme fire weather? (8) Is the scale of the problem too great? Can we ever catch up? (9) Will planting more trees mitigate climate change in wNA forests? And (10) is post-fire management needed or even ecologically justified? **Adapting western North American forests to climate change and wildfires: 10 common questions.** SUSAN J. PRICHARD, PAUL F. HESSBURG, R. KEALA HAGMANN, NICHOLAS A. POVAK, SOLOMON Z. DOBROWSKI, MATTHEW D. HURTEAU, VAN R. KANE, ROBERT E. KEANE, LEDA N. KOBZIAR, CRYSTAL A. KOLDEN, MALCOLM NORTH, SEAN A. PARKS, HUGH D. SAFFORD, JENS T. STEVENS, LARISSA L. YOCOM, DEREK J. CHURCHILL, ROBERT W. GRAY, DAVID W. HUFFMAN, FRANK K. LAKE, AND PRATIMA KHATRI-CHHETRI

National Parks are hallmarks of ecosystem preservation in the United States. The introduction of alien invasive plant species threatens protection of these areas. Bromus tectorum L. (commonly called downy brome or cheatgrass), which is found in Rocky Mountain National Park (hereafter, the Park), Colorado, USA, has been implicated in early spring competition with native grasses, decreased soil nitrogen, altered nutrient and hydrologic regimes, and increased fire intensity. We estimated the potential distribution of B. tectorum in the Park based on occurrence records (n = 211), current and future climate, and distance to roads and trails. **Using High-Resolution Future Climate Scenarios to Forecast Bromus tectorum Invasion in Rocky Mountain National Park.** Amanda M. West, Sunil Kumar, Tewodros Wakie, Cynthia S. Brown, Thomas J. Stohlgren, Melinda Laituri, Jim Bromberg

Invasive Annual Grasses Management

As public lands come under increasing stress from invader–fire interactions, managers need tools that deplete nonnative propagules at meaningful temporal and spatial scales. The pre-emergent herbicide indaziflam, which has been approved for use in natural areas, achieves multi-year control of *Bromus tectorum* (cheatgrass) and other short-lived nonnative species, while leaving co-occurring, established perennials largely intact. Here we explore how pre-fire management with indaziflam shapes plant community assembly post-fire. **Incorporation of Indaziflam into Natural Areas Management of Cheatgrass and Other Short-Lived Invasive Species: PostFire Assessment in a Semi-Arid Colorado Grassland.** Christina Alba, Michelle DePrenger-Levin, and Rebecca Hufft

Ventenata (*Ventenata dubia (*Leers*) Coss*.) is a nonindigenous, invasive grass in the inland Pacific Northwest (PNW) of the United States. It appears to be present in the PNW without any evidence of disease expression. Surveys of V. dubia in the PNW (Idaho, Montana, Oregon, and Washington) were entirely negative for fungi, including types of pathogens that might be expected in grasses (e.g., rust, powdery mildew, choke). **Ventenata dubia's native range and consideration of plant pathogens for biological control.** Maryam Alomran, George Newcombe and Timothy Prather

Invasive annual grasses, such as medusahead (*Taeniatherum caput-medusae* [L.] *Nevski*), have invaded tens of millions of hectares of the sagebrush ecosystem. These invasions severely reduce ecosystem goods and services provided, as well as increase the probability of frequent, large wildfires. Revegetation of invasive annual grass–invaded rangeland with perennial bunchgrasses is critical to reversing these negative consequences. Short-term evaluations of revegetation efforts have shown promising results. However, long-term evaluations of revegetation efforts in medusahead-invaded rangelands are lacking, so it remains unknown if revegetation attempts in these invaded rangelands have persistent effects. We evaluated the effects of controlling medusahead with prescribed burning and imazapic application followed 1 year later with drill-seeding large perennial bunchgrasses at two seeding rates (medium and high) for more than a decade post seeding. **Long-Term Effects of Revegetation Efforts in Annual Grass–Invaded Rangeland.** Kirk W. Davies, Chad S. Boyd, Lauren N. Svejcar, Danielle R. Clenet

Invasive annual grasses have degraded tens of millions of hectares of the sagebrush ecosystem of western North America. Restoration of perennial vegetation in annual grass–invaded rangelands is a management priority to decrease fire risk, increase livestock forage quality, and improve wildlife habitat. Annual grasses are traditionally controlled in the fall with preemergent herbicides, such as imazapic, and treated areas are often seeded with perennial bunchgrasses 1 year later to avoid nontarget herbicide damage to revegetation species. However, there is a limited window of time in the fall to accomplish annual grass control treatments. Spring-applied control treatments may be another option compared with only fall control treatments, but they have received little attention. **Spring-Applied Treatments Offer Another Window of Opportunity for Revegetation of Annual Grass–Invaded Rangelands.** K.W. Davies, V.M. Schroeder, D.D. Johnson, L.N. Svejcar, D.R. Clenet

Ventenata (*Ventenata dubia (*Leers*) Coss.*) is an exotic annual grass that can invade Intermountain rangeland plant communities, where it can form monotypic stands, degrade wildlife habitat, and reduce livestock forage. There is limited information on ventenata control in rangelands as it has only recently been identified as a substantial problem. Imazapic is a pre-emergent herbicide commonly used to

control other exotic annual grasses and therefore, is likely to control ventenata in rangelands. We evaluated five application rates of imazapic on ventenata and other exotic annual grass control and plant community response at two rangeland sites in two years. **Ventenata (*Ventenata dubia*) and other co-existing exotic annual grass control and plant community response to increasing imazapic application rates.** Kirk W. Davies and Erik Hamerlynck

Island ecosystems are notably susceptible to biological invasions (Elton 1958), and the Hawaiian Islands in particular have been colonized by many introduced species (Loope and Mueller-Dombois 1989). Introduced plants now dominate extensive areas of the Hawaiian Islands, and 86 species of alien plants are presently considered to pose serious threats to Hawaiian communities and ecosystems (Smith 1985). **ALIEN GRASS INVASION AND FIRE IN THE SEASONAL SUBMONTANE ZONE OF HA WAI'I.** Flint Hughes, Peter M. Vitousek, and Timothy Tunison

A global overview of invasive species and the human influence on their establishment and spread. **Invasive Alien Species. A Prodigious Global Threat in the Anthropocene.** Michael R. Ielmini and K.V. Sankaran

Ventenata [*Ventenata dubia (*Leers*) Coss.*], an invasive winter annual grass, significantly reduces forage production in grassland systems and displaces species within both perennialand annual-dominated grasslands within the Inland Northwest. The range of V. dubia is expanding into sagebrush steppe communities, an expansive habitat critical for forage production, wildlife, and recreation. Currently, there is limited knowledge of V. dubia's distribution and abundance within sagebrush steppe communities. We performed field surveys at 15 locations in sagebrush steppe rangelands in southern Idaho and eastern Oregon to assess where V. dubia occurs, with the aim of providing insight about its niche in this new habitat**. Indicators of Ventenata (*Ventenata dubia*) Invasion in Sagebrush Steppe Rangelands.** Lisa C. Jones, Nicholas Norton, and Timothy S. Prather

Exotic grasses are a widespread set of invasive species that are notable for their ability to significantly alter key aspects of ecosystem function. Understanding the role and importance of these invaders in forested landscapes has been limited but is now rising, as grasses from Eurasia and Africa continue to spread through ecosystems of the Americas, Australia, and many Pacific islands, where they threaten biodiversity and alter various aspects of the fire regime. The ecological, social and economic impacts of the grass-fire cycle associated with species such as cheatgrass (Bromus tectorum) have been long recognized in aridlands such as the iconic sagebrush ecosystems of the western US. However, the damaging impacts of invasive grasses in forestlands have received considerably less attention. We review literature, conceptual models, model output, and empirical evidence that indicate grass invasion in forest ecosystems may be an important yet largely under-recognized phenomenon. **Invasive grasses: A new perfect storm for forested ecosystems?** Becky K. Kerns, Claire Tortorelli, Michelle A. Day, Ty Nietupski, Ana M.G. Barros, John B. Kim, Meg A. Krawchuk

Ventenata has rapidly spread across the inland Pacific Northwest, where it threatens to replace native plants and alter fire behavior. The annual grass is invading many open areas and those with low tree cover at higher elevation (above 4,000 feet) within forests that in the recent past were resistant to invasion by other invasive grasses, including cheatgrass. Ventenata invasion can increase fine fuels and alter fire behavior. Fire simulations demonstrate that invasion can lead to larger and potentially more

severe fires across the landscape by facilitating fire spread between forests and invaded open areas. This behavior has also been observed by firefighters. **Not Just Another Cheatgrass: The Ventenata Invasion in the Interior Northwest.** John Kirkland and Becky Kerns

Portions of the United States are becoming increasingly dominated by annual species, with cheatgrass (Bromus tectorum L.) and medusahead (Taeniatherum caput-medusae [L.] Nevski) as the most common and well-known invaders (Bansal et al. 2014). Other invasive annual species also are present and increasing in abundance, including ventenata (Ventenata dubia [Leers] Coss.), an invasive annual grass that has been expanding within the Pacific Northwest, Great Basin, and Great Plains regions of the United States. **EXAMINING THE PO TES: EXAMINING THE POTENTIAL COMPE AL COMPETITIVE EFFEC TIVE EFFECTS OF VENTENATA DUBIA ON ANNU A ON ANNUAL AND PERENNI AL AND PERENNIAL GRASSES AL GRASSES.** Shawn McKay, Lesley R. Morris, Christopher E. Morris, Elizabeth A. Leger

This comprehensive review of a century of scientific inquiry illuminates the causes and consequences of cheatgrass (Bromus tectorum) invasion and evaluates solutions to restore healthy native ecosystems. Introduced to North America in the 1800s, this Eurasian annual was spread by railroads, vehicles, and livestock, colonizing lands disturbed and degraded by overgrazing and other factors. Today, millions of acres have been converted to cheatgrass monoculture. Tens of millions of acres more remain at high risk of invasion. **Cheatgrass invasions: History, causes, consequences, and solutions.** Erik M. Molvar, Roger Rosentreter, Don Mansfield, and Greta M. Anderson

Given the high cost of restoration and the underlying assumption that reducing annual grass abundance is a necessary precursor to rangeland restoration in the Intermountain West, United States, we sought to identify limitations and strengths of annual grass control methods and refine future management strategies. We systematically reviewed all published journal articles spanning a 64-yr period (1948−2012; n = 119) reporting data on research efforts to either directly or indirectly reduce the abundance of the most common invasive annual grass, downy brome (Bromus tectorum L.). The seven most common control methods studied were herbicide, burning, revegetation, woody removal, defoliation or grazing, soil disturbance, and soil amendment. **Downy Brome Control and Impacts on Perennial Grass Abundance: A Systematic Review Spanning 64 Years.** Thomas A. Monaco, Jane M. Mangold, Brian A. Mealor, Rachel D. Mealor, Cynthia S. Brown

Wiregrass (Ventenata dubia [Leers] Coss.), an annual grass from the Mediterranean region of North Africa and Eurasia that has aggressive invasion potential in many North American plant communities, has only recently been reported in low-elevation sagebrush steppe. We first encountered wiregrass in 2014 in the John Day Fossil Beds National Monument, a low-elevation steppe protected area in central Oregon. This discovery was incidental to formal vegetation monitoring that was initiated in the monument in 2009. Wiregrass exhibited a broad ecological niche within our survey area, occurring across all surveyed elevations and on all but steep southern slopes. Invaded sites were in well-drained clay soils in association with other invasive annual grasses. Our observations contribute to the growing evidence that wiregrass poses a greater threat to low-elevation sagebrush ecosystems than previously recognized. **Rapid invasion by the annual grass Ventenata dubia into protected-area, low-elevation sagebrush steppe.** MELISSA NICOLLI, THOMAS J. RODHOUSE, DEVIN S. STUCKI, AND MATTHEW SHINDERMAN

Invasive annual grasses, such as medusahead (Taeniatherum caput-medusae [L.] Nevski), ventenata (Ventenata dubia [Leers] Coss.), downy brome (Bromus tectorum L.), and Japanese brome (Bromus japonicus Thunb. ex Murr.), are negatively impacting millions of hectares of US rangelands. Amino acid synthesis inhibitor and photosynthesis inhibitor herbicides are sometimes used to control invasive annual grasses. Conversely, growth regulator herbicides are generally considered ineffective against invasive annual grasses. However, in a recent study of pre-emergence herbicide applications, the growth regulator aminopyralid appreciably reduced medusahead cover, primarily by killing emerging medusahead plants. Additionally, in recent studies of postemergence herbicide applications, we found the growth regulators aminopyralid, dicamba, and picloram drastically reduced downy brome and Japanese brome seed production. **Aminopyralid Constrains Seed Production of the Invasive Annual Grasses Medusahead and Ventenata.** Matthew J. Rinella, Susan E. Bellows, and Aaron D. Roth

Globally, invasive grasses are a major threat to protected areas (PAs) due to their ability to alter community structure and function, reduce biodiversity, and alter fire regimes. However, there is often a mismatch between the threat posed by invasive grasses and the management response. We document a case study of the spread and management of the ecosystem-transforming invasive grass, *Andropogon gayanus* Kunth. (gamba grass), in Litchfield National Park; an iconic PA in northern Australia that contains significant natural, cultural and social values. **The cost of not acting: Delaying invasive grass management increases costs and threatens assets in a national park, northern Australia.** Natalie A. Rossiter-Rachor, Vanessa M. Adams, Caroline A. Canham, Dan J. Dixon, Thorsteinn N. Cameron, Samantha A. Setterfield

Ventenata dubia is an exotic winter annual grass that has invaded Conservation Reserve Program (CRP) lands, improved pastures, intensively managed hay fields, and rangelands within the Intermountain Pacific Northwest (PNW). Currently, producers are attempting to develop V. dubia management strategies with little knowledge of its life history traits. We conducted several studies to characterize V. dubia life history patterns. Preliminary germination trials were completed to describe primary and secondary dormancy characteristics. Field studies were conducted to evaluate (1) seed bank persistence patterns, (2) seedling emergence patterns under V. dubia litter, and (3) seedling emergence and phenological development patterns within timothy hay, CRP, and rangeland habitats. **Ecological Characteristics of Ventenata dubia in the Intermountain Pacific Northwest.** John M. Wallace, Pamela L. S. Pavek, and Timothy S. Prather

Plant Community Structure

Ecological restoration of shrub–steppe communities in the western United States is often hampered by invasion of exotic annual grasses during the process. An important question is how to create restored communities that can better resist reinvasion by these weeds. One hypothesis is that communities comprised of species that are functionally similar to the invader will best resist invasion, while an alternative hypothesis is that structurally more complex and diverse communities will result in more effective competitive exclusion. **Community Structure Affects Annual Grass Weed Invasion During Restoration of a Shrub–Steppe Ecosystem.** Phil S. Allen and Susan E. Meyer

The data and analyses presented here were collected at the Zumwalt Prairie Preserve (ZPP), northeastern Oregon. Vegetation composition was measured within 124 (1-ha) plots using the line-point

intercept method. These data include vascular plant species abundance matrices at two different time periods, seven years apart (2008/2009 & 2015/2016); boxplots of species abundance (cover and frequency) change over time; Non-parametric Multiplicative Regression (NPMR) estimated abundance of Ventenata dubia, an invading non-native annual grass, in geographic and ordination (Non-metric Multidimensional Scaling ordination; NMS) space over time. **Dataset of plant composition change over seven years at the Zumwalt Prairie Preserve, Oregon, USA.** Joshua P. Averett, Lesley R. Morris, Bryan A. Endress

Changes in the quantity and quality of plant litter occur in many ecosystems as they are invaded by exotic species, which impact soil nutrient cycling and plant community composition. Such changes in sagebrush-steppe communities are occurring with invasion of annual grasses (AG) into a perennial grass (PG) dominated system. Researchers conducted a 5-year litter manipulation study located in the northern Great Basin, USA. **Plant litter effects on soil nutrient availability and vegetation dynamics: changes that occur when annual grasses invade shrub-steppe communities.** Sheel Bansal, Roger L. Sheley, Bob Blank, and Edward A. Vasquez

Some of the last remaining grassland communities of the Pacific Northwest Bunchgrass Region (PNWBR) in North America are found in canyon grasslands, primarily because the rugged topography has left many of these associations untouched by agricultural development. However, there have been no prior examinations into how canyon grassland communities change over the long term or how topography relates to these changes. In this study, we examined how successional stages changed over a 33-yr time period and which topographical variables were most related to these long-term outcomes (elevation, aspect or slope). We predicted that areas with more gentle slopes (<20%) would have changed the most because they have seen a higher concentration of historical land uses. **Influence of topography on long-term successional trajectories in canyon grasslands.** Samantha J. Bernards & Lesley R. Morris

The seed bank represents the future trajectory of plant communities following disturbance and is vital to their regeneration. Worldwide, grassland seed banks have been well studied. However, there are no examinations of the seed bank for the Pacific Northwest Bunchgrass Prairie system found in the Pacific Northwest of the United States. This absence may arise from the limited amount of intact grasslands in this type following decades of agricultural development and cultivation. In this study, we examined the seed bank from grasslands sites along an early successional gradient to evaluate how they relate to above ground vegetation, successional stage, and historical cultivation. We found that similarities between above ground vegetation and the seed bank were the strongest in the earliest successional stages, when annual grasses dominate. Surprisingly, this relationship was driven by the presence of a relatively new introduced annual grass, *Ventenata dubia*. **Comparisons of Canyon Grassland Vegetation and Seed Banks Along an Early Successional Gradient.** Samantha J. Bernards and Lesley R. Morris

Invasive annual grasses on sagebrush rangelands are negatively impacting land uses and values ranging from forage for grazing livestock to native plant diversity, wildlife habitat, and human safety via associated increases in the wildfire footprint. This article provides a broad overview of sagebrush plant community ecology, how that ecology has varied through time, the role of invasive annual grasses in influencing sagebrush plant community ecology, and thoughts on a productive path forward. **Managing for resilient sagebrush plant communities in the modern era: We're not in 1850 anymore.** Chad S. Boyd

Wildfires are increasingly impacting ecosystem processes and ecological services provided by sagebrush rangelands in the western United States. Mitigating this problem involves actions taken before, during, and after fire. In recent years, there has been increased emphasis on prefire fuel management, including fuel breaks. Cattle grazing can be used as a tool to manage fine fuel loading within fuel breaks; however, spatially focusing grazing impacts inside a linear fuel break is challenging. We evaluated using virtual fencing (VF) technology for concentrating grazing impacts inside a 200-m wide, 3-km long fuel break within a 410-ha pasture in sagebrush steppe. The fuel break was bounded by four 35-m wide virtual fences, each consisting of boundaries for auditory (10-m wide) and electrical cues (25-m wide), and a traditional 5-strand barbed wire perimeter fence delineated the pasture perimeter. Data suggest virtual fencing can be a highly effective method of concentrating grazing to reduce herbaceous fuel biomass within linear fuel break. **Using Virtual Fencing to Create Fuel Breaks in the Sagebrush Steppe.** Chad S. Boyd, Rory C. O'Connor, Juliana Ranches, David W. Bohnert, Jon D. Bates, Dustin D. Johnson, Kirk W. Davies, Todd Parker, Kevin E. Doherty

Despite a large body of research documenting invasive plant impacts, few studies have followed individual invaded sites over decades to observe how they change, and none have contrasted how compositional impacts from invasion compare to ecosystem-process impacts over a multi-decadal timescale. We report here that woody plant composition and structure continue to be dramatically changed by the initial invasions and fires that occurred 25 years ago and invaders continue to dominate in burned sites. We conclude that fire, an unusual disturbance in this system, has perpetuated the dominance of these sites by invasive species and that despite the dramatic recovery of above-ground net primary production and N pools, the ecosystem continues to be in a distinctly different state than the pre-fire, pre-Melinis community. **Ecosystem vs. community recovery 25 years after grass invasions and fire in a subtropical woodland.** Carla M. D'Antonio, Stephanie G. Yelenik and Michelle C. Mack

Exotic annual grasses dominate millions of hectares and increase fire frequency in the sagebrush ecosystem of North America. This devastating invasion is so costly and challenging to revegetate with perennial vegetation that restoration efforts need to be prioritized and strategically implemented. Management needs to break the annual grass-fire cycle and prevent invasion of new areas, while research is needed to improve restoration success. Under current land management and climate regimes, extensive areas will remain annual grasslands, because of their expansiveness and the low probability of transition to perennial dominance. We propose referring to these communities as Intermountain West Annual Grasslands, recognizing that they are a stable state and require different management goals and objectives than perennial-dominated systems. **Living with exotic annual grasses in the sagebrush ecosystem.** Kirk W. Davies, Elizabeth A. Leger, Chad S. Boyd, Lauren M. Hallett

Introduced annual grasses (IAGs) have invaded tens of millions of hectares of western US rangelands, displacing native vegetation and altering ecosystem functions and services. Our main goal was to assess the influence of introduced annual grasses by 1) exploring the relationships among IAG cover, species richness, diversity, and cover of other plant functional groups; and 2) identifying biotic and abiotic indicators of IAG cover. Using data from 64 sites and 420 plots from rangelands of the northwestern United States, we explored linear correlations between IAG cover and species richness, Shannon index, and plant functional group cover. **Plot-Measured Variables Indicate Landscape-Scale Patterns of Annual**

Grass Invasion in Northwestern US Rangelands. Andrea De Stefano, Brian A. Mealor, Lisa C. Jones, Erik A. Lehnhoff, Jane M. Mangold, Timothy Prather, Corey V. Ransom, Lisa J. Rew

Wildfires in dry forest ecosystems in western North America are producing fire effects that are more severe than historical estimates, raising concerns about the resilience of these landscapes to contemporary disturbances. Despite increasing fire activity, relatively little is known about the structure and composition of fire refugia - unburned or low-severity burned patches where trees survived fire — or the degree to which their understory composition differs from fire-generated early-seral forests. **How do plant communities differ between fire refugia and fire-generated early-seral vegetation?** William M. Downing, Meg A. Krawchuk, Jonathan D. Coop, Garrett W. Meigs, Sandra L. Haire, Ryan B. Walker, Ellen Whitman, Geneva Chong, Carol Miller, Claire Tortorelli

Wildfires in forested ecosystems are increasing in severity and extent. The adaptations many plants have acquired in response to their natural fire regime may not be sufficient to allow some species to persist. This could impact the forest understory and its seed bank, which are vital reservoirs of biodiversity, and forest resilience in the face of global change. We present a case study of the montane forests of south-eastern Australia, an area subjected to an increase in frequency and severity of fires. We utilize field surveys and a soil seed bank germination study to investigate if short-interval, high-severity wildfires affect the understory diversity in montane forests, and if the extant vegetation and the soil seed bank exhibit contrasting responses. **Short-interval, high-severity wildfires cause declines in soil seed bank diversity in montane forests of south-eastern Australia.** Emily Duivenvoorden, Benjamin Wagner, Craig R. Nitschke, Sabine Kasel

These data support the research article: “Non-native species threaten the biotic integrity of the largest remnant Pacific Northwest Bunchgrass prairie in the United States”. The data were collected at the Zumwalt Prairie Preserve (Zumwalt), northeastern Oregon, USA, and include vascular plant species abundance matrices from 123 plots sampled in 2008 and 2009 and the estimated abundance of dominant species in community space. **Dataset of plant community composition in the Zumwalt Prairie Preserve, Oregon, USA.** Bryan A. Endress, Joshua P. Averett

The Pacific Northwest Bunchgrass ecosystem is one of the most endangered in the United States, yet community-level patterns of non-native plant distribution and abundance remain largely unexplored. To address this information gap, we asked the following questions: What are the distinct plant communities within Zumwalt Prairie Preserve? What are the most widespread and abundant non-native species and how does non-native species composition and dominance vary across plant communities? How do historic land use, biotic and environmental factors influence plant community composition, particularly in terms of non-native species abundance and dominance? **Non-native species threaten the biotic integrity of the largest remnant Pacific Northwest Bunchgrass prairie in the United States.** Bryan A. Endress, Joshua P. Averett, Bridgett J. Naylor, Lesley R. Morris, Robert V. Taylor

Recovery requires the establishment of new individuals from seed or other propagules following dispersal from the parent plant. When recovery fails to re-establish the pre-disturbance community, the ecosystem will assemble into a new state. Reorganization occurs along a gradient of magnitude, from changes in the relative dominance of species present in a community, to individual species replacements within an essentially intact community, to complete species turnover and shift to dominance by plants of

different functional types, e.g., transition from forest to shrub or grass dominance. When this latter outcome is persistent and involves reinforcing mechanisms, the resulting state represents a vegetation type conversion (VTC), which in this framework represents an end member of reorganization processes. We explore reorganization in greater detail as this phase is increasingly observed but the least understood of the resilience responses. This resilience framework provides a direct and actionable basis for ecosystem management in a rapidly changing world, by targeting specific components of ecological response and managing for sustainable change. **Mechanisms of forest resilience**. Donald A Falk, Philip J van Mantgem, Jon E Keeley, Rachel M Gregg, Christopher H Guiterman, Alan J Tepley, Derek JN Young, Laura A Marshall

Species interactions shape native plant communities, influencing both composition and ecosystem processes, with invasion by non-native species threatening these dynamic relationships, native species, and function. The consequences of invasive plants in particular may stretch across taxa to impact plant, insect, and soil microbial communities directly and indirectly, with consequences for ecological functioning. In northern mixed-grass prairies in the United States, invasion by two annual brome grasses, Bromus arvensis and B. tectorum, negatively impacts rangeland plants; however, the simultaneous effects on insects and soil microbes (bacteria and archaea), and the implications for ecological function, have received less attention. Here, using observational field studies conducted at two mixed-grass prairie sites in Montana and Wyoming, we assessed the relationships between plants, insects, and soil microbes across gradients of invasion by B. arvensis and B. tectorum. **Plant, insect, and soil microbial communities vary across brome invasion gradients in northern mixed-grass prairies.** Morgan D. T. Frost, Kimberly J. Komatsu, Lauren M. Porensky, Kurt O. Reinhart, Kevin R. Wilcox, Zachary L. T. Bunch, Ashley D. Jolin, Katielyn A. Johnston, Gracen E. Trimas and Sally E. Koerner

We lack an understanding of how vegetation naturally recovers on disturbed lands. Using remote sensing and land survey data, we characterized the structure, composition, and function of secondary vegetation canopies on former sugarcane fields in Hawai‘i that were abandoned between 4 and 117 years ago. We used a species distribution model to identify patches of uncultivated land with similar environmental conditions to abandoned sugarcane fields to serve as reference ecosystems. Using these reference ecosystems, we evaluated how secondary ecosystems at different ages since abandonment compare in terms of canopy structure, composition, and function. **What follows fallow? Assessing revegetation patterns on abandoned sugarcane land in Hawai‘i.** D. Nakoa Farrant, Dar A. Roberts, Carla M. D’Antonio, Ashley E. Larsen

In this greenhouse experiment, we examine how buffelgrass growth and traits were impacted by the combination of competition with eight native grasses species and water availability. We found that when buffelgrass was grown with species that establish rapidly and have large biomass, buffelgrass tends to exhibit rapid growth, despite becoming more drought stressed. Conversely, when buffelgrass was grown with species that are slow growing and conserve their size under drought conditions, buffelgrass biomass is arrested. **Impacts of drought and native grass competition on buffelgrass (*Pennisetum ciliare*).** Hannah L. Farrell, Jennifer Funk, Darin Law, Elise S. Gornish

The spread of ecosystem modifying invasive plant (EMIP) species is one of the largest threats to native ecosystems in Hawai‘i. However, differences in niche characteristics between Hawai‘i’s isolated insular

environment and the wider global distribution of these species have not been carefully examined. We used species distribution modeling (SDM) methods to assess similarities and differences in niche characteristics between global and regional scales for 17 EMIPs present in Hawai'i. With a clearer understanding of the global context of regional plant invasion, we combined two SDM methods to better understand the potential future regional spread. **Exploring and integrating differences in niche characteristics across regional and global scales to better understand plant invasions in Hawai'i.** Lucas Berio Fortini, Lauren R. Kaiser, Curtis C. Daehler, James D. Jacobi, Monica Dimson, Thomas W. Gillespi

This study evaluates the secondary successional pathways of Hawaiian lowland rainforest following anthropogenic disturbance. Whereas primary succession on lava flows has been well studied in Hawaii, secondary successional dynamics on disturbed habitats in the presence of nonnative species has been poorly researched and documented. Our study was based on two vegetation sampling efforts conducted on 200–400-year-old lava flows 2 and 27 years following a 400-hectare clearcutting operation in the Puna District of the southeast quadrant of Hawaii Island. **Vegetation Succession Following Clearcutting of Lowland Hawaiian Rainforest on the Island of Hawai'i.** Dennis H. Grossman and R. Flint Hughes

Forest and non-forest ecosystems of the western United States are experiencing major transformations in response to land-use change, climate warming, and their interactive effects with wildland fire. Some ecosystems are transitioning to persistent alternative types, hereafter called "vegetation type conversion" (VTC). VTC is one of the most pressing management issues in the southwestern US, yet current strategies to intervene and address change often use trial-and-error approaches devised after the fact. To better understand how to manage VTC, we gathered managers, scientists, and practitioners from across the southwestern US to collect their experiences with VTC challenges, management responses, and outcomes. **Vegetation type conversion in the US Southwest: frontline observations and management responses.** Christopher H. Guiterman, Rachel M. Gregg, Laura A. E. Marshall, Jill J. Beckmann, Phillip J. van Mantgem, Donald A. Falk, Jon E. Keeley, Anthony C. Caprio, Jonathan D. Coop, Paula J. Fornwalt, Collin Hafey, R. Keala Hagmann, Stephen T. Jackson, Ann M. Lynch, Ellis Q. Margolis, Christopher Marks, Marc D. Meyer, Hugh Saford, Alexandra Dunya Syphard, Alan Taylor, Craig Wilcox, Dennis Carril, Carolyn A. F. Enquist, David Hufman, Jose Iniguez, Nicole A. Molinari, Christina Restaino and Jens T. Stevens

Weed communities influence the dynamics of ecosystems, particularly in disturbed environments where anthropogenic activities often result in higher pollution. Understanding the dynamics existing between native weed communities and invasive species in disturbed environments is crucial for effective management and normal ecosystem functioning. Recognizing the potential resistance of native weed communities to invasion in disturbed environments can help identify suitable native plants for restoration operations. This review aims to investigate the adaptations exhibited by native and non-native weeds that may affect invasions within disturbed environments. Factors such as ecological characteristics, altered soil conditions, and adaptations of native weed communities that potentially confer a competitive advantage relative to non-native or invasive weeds in disturbed environments are analyzed. Moreover, the roles of biotic interactions such as competition, mutualistic relationships, and allelopathy in shaping the invasion resistance of native weed communities are described. **Unveiling the resistance of native weed communities: insights for managing invasive weed species in disturbed**

environments. Wajid Ali Khattak, Jianfan Sun, Rashida Hameed, Fawad Zaman, Adeel Abbas, Khalid Ali Khan, Noureddine Elboughdiri, Rasheed Akbar, Feng He, Muhammad Wajid Ullah, Abeer Al-Andal and Daolin Du

New geographic strategies provide the landscape context needed for effective management of invasive annual grasses in sagebrush country. Identifying and proactively defending intact rangeland cores from annual grass invasion is a top priority for management. Minimizing vulnerability of rangeland cores to annual grass conversion includes reducing exposure to annual grass seed sources, improving resilience and resistance by promoting perennial plants, and building capacity of communities and partnerships to adapt to changing conditions and respond to the problem with appropriate actions in a timely manner. **Defend the core: Maintaining intact rangelands by reducing vulnerability to invasive annual grasses.** Jeremy D. Maestas, Mark Porter, Matt Cahill, and Dirac Twidwel

Changing climatic conditions prompt concerns about vegetation response to disturbance under future compared to past conditions. In this long-term study, we examined soil climate and vegetation differences at lower, mid, and upper elevations in two separate locations in the Great Basin, USA. We hypothesized that soil climate and vegetation associations across the elevational gradient could help predict responses under future warming and drying. We measured soil water availability, soil temperatures, and vegetation cover in relation to fire and perennial herb removal at each elevation for 13–17 yr after treatment. **Effects of elevation and selective disturbance on soil climate and vegetation in big sagebrush communities.** BRUCE A. ROUNDY AND JEANNE C. CHAMBERS

In the western United States, sagebrush (Artemisia spp.) and salt desert shrublands are rapidly transitioning to communities dominated by exotic annual grasses, a novel and self-reinforcing state that threatens the economic sustainability and conservation value of rangelands. Climate change is predicted to favour annual grasses, potentially pushing transitions to annual grass dominance into higher elevations and north-facing aspects. We sought to quantify expansion of annual grass-dominated vegetation communities along topographic gradients over the past several decades. **The elevational ascent and spread of exotic annual grass dominance in the Great Basin, USA.** Joseph T. Smith, Brady W. Allred, Chad S. Boyd, Kirk W. Davies, Matthew O. Jones, Andrew R. Kleinhesselink, Jeremy D. Maestas, Scott L. Morford, David E. Naugle

This study assessed the extent of woody cover change and the relative importance of fire history, topography, soil moisture, and distance to human infrastructure in explaining change across a hierarchy of spatial extents and regions. We found substantial net decline in woody cover and expansion of herbaceous vegetation across all regions, but the most dramatic changes occurred in the northern interior and southern coastal areas. Variables related to frequent, short-interval fire were consistently top ranked as the explanation for shrub to grassland type conversion, but low soil moisture and topographic complexity were also strong correlates. **Fire-driven vegetation type conversion in Southern California.** Alexandra D. Syphard, Teresa J. Brennan, Heather Rustigian-Romsos, Jon E. Keeley

The native chaparral shrublands of Southern California support exceptional biodiversity and provide critical ecological services, but increased fire frequency threatens to extirpate much of the chaparral due to long regeneration times needed between fires for many species. When short fire intervals inhibit shrub recovery, this favors invasion of exotic herbaceous species, and vegetation type conversion from

woody shrubs to grassland is therefore a serious ecological concern in this biodiversity hotspot. Despite a history of field studies documenting the detrimental effect of short-interval fire, the extent of vegetation type conversion and the conditions under which it occurs have not been documented at a landscape scale. Our objective was thus to provide an unbiased assessment of how and how much vegetation type conversion is occurring in Southern California chaparral. **Extent and drivers of vegetation type conversion in Southern California chaparral.** ALEXANDRA D. SYPHARD, TERESA J. BRENNAN, AND JON E. KEELEY

The boundary between woodlands and shrublands delineates the distribution of the tree biome in many regions across the globe. Woodlands and shrublands interface at multiple spatial scales, and many ecological processes operate at different spatial scales to determine the position of the woodland-shrubland boundary. The overall objective of this dissertation was to examine processes affecting vegetation dynamics at the woodland-shrubland interface in the western United States, at spatial scales ranging from biomes to individual plants. **Vegetation dynamics at the woodland-shrubland interface: Role of climate, disturbance, and species interactions.** ALEXANDRA K. URZA

Vegetation Mapping and Modeling

Invasion by annual grasses (IAGs) and concomitant increases in wildfire are impacting many drylands globally, and an understanding of factors that contribute to or detract from community resistance to IAGs is needed to inform postfire restoration interventions. Prefire vegetation condition is often unknown in rangelands, but it likely affects variation in postfire invasion resistance across large, burned scars. Whether satellite-derived products like the Rangeland Analysis Platform (RAP) can fulfill pre-fire information needs and be used to parametrize models of fire recovery to inform postfire management of IAGs is a key question. **Satellite-derived prefire vegetation predicts variation in field-based invasive annual grass cover after fire.** Christopher R. Anthony, Cara V. Applestein, Matthew J. Germino

Cheatgrass (*Bromus tectorum* L.) is a highly invasive species in the Northern Great Basin that helps decrease fire return intervals. Fire fragments the shrub steppe and reduces its capacity to provide forage for livestock and wildlife and habitat critical to sagebrush obligates. Of particular interest is the greater sage grouse (Centrocercus urophasianus), an obligate whose populations have declined so severely due, in part, to increases in cheatgrass and fires that it was considered for inclusion as an endangered species. Remote sensing technologies and satellite archives help scientists monitor terrestrial vegetation globally, including cheatgrass in the Northern Great Basin. Along with geospatial analysis and advanced spatial modeling, these data and technologies can identify areas susceptible to increased cheatgrass cover and compare these with greater sage grouse priority areas for conservation (PAC). Future climate models forecast a warmer and wetter climate for the Northern Great Basin, which likely will force changing cheatgrass dynamics. Therefore, we examine potential climate-caused changes to cheatgrass. **Cheatgrass Percent Cover Change: Comparing Recent Estimates to Climate Change–Driven Predictions in the Northern Great Basin.** Stephen P. Boyte, Bruce K. Wylie, Donald J. Major

The spatial patterns and context of invasions are increasingly recognized as important for successful and efficient management actions. Beyond mapping occurrence or percent cover in pixels, spatial summary information that describes the size and arrangement of patches in the context of a larger landscape (e.g., infested regions, connected patch networks) can add a depth of information for managing invasive

grasses that threaten native ecosystems. Few invasive annual grass analyses have explored the use of landscape and circuit-based connectivity metrics to characterize and compare spatial patterns of invasion. **Landscape and connectivity metrics as a spatial tool to support invasive annual grass management decisions.** Erin K. Buchholtz, Julie Heinrichs, Michele Crist

We developed spatial layers of the dominant sagebrush associations by overlaying LANDFIRE Existing Vegetation Type, Biophysical Setting, and Mapping Zone, extracting vegetation plot data from the LANDFIRE 2016 LF Reference Database for each combination, and identifying associated sagebrush, grass, shrub, and tree species. We derived spatial layers of pinyon-juniper (PJ) cover and expansion phase within the sagebrush associations from the Rangeland Analysis Platform and identified persistent PJ woodlands from the LANDFIRE Biophysical Setting. TRGs were created by overlaying dominant sagebrush associations, with and without PJ expansion, and new indicators of resilience and resistance. We assigned appropriate woody fuel treatments to the TRGs based on prior research on treatment responses. **Fuel treatment response groups for fire-prone sagebrush landscapes.** Jeanne C. Chambers, Jessi L. Brown, Matthew C. Reeves, Eva K. Strand, Lisa M. Ellsworth, Claire M. Tortorelli, Alexandra K. Urza and Karen C. Short

The sagebrush biome is a dryland region in the western United States experiencing rapid transformations to novel ecological states. Threat-based approaches for managing anthropogenic and ecosystem threats have recently become prominent, but successfully mitigating threats depends on the ecological resilience of ecosystems. We used a spatially explicit approach for prioritizing management actions that combined a threat-based model with models of resilience to disturbance and resistance to annual grass invasion. **Combining resilience and resistance with threat-based approaches for prioritizing management actions in sagebrush ecosystems.** Jeanne C. Chambers, Jessi L. Brown, John B. Bradford, Kevin E. Doherty, Michele R. Crist, Daniel R. Schlaepfer, Alexandra K. Urza, Karen C. Short

Sagebrush shrublands in the Great Basin, USA, are experiencing widespread increases in wildfire size and area burned resulting in new policies and funding to implement fuel treatments. However, we lack the spatial data needed to optimize the types and locations of fuel treatments across large landscapes and mitigate fire risk. To address this, we developed treatment response groups (TRGs)—sagebrush and pinyon-juniper vegetation associations that differ in resilience to fire and resistance to annual grass invasion (R&R) and thus responses to fuel treatments. We developed spatial layers of the dominant sagebrush associations by overlaying LANDFIRE Existing Vegetation Type, Biophysical Setting, and Mapping Zone, extracting vegetation plot data from the LANDFIRE 2016 LF Reference Database for each combination, and identifying associated sagebrush, grass, shrub, and tree species. We derived spatial layers of pinyon-juniper (PJ) cover and expansion phase within the sagebrush associations from the Rangeland Analysis Platform and identified persistent PJ woodlands from the LANDFIRE Biophysical Setting. **Fuel treatment response groups for fire-prone sagebrush landscapes.** Jeanne C. Chambers, Jessi L. Brown, Matthew C. Reeves, Eva K. Strand, Lisa M. Ellsworth, Claire M. Tortorelli, Alexandra K. Urza and Karen C. Short

Narrowing the communication and knowledge gap between producers and users of scientific data is a longstanding problem in ecological conservation and land management. Decision support tools (DSTs), including websites or interactive web applications, provide platforms that can help bridge this gap. DSTs

can most effectively disseminate and translate research results when producers and users collaboratively and iteratively design content and features. One data resource seldom incorporated into DSTs are species distribution models (SDMs), which can produce spatial predictions of habitat suitability. Outputs from SDMs can inform management decisions, but their complexity and inaccessibility can limit their use by resource managers or policy makers. To overcome these limitations, we present the Invasive Species Habitat Tool (INHABIT), a novel, web-based DST built with R Shiny to display spatial predictions and tabular summaries of habitat suitability from SDMs for invasive plants across the contiguous United States. INHABIT provides actionable science to support the prevention and management of invasive species. **INHABIT: A web-based decision support tool for invasive plant species habitat visualization and assessment across the contiguous United States.** Peder Engelstad, Catherine S. Jarnevich, Terri Hogan, Helen R. Sofaer, Ian S. Pearse, Jennifer L. Sieracki, Neil Frakes, Julia Sullivan, Nicholas E. Young, Janet S. Preve, Pairsa Belamaric, Jillian LaRoe

Globally, invasive plant-fueled wildfires have tremendous environmental, economic, and societal impacts, and the frequencies of wildfires and plant invasions are on an upward trend globally. Identifying which plant species tend to increase the frequency or severity of wildfire is important to help manage their impacts. We developed a screening system to identify introduced plant species that are likely to increase wildfire risk, using the Hawaiian Islands to test the system and illustrate how the system can be applied to inform management decisions. **A screening system to predict wildfire risk of invasive plants.** Kevin Faccenda, Curtis C. Daehler

Conservation planning for wildlife species requires mapping and assessment of habitat suitability across broad areas, often relying on a diverse suite, or stack, of geospatial data presenting multidimensional controls on a species. Stacks of univariate, independently developed vegetation layers may not represent relationships between each variable that can be characterized by multivariate modeling techniques, leading to inaccurate inferences on the distribution of suitable habitat. In this paper, we examine the role of variable combining in mapping multiple dimensions of greater sage-grouse (Centrocercus urophasianus, GRSG) habitat as a basis for GRSG conservation in the great basin ecoregion within southeastern Oregon. **Vegetation mapping to support greater sage-grouse habitat monitoring and management: multi- or univariate approach?** EMILIE B. HENDERSON, DAVID M. BELL, AND MATTHEW J. GREGORY

This study used newly developed remote-sensing tools to conduct an unprecedented assessment of trends in vegetation cover and production for all BLM rangelands from 1991 to 2020. We found widespread increases in cover and production of annual grasses and forbs, declines in herbaceous perennial cover, and expansion of trees. Cover and production of annual plants now exceed that of perennials on > 21 million ha of BLM rangeland, marking a fundamental shift in the ecology of these lands. This trend was most dramatic in the Western Cold Desert of Nevada and parts of surrounding states where aboveground production of annuals has more than tripled. **Long-Term Trends in Vegetation on Bureau of Land Management Rangelands in the Western United States.** Andrew R. Kleinhesselink, Emily J. Kachergis, Sarah E. McCord, Justin Shirley, Nicole R. Hupp, Jennifer Walker, John C. Carlson, Scott L. Morford, Matthew O. Jones, Joseph T. Smith, Brady W. Allred, David E. Naugle

Emerging applications of ecosystem resilience and resistance concepts in sagebrush ecosystems allow managers to better predict and mitigate impacts of wildfire and invasive annual grasses. Widely available soil survey information can be harnessed to spatially depict and evaluate relative resilience and resistance from regional to site scales. New products and tools illustrate how managers can use soils data to inform rapid risk assessments, determine appropriate management strategies, and prioritize resources to maintain and restore functioning sagebrush ecosystems. **Tapping Soil Survey Information for Rapid Assessment of Sagebrush Ecosystem Resilience and Resistance.** Jeremy D. Maestas, Steven B. Campbell, Jeanne C. Chambers, Mike Pellant, and Richard F. Miller

Nonnative invasive plant species (NNIPS) cause significant damage to the native forest ecosystems in the southern United States forestlands, such as habitat degradation, ecological instability, and biodiversity loss. Taking the state of Alabama as an example, we used more than 5,000 permanent United States Department of Agriculture-Forest Service's Forest Inventory and Analysis (FIA) plots measured between 2001 and 2019 over three measurement cycles to test the suitable modeling unit for quantifying invasion patterns and associated factors for regional NNIPS monitoring and management. **Determining spatial units for modeling regional nonnative invasive plant species spread in the southern US forestlands: using the state of Alabama as an example.** Sunil Nepal, Martin A. Spetich and Zhaofei Fan

Decision-making resource stewardship models rely on statistical relationships between management actions and ecosystem services provisioning. The operationalization of management actions benefits from models capable to isolate synergic statistical relationships from trade-offs. We showcase two existing watershed planning studies requiring spatiotemporal operationalization to better schedule management actions. The study in Hawai'i Island (USA) focused on invasive species while another in Babeldaob Island (Republic of Palau) tackled wildfire management. **Integrating ecosystem services modeling and efficiencies in decision-support models conceptualization for watershed management.** Adrian ´ Pascuala, Christian P. Giardina, Nicholas A. Povak, Paul F. Hessburg, Gregory P. Asner

Exotic annual grasses (EAG) are one of the most damaging agents of change in western North America. Despite known socio-environmental effects of EAG there remains a need to enhance monitoring capabilities for better informing conservation and management practices. Here, we integrate field observations, remote sensing and climate data with machine-learning techniques to estimate and assess patterns of historical, present, and future EAG abundance (30-m) across much of the western United States. **Rapid Monitoring of the Abundance and Spread of Exotic Annual Grasses in the Western United States Using Remote Sensing and Machine Learning.** Neal J. Pastick, Bruce K. Wylie, Matthew B. Rigge, Devendra Dahal, Stephen P. Boyte, Matthew O. Jones, Brady W. Allred, Sujan Parajuli, and Zhuoting Wu

Wildfires are a growing management concern in western US rangelands, where invasive annual grasses have altered fire regimes and contributed to an increased incidence of catastrophic large wildfires. Fire activity in arid, non-forested ecosystems is thought to be largely controlled by interannual variation in fuel amount, which in turn is controlled by antecedent weather. Thus, long-range forecasting of fire activity in rangelands should be feasible given annual estimates of fuel quantity. Using a 32-yr time series of spatial data, we employed machine learning algorithms to predict the relative probability of large (>405 ha) wildfire in the Great Basin based on fine-scale annual and 16-d estimates of cover and production of vegetation functional groups, weather, and multitemporal scale drought indices. We

evaluated the predictive utility of these models with a leave-1-yr-out cross-validation, building spatial hindcasts of fire probability for each year that we compared against actual footprints of large wildfires. **Where There's Smoke, There's Fuel: Dynamic Vegetation Data Improve Predictions of Wildfire Hazard in the Great Basin.** Joseph T. Smith, Brady W. Allred, Chad S. Boyd, Kirk W. Davies, Matthew O. Jones, Andrew R. Kleinhesselink, Jeremy D. Maestas, David E. Naugle

Context Anticipating where an invasive species could become abundant can help guide prevention and control efforts aimed at reducing invasion impacts. Information on potential abundance can be combined with information on the current status of an invasion to guide management towards currently uninvaded locations where the threat of invasion is high. Objectives We aimed to support management by developing predictive maps of potential cover for cheatgrass (Bromus tectorum), a problematic invader that can transform plant communities. We integrated our predictions of potential abundance with mapped estimates of current cover to quantify invasion potential within lightly invaded areas. Methods We used quantile regression to model cheatgrass abundance as a function of climate, weather, and disturbance, treating outputs as low to high invasion scenarios. We developed a species-specific set of covariates and validated model performance using spatially and temporally independent data. **Potential cheatgrass abundance within lightly invaded areas of the Great Basin**. Helen R. Sofaer, Catherine S. Jarnevich, Erin K. Buchholtz, Brian S. Cade, John T. Abatzoglou, Cameron L. Aldridge, Patrick J. Comer, Daniel Manier, Lauren E. Parker, Julie A. Heinrichs

Invasions of native plant communities by non-native species present major challenges for ecosystem management and conservation. Invasive annual grasses such as cheatgrass, medusahead, and ventenata are pervasive and continue to expand their distributions across imperiled sagebrush-steppe communities of the western United States. These invasive grasses change native plant communities, ecosystem function, and fire regimes, threatening sagebrush ecosystem persistence. Spatial data describing the distribution and abundance of invasive species are often used by resource managers to identify, target, and determine needed interventions. However, there are challenges associated with translating these datasets into management actions. We conducted a review of available spatial products to assess advances in, and barriers to, applying contemporary model-based maps to support rangeland management. We found dozens of regional data products describing cheatgrass or annual herbaceous cover and few maps describing ventenata or medusahead. **Bridging the Gap Between Spatial Modeling and Management of Invasive Annual Grasses in the Imperiled Sagebrush Biome.** Bryan C. Tarbox, Nathan D. Van Schmidt, Jessica E. Shyvers, D. Joanne Saher, Julie A. Heinrichs, Cameron L. Aldridge

The interactions of nonnative invasions and landscape disturbances on novel fuel beds exacerbate the impacts of wildfire in Hawaii, and throughout the tropical Pacific Islands. Intensive field sampling and hybrid remote sensing techniques are valuable means of assessing regional and local variability in fuels in response to environmental gradients and management actions. **Modeling fuels and wildfire behavior in Hawaiian ecosystems.** Timothy R. Zhu

Fine Fuels Management, Wildfire, and Invasives

Rangeland wildfire is a wicked problem that cuts across a mosaic of public and private rangelands in the western United States and countless countries worldwide. Fine fuel accumulation in these ecosystems contributes to large-scale wildfires and undermines plant communities' resistance to invasive annual

grasses and resilience to disturbances such as fire. Yet it can be difficult to implement fuels management practices, such as grazing, in socially and politically complex contexts such as federally managed rangelands in the United States. In this Research-Partnership Highlight, we argue that private-public partners in such settings must be strategic in their selection of tasks to generate "small wins" in order to build the trust, competency, and legitimacy needed to advance an approach for landscape-scale fine fuels management. **Strategic Partnerships to Leverage Small Wins for Fine Fuels Management.** Sergio A. Arispe, Dustin D. Johnson, Katherine L. Wollstein, April Hulet, K. Scott Jensen, Brad W. Schultz, James E. Sprinkle, Michele F. McDaniel, Thomas Ryan, Mark Mackenzie, Sean Cunningham

Non-native, invasive grasses have been linked to altered grass-fire cycles worldwide. Although a few studies have quantified resulting changes in fire activity at local scales, and many have speculated about larger scales, regional alterations to fire regimes remain poorly documented. We assessed the influence of large-scale Bromus tectorum (here after cheatgrass) invasion on fire size, duration, spread rate, and interannual variability in comparison to other prominent land cover classes across the Great Basin, USA. We compared regional land cover maps to burned area measured using the Moderate Resolution Imaging Spectroradiometer (MODIS) for 2000–2009 and to fire extents recorded by the USGS registry of fires from 1980 to 2009. Cheatgrass dominates at least 6% of the central Great Basin (650 000 km2). MODIS records show that 13% of these cheatgrass-dominated lands burned, resulting in a fire return interval of 78 years for any given location within cheatgrass. **Introduced annual grass increases regional fire activity across the arid western USA (1980–2009).** JENNIFER K. BALCH, BETHANY A. BRADLEY, CARLA M. D'ANTONIO and JOSE´ GO´ MEZ-DANS

Plant invasions are widely recognized as significant threats to biodiversity conservation worldwide. One or the ways invasions can affect native ecosystems is by changing fuel properties, which can in turn affect fire behavior and, ultimately, alter fire regime characteristics such as frequency, intensity, extent, type, and seasonality of fire. If the regime changes subsequently promote the dominance of the invaders, then an invasive plant–fire regime cycle can be established. As more ecosystem components and interactions are altered, restoration of preinvasion conditions becomes more difficult. Restoration may require managing fuel conditions, fire regimes, native plant communities, and other ecosystem properties in addition to the invaders that caused the changes in the first place. We present a multiphase model describing the interrelationships between plant invaders and fire regimes, provide a system for evaluating the relative effects of invaders and prioritizing them for control, and recommend ways to restore preinvasion fire regime properties. **Effects of Invasive Alien Plants on Fire Regimes.** MATTHEW L. BROOKS, CARLA M. D'ANTONIO, DAVID M. RICHARDSON, JAMES B. GRACE, JON E. KEELEY, JOSEPH M. DITOMASO, RICHARD J. HOBBS, MIKE PELLANT, AND DAVID PYKE

Forest-savanna mosaics are maintained by fire-mediated positive feedbacks; whereby forest is fire suppressive, and savanna is fire promoting. Forest-savanna transitions therefore represent the interface of opposing fire regimes. Within the transition there is a threshold point at which tree canopy cover becomes sufficiently dense to shade out grasses and thus suppress fire. Prior to reaching this threshold, changes in fire behavior may already be occurring within the savanna. Such changes are neither empirically described, nor their drivers understood. Fire behavior is largely driven by fuel flammability. Flammability can vary significantly between grass species and grass species composition can change near forest-savanna transitions. This study measured fire behavior changes at eighteen forest-savanna

transition sites in a vegetation mosaic in Lopé National Park in Gabon, central Africa. **Grass Species Flammability, Not Biomass, Drives Changes in Fire Behavior at Tropical Forest-Savanna Transitions.** Anabelle W. Cardoso, Imma Oliveras, Katharine A. Abernethy, Kathryn J. Jeffery, David Lehmann, Josué Edzang Ndong, Ian McGregor, Claire M. Belcher, William J. Bond and Yadvinder S. Malhi

Plant invasions can affect fuel characteristics, fire behavior, and fire regimes resulting in invasive plant-fire cycles and alternative, self-perpetuating states that can be difficult, if not impossible, to reverse. Concepts related to general resilience to disturbance and resistance to invasive plants provide the basis for managing landscapes to increase their capacity to reorganize and adjust following fire, while concepts related to spatial resilience provide the basis for managing landscapes to conserve resources and habitats and maintain connectivity. New, spatially explicit approaches and decision-tools enable managers to understand and evaluate general and spatial resilience to fire and resistance to invasive grasses across large landscapes in arid and semi-arid shrublands and woodlands. These approaches and tools provide the capacity to locate management actions strategically to prevent development of invasive grass-fire cycles and maintain or improve resources and habitats. In this review, we discuss the factors that influence fire regimes, general and spatial resilience to fire, resistance to invasive annual grasses, and thus invasive grass-fire cycles in global arid and semi-arid shrublands and woodlands. **Operationalizing Resilience and Resistance Concepts to Address Invasive Grass-Fire Cycles.** Jeanne C. Chambers, Matthew L. Brooks, Matthew J. Germino, Jeremy D. Maestas, David I. Board, Matthew O. Jones, and Brady W. Allred.

Sagebrush ecosystems are experiencing increases in wildfire extent and severity. Most research on vegetation treatments that reduce fuels and fire risk has been short term (2–3 years) and focused on ecological responses. We review causes of altered fire regimes and summarize literature on the longer-term effects of treatments that modify (1) shrub fuels, (2) pinyon and juniper canopy fuels, and (3) fine herbaceous fuels. We describe treatment effects on fuels, fire behavior, ecological resilience, and resistance to invasive annual grasses. **Review of fuel treatment effects on fuels, fire behavior and ecological resilience in sagebrush (Artemisia spp.) ecosystems in the Western U.S.** Jeanne C. Chambers, Eva K. Strand, Lisa M. Ellsworth, Claire M. Tortorelli, Alexandra K. Urza, Michele R. Crist, Richard F. Miller, Matthew C. Reeves, Karen C. Short and Claire L. Williams

Fire and fuel management is a high priority in North American sagebrush ecosystems where the expansion of pinon and juniper trees and the invasion of nonnative annual grasses are altering fire regimes and resulting in loss of sagebrush species and habitat. We evaluated 10-yr effects of woody fuel treatments on sagebrush recruitment and plant functional group interactions using Sagebrush Steppe Treatment Evaluation Project data. We used mixed-effects ANOVAs to examine treatment effects on sagebrush density and cover and perennial and annual grass cover in expansion woodlands (prescribed fire and cut-and-leave) and annual grass invasion areas (prescribed fire, mowing, tebuthiuron herbicide application). We used piecewise structural equation models to evaluate interactions among sagebrush seedling density, juvenile and adult density, and cover and perennial and annual grass cover. **Sagebrush recovery patterns after fuel treatments mediated by disturbance type and plant functional group interactions.** JEANNE C. CHAMBERS, ALEXANDRA K. URZA, DAVID I. BOARD, RICHARD F. MILLER, DAVID A. PYKE, BRUCE A. ROUNDY, EUGENE W. SCHUPP, AND ROBIN J. TAUSCH

For most of the 20th century and beyond, national wildland fire policies concerning fire suppression and fuels management have primarily focused on forested lands. Using summary statistics and landscape metrics, wildfire spatial patterns and trends for non-forest and forest burned area over the past two decades were examined across the U.S, and federal agency jurisdictions. This study found that wildfires burned more area of non-forest lands than forest lands at the scale of the conterminous and western U.S. and the Department of Interior (DOI). In an agency comparison, 74% of DOI burned area occurred on non-forest lands and 78% of U.S. Forest Service burned area occurred on forested lands. In addition, a fire regime departure analysis comparing current large fire probability with historic fire trends identified certain vegetation types and locations experiencing more fire than historically. **Rethinking the focus on forest fires in federal wildland fire management: Landscape patterns and trends of non-forest and forest burned area.** Michele R. Crist

Fire regimes in sagebrush (Artemisia spp.) ecosystems have been greatly altered across the western United States. Broad-scale invasion of non-native annual grasses, climate change, and human activities have accelerated wildfire cycles, increased fire size and severity, and lengthened fire seasons in many sagebrush ecosystems to the point that current wildfire-management practices and postfire restoration efforts cannot keep pace to ameliorate the ecological consequences of sagebrush ecosystem loss. The greatest impact of uncharacteristically frequent fire is the transition from native sagebrush-perennial grass communities to invasive, non-native, annual grasslands that are highly flammable. **Trends, Impacts, and Cost of Catastrophic and Frequent Wildfires in the Sagebrush Biome.** Michele R. Crist, Rick Belger, Kirk W. Davies, Dawn M. Davis, James R. Meldrum, Douglas J. Shinneman, Thomas E. Remington, Justin Welty, Kenneth E. Mayer

Frequent and Catastrophic Wildfires in Great Basin Rangelands: Time for a Proactive Management Approach. Kirk W. Davies, Dustin D. Johnson, Joe Smith

Restoration efforts are underway in dry conifer forests across the western United States to increase their resilience to wildfire and other disturbances. Because such treatments typically decrease overstory density and homogeneity, they can also drive changes in the understory plant community. Past studies of post-treatment changes in understories have found variable results over short time frames and across regions, highlighting the need to study longer-term, region-specific responses. We investigated whether mechanical restoration treatments benefited understory plants in dry conifer forests of the Colorado Front Range, and what biotic and abiotic variables modified understory plant responses in treated areas. **Mechanical forest restoration treatments stimulate understory plants in the Colorado Front Range.** Ari`el B. Demarest, Paula J. Fornwalt, Brett H. Wolk, Kyle C. Rodman, Miranda D. Redmond

Increased fire size and frequency coupled with annual grass invasion pose major challenges to sagebrush (Artemisia spp.) ecosystem conservation, which is currently focused on protecting sagebrush community composition and structure. A common strategy for mitigating potential fire is to use fuel treatments that alter the structure and amount of burnable material, thus reducing fire behavior and creating access points for fire suppression resources. While there is some recent information on the impacts of fuel treatments on ecological communities, we have little information on fuel treatment effectiveness at modifying fire behavior in sagebrush ecosystems. We present 10 years of data on fuel accumulation and the resultant modeled fire behavior in prescribed fire, mowed, herbicide (tebuthiuron or imazapic), and

untreated control plots in the Sagebrush Treatment Evaluation Project (SageSTEP) network in the Great Basin, USA. **Fuel reduction treatments reduce modeled fire intensity in the sagebrush steppe.** L. M. Ellsworth, B. A. Newingham, S. E. Shaff, C. L. Williams, E. K. Strand, M. Reeves, D. A. Pyke, E. W. Schupp, J. C. Chambers

How does potential fire behaviour differ in grass-invaded nonnative forests vs open grasslands? How has land cover changed from 1950–2011 along two grassland/forest ecotones in Hawaii with repeated fires? **Invasive grasses change landscape structure and fire behaviour in Hawaii**. Lisa M. Ellsworth, Creighton M. Litton, Alexander P. Dale & Tomoaki Miura

Prescribed burning is a key tool used in prairie and savanna restoration projects. The timing and frequency of prescribed fires are important variables to consider because they can differentially affect the survival of individual plant species, including noxious exotic species. We used annual censuses and population matrix analysis to evaluate the demographic consequences of burning on populations of the invasive species spotted knapweed *Centaurea maculosa* in a Michigan, USA, prairie restoration experiment. We compared spring, summer and autumn burns at two frequencies: annually (2000–03) and in alternate years (2001, 2003). We examined the effects of different seasons and frequencies of prescribed fire on the survival, growth and reproduction of *C. maculosa* populations, and used life-table response experiments and elasticity analyses to determine how season of fire affects population growth rates. We found that annual summer burning was the only treatment that significantly reduced overall population growth rates. **Effects of timing of prescribed fire on the demography of an invasive plant, spotted knapweed Centaurea maculosa.** SARAH M. EMERY and KATHERINE L. GROSS

While the existence of an invasive grass-fire cycle is well known, evidence of altered fire regimes is typically based on local scale studies or expert knowledge. Here, we quantify the effects of 12 nonnative, invasive grasses on fire occurrence, size, and frequency across 29 US ecoregions encompassing more than one third of the conterminous United States. These 12 grass species promote fire locally and have extensive spatial records of abundant infestations. We combined agency and satellite fire data with records of abundant grass invasion to test for differences in fire regimes between invaded and nearby "uninvaded" habitat. **Invasive grasses increase fire occurrence and frequency across US ecoregions.** Emily J. Fusco, John T. Finn, Jennifer K. Balch, R. Chelsea Nagy, and Bethany A. Bradley

Invasive grass species can alter fire regimes, converting native terrestrial ecosystems into non-native, grass-dominated landscapes, creating a self-reinforcing cycle of increasing fire activity and flammable grass expansion. Analyses of this phenomenon tend to focus on the ecology and geography of the grass–fire cycle independent of human activities. Yet people introduce non-native grasses to new landscapes (e.g., via agriculture), facilitate their spread (e.g., via road networks), and are a primary source of ignition (e.g., via debris burning). We propose a new framework for this phenomenon that explicitly recognizes the important role of anthropogenic activities in the human–grass–fire cycle. We review links between land use and invasive species as well as ignitions, with a particular focus on the spatial and temporal co-occurrences of these activities to show that these two drivers of wildfires are inextricable. Finally, management strategies that could mitigate impacts are discussed. **The human–grass–fire cycle: how people and invasives co-occur to drive fire regimes.** Emily J Fusco, Jennifer K Balch, Adam L Mahood, R Chelsea Nagy, Alexandra D Syphard, and Bethany A Bradley

Linear fuel breaks are being implemented to moderate fire behavior and improve wildfire containment in semiarid landscapes such as the sagebrush steppe of North America, where extensive losses in perennial vegetation and ecosystem functioning are resulting from invasion by exotic annual grasses (EAGs) that foster large and recurrent wildfires. However, fuel-break construction can also pose EAG invasion risks, which must be weighed against the intended fire-moderation benefits of the treatments. We investigated how shrub reductions (mowing, cutting), pre-emergent EAG-herbicides, and/or drill seedings of fire-resistant perennial bunchgrasses (PBGs) recently applied to create a large fuel-break system affected native and exotic plant abundances and their associated fuel loading and predicted fire behavior. **Vegetation, fuels, and fire-behavior responses to linear fuel-break treatments in and around burned sagebrush steppe: are we breaking the grass-fire cycle?** Matthew J. Germino, Samuel "Jake" Price and Susan J. Prichard

Strategic placement of fuel treatments across large landscapes is an important step to mitigate the collective effects of fires interacting over broad spatial and temporal extents. On landscapes where highly invasive cheatgrass (Bromus tectorum) is increasing fire activity, such an approach could help maintain landscape resilience. Objectives Our objectives are to 1) model and map fire connectivity on a cheatgrass-invaded landscape, as well as the centrality of large cheatgrass patches, in order to inform a landscape fuel treatment (i.e., a network of greenstrips); and 2) evaluate the modeled greenstrip network based on changes to cheatgrass patch centrality. **Applying fire connectivity and centrality measures to mitigate the cheatgrass-fire cycle in the arid West, USA.** Miranda E. Gray, Brett G. Dickson

The invasive annual grass cheatgrass (Bromus tectorum) increases fuel continuity, alters patterns of fire spread, and changes plant communities in sagebrush shrublands of the Great Basin (USA) and adjacent sagebrush steppe areas, but no studies have contrasted its flammability to native perennial grasses. Understanding cheatgrass flammability is crucial for predicting fire behavior, informing management decisions, and assessing fire potential of invaded areas. This study aimed to determine the flammability of cheatgrass compared to two native perennial grasses (Columbia needlegrass [*Achnatherum nelsonii*] and bluebunch wheatgrass [*Pseudoroegneria spicata*]) across a range of typical fire season fuel moistures. This study provides experimental evidence supporting previous qualitative observations of high cheatgrass flammability. Even at high fuel moisture, cheatgrass increased perennial grass flammability, suggesting that cheatgrass poses a significant fire threat to native grasses for an extended season than expected for the native grasses without cheatgrass. The study's findings inform invasive plant management and fire potential, and guide efforts to prevent or mitigate cheatgrass-induced wildfires. **Cheatgrass alters flammability of native perennial grasses in laboratory combustion experiments.** Georgia R. Harrison, Lisa C Jones, Lisa M Ellsworth, Eva K. Strand, Timothy S. Prather

Floristic composition of dominant plant species varies significantly among dry sclerophyll woodland and wet sclerophyll gully forest (wildland) and home gardens and parks and recreational (urban) areas of the WUI. Notably, urban areas have higher exotic species richness and canopy cover which is driven by the prevalence of exotics in household gardens. Given the significant floristic differences between urban and wildland areas, I then compare patterns in shoot flammability across 45 woody plant species between these WUI areas. I show that wildland plants are more flammable than urban plants via their longer burn times (higher sustainability) and larger amounts of consumed shoot biomass (higher consumability). In

terms of native and exotic plants in wildland and urban areas, not only are wildland native plants more flammable than urban exotic plants, but urban native plants also have longer burn times, consume more biomass and in addition reach higher combustion temperatures (higher combustibility) than urban exotic plants. **Patterns in plant flammability at a fire-prone wildland-urban interface in eastern Australia.** Thomas Hawthorne

Extant dry forests no longer appear or function as they once did. Large landscapes are homogeneous in their composition and structure, and the regional landscape is set up for severe, large fire and insect disturbance events. Among ecologists, there is also a high degree of concern about how future dry forests will develop, if fires continue to be large and severe. In this paper, we describe the key landscape pattern and process changes wrought by the sum of the settlement and management influences to date, and we point to an uncertain future for ecosystem management. Widespread selection cutting of the largest and oldest ponderosa pine and Douglas-fir in the 20th century has reduced much of the economic opportunity that might have been associated with restoration, and long-term investment will likely be needed, if large-scale restoration activities are attempted. **Dry forests and wildland fires of the inland Northwest USA: Contrasting the landscape ecology of the pre-settlement and modem eras.** Paul F. Hessburg, James K. Agee, Jerry Franklin

Prescription burning is increasingly used to control invasion of particularly noxious weeds that are typically targeted because they alter the functioning of ecosystems, e.g., making rangelands unpalatable to livestock or wildlife. Such use of prescription burning may enhance resource benefits for some stakeholders, but generally burning of annual grasslands does not greatly alter the native to nonnative composition, unless accompanied by active native plant restoration. **FIRE AND INVASIVE SPECIES IN MEDITERRANEAN-CLIMATE ECOSYSTEMS OF CALIFORNIA.** Jon E. Keeley

Fire management practices affect alien plant invasions in diverse ways. I considered the impact of six fire management practices on alien invasions: fire suppression, forest fuel reduction, prescription burning in crown-fire ecosystems, fuel breaks, targeting of noxious aliens, and postfire rehabilitation. Most western United States forests have had fire successfully excluded for unnaturally long periods of time, and this appears to have favored the exclusion of alien plant species. Forest fuel reduction programs have the potential for greatly enhancing forest vulnerability to alien invasions. **Fire Management Impacts on Invasive Plants in the Western United States.** JON E. KEELEY

Disturbances create fluctuations in resource availability that alter abiotic and biotic constraints. Exotic invader response may be due to multiple factors related to disturbance regimes and complex interactions between other small- and largescale abiotic and biotic processes that may vary across invasion stages. We explore how cheatgrass responds to both frequency and season of prescribed burning for a 10-year period in ponderosa pine forested stands. **The importance of disturbance by fire and other abiotic and biotic factors in driving cheatgrass invasion varies based on invasion stage.** Becky K. Kerns, Michelle A. Day

High-impact mega-fires in many temperate forests and shrublands of the world have called for pre-emptive approaches to mitigate fire risk. Comparative appraisals of the characteristics and flammability of plant fuels can inform fire risk predictions and vegetation management efforts in the wildland–urban interface of such fire-prone regions. Prompted by recent extreme fires in the Cape Floristic Region of

South Africa, we assessed the flammability and fuel traits of excised terminal branches of 30 woody species (many of which have never been studied before) that commonly occur as native, alien or invasive species in this region and some other temperate regions of the world. We furthermore assessed changes in flammability and fuel moisture in these species after partial drying of excised branches under ambient conditions for 2–4 weeks to simulate extreme drought conditions. Several prominent alien invasive taxa in the study region and elsewhere showed high flammability. **Flammability of native and invasive alien plants common to the Cape Floristic Region and beyond: Fire risk in the wildland–urban interface.** Tineke Kraaij, Samukelisiwe T Msweli, Alastair J Potts

A key challenge in modern wildfire mitigation and forest management is accurate mapping of forest fuels in order to determine spatial fire hazard, plan mitigation efforts, and manage active fires. This study quantified forest fuels of the montane zone of Boulder County, CO, USA in an effort to aid wildfire mitigation planning and provide a metric by which LANDFIRE national fuel maps may be compared. Using data from 196 randomly stratified field plots, pre-existing vegetation maps, and derived variables, predictive classification and regression tree models were created for four fuel parameters necessary for spatial fire simulation with FARSITE (surface fuel model, canopy bulk density, canopy base height, and stand height). **Forest fuel mapping and evaluation of LANDFIRE fuel maps in Boulder County, Colorado, USA.** Kevin Krasnow, Tania Schoennagel, Thomas T. Veblen

Cheatgrass (Bromus tectorum) invasion is driving an emerging cycle of increased fire frequency and irreversible loss of wildlife habitat in the western US. Yet, detailed spatial information about its occurrence is still lacking for much of its presumably invaded range. Deep learning (DL) has demonstrated success for remote sensing applications but is less tested on more challenging tasks like identifying biological invasions using sub-pixel phenomena. We compare two DL architectures and the more conventional Random Forest and Logistic Regression methods to improve upon a previous effort to map cheatgrass occurrence at >2% canopy cover. **Deep Learning Classification of Cheatgrass Invasion in the Western United States Using Biophysical and Remote Sensing Data.** Kyle B. Larson and Aaron R. Tuor

Spatial and temporal dynamics of rangeland fuels is a primary factor driving large wildfires. Yet detailed information capturing variation in fine fuels has largely been missing from rangeland fire planning and fuels management. New fuels-based maps of Great Basin rangeland fire probability help bridge this gap by coupling dynamic vegetation cover and production data from the Rangeland Analysis Platform with weather and climate data to provide annual forecasts of the relative probability of large wildfire. In this paper, we review these new fuels-based maps and discuss implications for prefire planning, preparedness, and strategic fuels management. **Using Dynamic, Fuels-Based Fire Probability Maps to Reduce Large Wildfires in the Great Basin.** Jeremy D. Maestas, Joseph T. Smith, Brady W. Allred, David E. Naugle, Matthew O. Jones, Casey O'Connor, Chad S. Boyd, Kirk W. Davies, Michele R. Crist, Andrew C. Olsen

Fire regimes influence and are influenced by the structure and composition of plant communities. This complex reciprocal relationship has implications for the success of plant invasions and the subsequent impact of invasive species on native biota. Although much attention has been given to the role of invasive grasses in transforming fire regimes and native plant communities, little is known about the

relationship between woody invasive species and fire regime. Despite this, prescribed burning is frequently used for managing invasive woody species. In this study we review relationships between woody exotic plant invasions and fire in invaded ecosystems worldwide. **Woody exotic plant invasions and fire: reciprocal impacts and consequences for native ecosystems.** Lisa Mandle, Jennifer L. Bufford, Isabel B. Schmidt, Curtis C. Daehler

Buffelgrass (Pennisetum ciliare [L.] Link) can create a grass-fire cycle in many parts of the world because it is a highly competitive, fire-tolerant grass and can replace less fire-tolerant native plants. Fuel loads, loss of buffelgrass biomass after herbicide treatments, and allometric data of buffelgrass growth were measured across sites in southern Arizona, USA. Prescribed fires also were conducted in buffelgrass-dominated fields to measure fire temperatures and quantify relationships between temperature and fuel load. We directly recorded temperatures up to 871 °C and indirectly recorded temperatures of 900 °C. **CREATING HOTTER FIRES IN THE SONORAN DESERT: BUFFELGRASS PRODUCES COPIOUS FUELS AND HIGH FIRE TEMPERATURES.** Christopher J. McDonald and Guy R. McPherson

In response to the recent expansion of pinon and juniper woodlands into sagebrush-steppe communities in the northern Great Basin region, numerous conifer-removal projects have been implemented, primarily to release understory vegetation at sites having a wide range of environmental conditions. Responses to these treatments have varied from successful restoration of native plant communities to complete conversion to nonnative invasive species. To evaluate the general response of understory vegetation to tree canopy removal in conifer-encroached shrublands, we set up a region-wide study that measured treatment induced changes in understory cover and density. **Response of Conifer-Encroached Shrublands in the Great Basin to Prescribed Fire and Mechanical Treatments.** Richard F. Miller, Jaime Ratchford, Bruce A. Roundy, Robin J. Tausch, April Hulet, and Jeanne Chambers

Grasslands occur on all of the continents. They collectively constitute the largest ecosystem in the world, making up 40.5% of the terrestrial land area, excluding Greenland and Antarctica. Grasslands are not entirely natural because they have formed and developed under natural and anthropogenic pressures. Their importance now is to the variety of ecosystem services that they provide: livestock grazing areas, water catchments, biodiversity reserves, tourism sites, recreation areas, religious sites, wild food sources, and natural medicine sources. An important function of grasslands is their sequestration and storage of carbon (C). Mollisol soils of grasslands have deep organic matter horizons that make this vegetation type almost as important as forests for C fixation and storage. Fire has been and continues to be an important disturbance in grassland evolution and management. **Effects of Fire on Grassland Soils and Water: A Review.** Daniel George Neary and Jackson McMichael Leonard

Wildfire activity is accelerating on many rangelands worldwide, yet the potential for grazing to be used as a fire management tool remains largely unknown. Particularly, little is known about the influence of grazing on ignition and initial spread of fire, as well as how these vary by differences in grazing management. We investigated effects of grazing intensity (light, moderate, high) on fuel characteristics, fire ignition, and initial spread during the wildfire season in a native-dominated shrub steppe in eastern Oregon. We found that differences in grazing intensity have differential effects on fuel profiles (cover, height, moisture, biomass) with resulting impacts on fire behavior. **Grazing Intensity Effects on Fire Ignition Risk and Spread in Sagebrush Steppe.** Devyn A. Orr, Jonathan D. Bates, Kirk W. Davies

Fires on agricultural land account for 8–11 % of the total number of fires that occur globally. These fires burn through various crops, pastures, and native vegetation on farms, causing economic and environmental losses. Fire management on farms will be aided by understanding the flammability of plant species as this would allow the design of low-flammability agricultural landscapes, but flammability data on large numbers of agricultural species are lacking. Many crop and vegetable species are assumed to be low in flammability, but this has rarely been tested. Therefore, we examined the shoot and whole-plant flammability of 47 plant taxa commonly grown on farms in Canterbury, New Zealand, which included many globally common temperate agricultural crops. **Measuring flammability of crops, pastures, fruit trees, and weeds: A novel tool to fight wildfires in agricultural landscapes.** Tanmayi Pagadala, Md Azharul Alam, Thomas M.R. Maxwell, Timothy J. Curran

Invasion of cheatgrass (Bromus tectorum) accentuates the problem by making the ecosystem more susceptible to frequent burns. Managers have implemented several techniques to cope with the cheatgrass–fire cycle, ranging from controlling undesirable fire effects by removing fuel loads either mechanically or via prescribed burns to seeding the fire-affected areas with shrubs and native perennial forbs. There have been a number of studies at local scales to understand the direct impacts of wildfire on vegetation; however, there is a larger gap in understanding these impacts at broad spatial and temporal scales. This need highlights the importance of dynamic global vegetation models (DGVMs) and remote sensing. In this study, we explored the influence of fire on vegetation composition and gross primary production (GPP) in the sagebrush ecosystem using the Ecosystem Demography (EDv2.2) model, a dynamic global vegetation model. **Understanding the effect of fire on vegetation composition and gross primary production in a semi-arid shrubland ecosystem using the Ecosystem Demography (EDv2.2) model.** Karun Pandit, Hamid Dashti, Andrew T. Hudak, Nancy F. Glenn, Alejandro N. Flores, and Douglas J. Shinneman

Do fuel models developed for North American fuel types accurately represent fuel beds found in non-native, grass-invaded tropical dry shrublands? Do standard or custom fuel models used in fire behaviour models within situ or remote automated weather stations (RAWS) measured fuel moistures affect the accuracy of predicted fire behaviour in grass-invaded tropical shrublands on Hawai'i Volcanoes National Park, Hawai'i, USA? **Using a prescribed fire to test custom and standard fuel models for fire behaviour prediction in a non-native, grass-invaded tropical dry shrubland.** Andrew D. Pierce, Sierra McDaniel, Mark Wasser, Alison Ainsworth, Creighton M. Litton, Christian P. Giardina & Susan Cordell

Fire influences plant survival, reproduction, and establishment. Consequently, plants exhibit fire-related traits. Grouping species with similar traits into Plant Functional Types (PFTs) enables predictions of fire–related change based on ecological mechanisms. However, if PFTs are to advance conservation decision-making, we must know if predictions are robust. We developed a PFT approach to predict how species relative abundance changes as a function of time since fire, and tested predictions empirically. **Using plant functional types to predict the influence of fire on species relative abundance.** Ella Plumanns-Pouton, Matthew Swan, Trent Penman, Luke T. Kelly

Model simulations of wildfire spread and assessments of their accuracy are needed for understanding and managing altered fire regimes in semiarid regions. The accuracy of wildfire spread simulations can be evaluated from post hoc comparisons of simulated and actual wildfire perimeters, but this requires

information on pre-fire vegetation fuels that is typically not available. We assessed the accuracy of the Fire-Area Simulator (FARSITE) model parameterized with maps of fire behavior fuel models (FBFMs) obtained from the widely used LANDFIRE, as well as alternative means which utilized the classification of Rangeland Analysis Platform (RAP) satellite-derived vegetation cover maps to create FBFM maps. **Modeling of fire spread in sagebrush steppe using FARSITE: an approach to improving input data and simulation accuracy.** Samuel "Jake" Price and Matthew J. Germino

Fuel-treatments targeting shrubs and fire-prone exotic annual grasses (EAGs) are increasingly used to mitigate increased wildfire risks in arid and semiarid environments, and understanding their response to natural factors is needed for effective landscape management. Using field-data collected over four years from fuel-break treatments in semiarid sagebrush-steppe, we asked 1) how the outcomes of EAG and sagebrush fuel treatments varied with site biophysical properties, climate, and weather, and 2) how predictions of fire behavior using the Fuel Characteristic Classification System fire model related to land-management objectives of maintaining fire behavior expected of low-load, dry-climate grasslands. **Variability in weather and site properties affect fuel and fire behavior following fuel treatments in semiarid sagebrush-steppe.** Samuel "Jake" Price, Matthew J. Germino

In 2006, we initiated fuel reduction treatments (prescribed fire, mowing, and herbicide applications [tebuthiuron and imazapic]) in six Artemisia tridentata ssp. wyomingensis communities. We evaluated long-term effects of these fuel treatments on: (1) magnitude and longevity of fuel reduction; (2) Greater Sage-grouse habitat characteristics; and (3) ecological resilience and resistance to invasive annual grasses. Responses were analyzed using repeated-measures linear mixed models. Response variables included plant biomass, cover, density and height, distances between perennial plants, and exposed soil cover. Prescribed fire produced the greatest reduction in woody fuel over time. **Ten-year ecological responses to fuel treatments within semiarid Wyoming big sagebrush ecosystems.** David A. Pyke, Scott E. Shaff, Jeanne C. Chambers, Eugene W. Schupp, Beth A. Newingham, Margaret L. Gray, Lisa M. Ellsworth

Ventenata (Ventenata dubia L.) is an invasive annual grass that has rapidly expanded its range across temperate grassland and shrub-steppe ecosystems in western North America. However, there is little published regarding its ecology, especially its relationship with fire on rangelands. The objective of this study was to examine the effect of fire on ventenata invasion in the Pacific Northwest Bunchgrass (PNB) Prairie. Given the influence of fire on the invasion of other annual grasses such as cheatgrass (Bromus tectorum L.), we expected that fire would facilitate the spread and increase in abundance of ventenata. In addition, we considered that annual variation in precipitation might mask the effect of fire and drive the year-to-year variation in production of ventenata. **Historical Fire and Ventenata dubia Invasion in a Temperate Grassland.** Luke W. Ridder, JoAnna M. Perrena, Lesley R. Morris, Bryan A. Endress, Robert V. Taylor, Bridgett J. Naylor

The exotic annual grass ventenata (Ventenata dubia L.) is raising concern as it rapidly invades multiple ecosystem types within the United States, including sagebrush steppe, ponderosa pine forests, woodlands, and much of the Palouse and Pacific Northwest Bunchgrass Prairie (PNB). Despite increasing attention, little is known about the invasion dynamics of ventenata, especially its response to disturbances such as grazing and fire. In this study, we examined how cattle grazing and prescribed fire

affect the abundance (standing crop, cover, frequency, and density) of ventenata and other plant groups on the PNB over time using two separate long-term studies established in 2004. **Ventenata (Ventenata dubia) Response to Grazing and Prescribed Fire on the Pacific Northwest Bunchgrass Prairie.** Luke W. Ridder, Lesley R. Morris, Michelle A. Day, Becky K. Kerns

Invasion and dominance of exotic grasses and increased fire frequency threaten native ecosystems worldwide. In the Great Basin region of the western United States, woody and herbaceous fuel treatments are implemented to decrease the effects of wildfire and increase sagebrush (Artemisia spp.) ecosystem resilience to disturbance and resistance to exotic annual grasses. High cover of the exotic annual cheatgrass (Bromus tectorum) after treatments increases fine fuels, which in turn increases the risk of passing over a biotic threshold to a state of increased wildfire frequency and conversion to cheatgrass dominance. Sagebrush ecosystem resilience to wildfire and resistance to cheatgrass depend on climatic conditions and abundance of perennial herbaceous species that compete with cheatgrass. In this study, we used longer-term data to evaluate the relationships among soil climate conditions, perennial herbaceous cover, and cheatgrass cover following fuel management treatments across the environmental gradients that characterize sagebrush ecosystems in the Great Basin. **Resilience and resistance in sagebrush ecosystems are associated with seasonal soil temperature and water availability.** BRUCE A. ROUNDY, JEANNE C. CHAMBERS, DAVID A. PYKE, RICHARD F. MILLER, ROBIN J. TAUSCH, EUGENE W. SCHUPP, BEN RAU, AND TREVOR GRUELL

Sagebrush ecosystems in the United States have been declining since EuroAmerican settlement, largely due to agricultural and urban development, invasive species, and altered fire regimes, resulting in loss of biodiversity and wildlife habitat. To combat continued conversion to undesirable ecological states and loss of habitat to invasive species fueled by frequent fire, a variety of fuel treatments, including networks of fuel breaks, are being implemented or proposed in sagebrush ecosystems, particularly in and around the Great Basin. In this forum paper we briefly review current knowledge of common fuel treatment approaches, their intended benefits, potential risks, and limitations. **Future Direction of Fuels Management in Sagebrush Rangelands.** Douglas J. Shinneman, Eva K. Strand, Mike Pellant, John T. Abatzoglou, Mark W. Brunson, Nancy F. Glenn, Julie A. Heinrichs, Mojtaba Sadegh, Nicole M. Vaillant

Fuel breaks are increasingly being implemented at broad scales (100s to 10,000s of square kilometers) in fire-prone landscapes globally, yet there is little scientific information available regarding their ecological effects (e.g., habitat fragmentation). Fuel breaks are designed to reduce flammable vegetation (i.e., fuels), increase the safety and effectiveness of fire-suppression operations, and ultimately decrease the extent of wildfire spread. In sagebrush (Artemisia spp.) ecosystems of the western US, installation of extensive linear fuel breaks is also intended to protect habitat, especially for the greater sage-grouse (Centrocercus urophasianus), a species that is sensitive to habitat fragmentation. We examine this apparent contradiction in the Great Basin region, where invasive annual grasses have increased wildfire activity and threaten sagebrush ecosystems. Given uncertain outcomes, we examine how implementation of fuel breaks might (1) directly alter ecosystems, (2) create edges and edge effects, (3) serve as vectors for wildlife movement and plant invasions, (4) fragment otherwise contiguous sagebrush landscapes, and (5) benefit from scientific investigation intended to disentangle their ecological costs and benefits. **The ecological uncertainty of wildfire fuel breaks: examples from the sagebrush steppe.**

Douglas J Shinneman, Matthew J Germino, David S Pilliod, Cameron L Aldridge, Nicole M Vaillant, and Peter S Coates

Wildfires are a growing management concern in western US rangelands, where invasive annual grasses have altered fire regimes and contributed to an increased incidence of catastrophic large wildfires. Fire activity in arid, non-forested ecosystems is thought to be largely controlled by interannual variation in fuel amount, which in turn is controlled by antecedent weather. Thus, long-range forecasting of fire activity in rangelands should be feasible given annual estimates of fuel quantity. Using a 32-yr time series of spatial data, we employed machine learning algorithms to predict the relative probability of large (> 405 ha) wildfire in the Great Basin based on fine-scale annual and 16-d estimates of cover and production of vegetation functional groups, weather, and multitemporal scale drought indices. We evaluated the predictive utility of these models with a leave-1-yr-out cross-validation, building spatial hindcasts of fire probability for each year that we compared against actual footprints of large wildfires. Herbaceous aboveground biomass production, bare ground cover, and long-term drought indices were the most important predictors of burning. **Where There's Smoke, There's Fuel: Dynamic Vegetation Data Improve Predictions of Wildfire Hazard in the Great Basin.** Joseph T. Smith, Brady W. Allred, Chad S. Boyd, Kirk W. Davies, Matthew O. Jones, Andrew R. Kleinhesselink, Jeremy D. Maestas, David E. Naugle

Sagebrush ecosystems of western North America are experiencing widespread loss and degradation by invasive annual grasses. Positive feedbacks between fire and annual grasses are often invoked to explain the rapid pace of these changes, yet annual grasses also appear capable of achieving dominance among vegetation communities that have not burned for many decades. Using a dynamic, remotely-sensed vegetation dataset in tandem with remotely-sensed fire perimeter and burn severity datasets, we examine the role of fire in transitions to and persistence of annual grass dominance in the U.S. Great Basin over the past 3 decades. **Fire needs annual grasses more than annual grasses need fire.** Joseph T. Smith, Brady W. Allred, Chad S. Boyd, Kirk W. Davies, Andrew R. Kleinhesselink, Scott L. Morford, David E. Naugle

The spread of invasive grasses across Earth are modifying fire cycles resulting in state changes in arid ecosystems. Disturbance, biotic resistance of native biological communities and propagule pressure, are likely important factors influencing the spread of invasive grasses and their influence on changing fire regimes. Over a 5-year period (2011–2016), we tested how the potential loss of biotic resistance of native plant and native rodent communities related to fire and rodent exclusion treatments, in concert with increased propagule pressure affected the establishment of Bromus tectorum L. (cheatgrass) and the spread of secondary fires. Our study results suggest that native plant and native rodent communities contribute to biotic resistance against cheatgrass invasion and that fire and high propagule pressure act to diminish biotic resistance by native communities. **Loss of biotic resistance and high propagule pressure promote invasive grass-fire cycles.** Samuel B. St. Clair, Tara B. B. Bishop

Managing longleaf pine ecosystems requires mimicking natural processes such as fire regimes and balancing sometimes competing management actions. Landscape-scale fire was historically a major driver of both the ecosystem services and the species composition of natural communities in longleaf pine ecosystems. Because prescribed fire and invasive species control are two common land-management actions in Florida, it is important that land managers have a solid understanding of their

interactions and how they affect the surrounding ecosystems. **Fire and Invasive Plant Interactions.** Deb Stone and Michael Andreu

Invasive annual grasses are a growing global concern because they facilitate larger and more frequent fires in historically fuel-limited ecosystems. Forests of the western United States have remained relatively resistant to invasion by annual grasses and their subsequent impacts. However, where forests are adjacent to invaded areas, increased fire spread across ecotones could alter fire behavior and ecosystem resilience. In the Inland Northwest, USA, recent invasion by the annual grass ventenata (Ventenata dubia) has increased fine fuel loads and continuity in non-forest patches embedded within the forested landscape. Despite ventenata's rapid spread across the American West and growing management concern, little is known regarding how invasion influences fire within invaded vegetation types or its potential to alter landscape-scale fire and management practices. Here, we examine how the ventenata invasion alters simulated fire across forest-mosaic landscapes of the 7 million ha Blue Mountains Ecoregion using the large fire simulator (FSim) with custom fuel landscapes: present-day invaded versus historic uninvaded. **Feeding the fire: Annual grass invasion facilitates modeled fire spread across Inland Northwest forest-mosaic landscapes.** Claire M. Tortorelli, John B. Kim, Nicole M. Vaillant, Karin Riley, Alex Dye, Ty C. Nietupski, Kevin C. Vogler, Rebecca Lemons, Michelle Day, Meg A. Krawchuk, Becky K. Kerns

A recently introduced non-native annual grass, Ventenata dubia, is challenging previous conceptions of community resistance in forest mosaic communities in the Inland Northwest. However, little is known of the drivers and potential ecological impacts of this rapidly expanding species. Here we (1 identify abiotic and biotic habitat characteristics associated with the V. dubia invasion and examine how these differ between V. dubia and other problematic non-native annual grasses, Bromus tectorum and Taeniatherum caput-medusae; and (2) determine how burning influences relationships between V. dubia and plant community composition and structure to address potential impacts on Inland Northwest Forest mosaic communities. **Expanding the invasion footprint: Ventenata dubia and relationships to wildfire, environment, and plant communities in the Blue Mountains of the Inland Northwest, USA.** Claire M. Tortorelli, Meg A. Krawchuk, Becky K. Kerns

Wildfire is a major threat to natural resources and native species in Hawai'i, but the frequency and extent of wildfires across the archipelago has not been well quantified. Our objective was to summarize the available wildfire data for Hawai'i and synthesize the social and ecological dimensions of wildfire drivers, impacts, and management responses. We constructed a 110-year span of wildfire records for the state of Hawai'i to examine historical trends (1904 – 2011) and summarized relationships between contemporary wildfire occurrence (2005 – 2011) and land use / land cover types and human population. **The Contemporary Scale and Context of Wildfire in Hawai'i.** Clay Trauernicht, Elizabeth Pickett, Chris tian P. Giardina, Creighton M. Litton, Susan Cordell, and Andrew Beavers

Native pinyon (Pinus spp.) and juniper (Juniperus spp.) trees are expanding into shrubland communities across the Western United States. These trees often outcompete with native sagebrush (Artemisia spp.) associated species, resulting in increased canopy fuels and reduced surface fuels. Woodland expansion often results in longer fire return intervals with potential for high severity crown fire. Fuel treatments are commonly used to prevent continued tree infilling and growth and reduce fire risk, increase ecological

resilience, improve forage quality and quantity, and/or improve wildlife habitat. Treatments may present a trade-of; they restore shrub and herbaceous cover and decrease risk of canopy fire but may increase surface fuel load and surface fire potential. **Fuel treatments in shrublands experiencing pinyon and juniper expansion result in trade-offs between desired vegetation and increased fire behavior.** Claire L. Williams, Lisa M. Ellsworth, Eva K. Strand, Matt C. Reeves, Scott E. Shaf, Karen C. Short, Jeanne C. Chambers, Beth A. Newingham and Claire Tortorelli

Management interventions for addressing invading annual grasses and encroaching conifers and their effects on fire dynamics in the sagebrush ecosystem are largely reactive. Reactive management limits tools for promoting long-term ecosystem resilience on a fire-prone landscape. We propose an integrated fire management approach in which all management activities before, during, and after wildfire are synergistic and improve long-term ecosystem response to fire. **Toward integrated fire management to promote ecosystem resilience.** Katherine Wollstein, Megan K. Creutzburg, Christopher Dunn, Dustin D. Johnson, Casey O'Connor and Chad S. Boyd

Post-Fire Invasion and Restoration

This analysis focuses on the newer invaders *Taeniatherum caput-medusae* (medusahead) and *Ventenata Dubia* (ventenata) in sagebrush-steppe communities previously invaded by *Bromus tectorum* (cheatgrass), during the first 5 years of recovery after wildfire. **Patterns of post-fire invasion of semiarid shrub-steppe reveals a diversity of invasion niches within an exotic annual grass community**. Cara Applestein, Matthew J. Germino

Seeds of Success (SOS) is a national seed collection program led by the Bureau of Land Management. SOS represents the most comprehensive native seed repository in the United States, supporting native plant restoration, management, and research. Since inception in 2000, SOS has collected seeds from over 24,400 native plant populations from ~5,600 taxa from 43 states. Collections include species important to wildlife, pollinators, and indigenous people, and over 10,000 collections have been shared for restoration and research use. We asked how many SOS sites have burned since collection and identified 662 fires at 631 sites. If fire continues at the pace observed since 2011, an estimated 14% of collection sites will burn by 2050 and over 24% by 2080, putting genetic diversity at risk in areas where fire is linked with invasion. Analysis of 14 native forb species from the western United States found that many collections were from the warmest and driest portions of their range, areas at the highest risk of wildfire, subsequent invasion, and local extinction. **Seeds of Success: A conservation and restoration investment in the future of U.S. lands.** Sarah C. Barga, Peggy Olwell, Fred Edwards, Leah Prescott, Elizabeth A. Leger

Post-wildfire disturbances such as salvage logging and seeding of agronomic species occur over large parts of the forested land base in British Columbia. However, there is surprisingly little research on the effects of these management practices on plant community composition and species diversity. The future of plant and animal biodiversity will depend increasingly on regional floras surviving in highly managed and disturbed environments. I examined vascular and nonvascular plant community responses four years after wildfire and post-wildfire management practices in interior Douglas-fir (*Pseudotsuga menziesii* var. *glauca*) forests following two separate 2003 wildfires near Kamloops, BC, Canada. Wildfire sites with all combinations of seeding and salvage logging disturbance were selected in similar post-

wildfire environments. **Plant Community Response to Post-wildfire Management Activities in Interior Douglas-Fir Forests of Southern BC.** Scott T. Black

Because it is more difficult to restore plant communities after they are dominated by invasive species, a potential approach is proactive restoration in sites at risk of crossing degradation thresholds (e.g., initiating restoration prior to invasive grass dominance). When developing a new restoration approach, it is important to consider operational feasibility, including social, budgetary, and environmental factors. Accordingly, we studied influences within land management agencies on the adoption of a specific proactive restoration approach: out-planting native grass and forb seedlings into sagebrush stands before they are dominated by cheatgrass (Bromus tectorum). Managers from federal and state land management agencies across the Great Basin, U.S.A, were interviewed regarding perceived feasibility of these practices. **Addressing barriers to proactive restoration of at-risk sagebrush communities: a causal layered analysis.** Carmen Calzado-Martinez, Mark W. Brunson, Sofia Koutzoukis, Jacopo Baggio, Kari E. Veblen

Conservation of imperiled species often demands addressing a complex suite of threats that undermine species viability. Regulatory approaches, such as the US Endangered Species Act (1973), tend to focus on anthropogenic threats through adoption of policies and regulatory mechanisms. However, persistent ecosystem-based threats, such as invasive species and altered disturbance regimes, remain critical issues for most at-risk species considered to be conservation-reliant. We describe an approach for addressing persistent ecosystem threats to at-risk species based on ecological resilience and resistance concepts that is currently being used to conserve greater sage-grouse (Centrocercus urophasianus) and sagebrush ecosystems. **Using Resilience and Resistance Concepts to Manage Persistent Threats to Sagebrush Ecosystems and Greater Sage-grouse.** Jeanne C. Chambers, Jeremy D. Maestas, David A. Pyke, Chad S. Boyd, Mike Pellant, and Amarina Wuenschel

Restoring degraded plant communities is a global challenge and a major priority for land managers and conservationists. Degraded Wyoming big sagebrush communities (Artemisia tridentata ssp. wyomingensis [Beetle & A. Young] S.L. Welsh) have high sagebrush cover with a depleted perennial herbaceous understory. They are widespread in western North America and are a priority for restoration because they provide habitat for sagebrush-associated species and an important forage base for livestock production. The results of our study indicate that seeding native bunchgrasses into degraded Wyoming big sagebrush communities has potential as a restoration treatment but needs refinement to improve success. **Long-term evaluation of restoring understories in Wyoming big sagebrush communities with mowing and seeding native bunchgrasses.** Kirk W. Davies, Jon D. Bates, Rory O'Connor

Logging and burning of the resultant woody debris are a management tools to reduce fire risk. Burning of the debris as piles affects the underlying soil biota and soil physical and (or) chemical properties. The resulting disturbance created by the burns may create opportunities for the establishment and spread of non-native plant species. Here, we test three restoration treatments on recent, approximately 1-year-old, pile burn scars, including an arbuscular mycorrhizal fungal (AMF) inoculant (present or absent), a ground cover (straw or no straw added), and different seeding types (native seed mix, agronomic seed mix, and no seed). The most effective treatment in reducing undesired non-native species cover was the

seeding of agronomic species; here “native” and “non-native” groups exclude sown agronomic species. **Restoration of slash pile burn scars to prevent establishment and propagation of non-native plants.** L. DeSandoli, R. Turkington, and L.H. Fraser

Historically, fire return intervals in Wyoming big sagebrush (*Artemisia tridentata* ssp*. wyomingensis*) ecosystems were 50–100 yr or more, but invasive species, climate change, and a legacy of intensive grazing practices have led to degraded rangeland condition, altered fire regimes and fire effects, and declines in sagebrush cover. Little is known about the long-term impacts of fire in this ecosystem in areas where grazing pressure has been removed, few invasive species exist, and fire return intervals are maintained. In this study, we quantified vegetation composition prior to prescribed burning, 1 year following fire, and 17 years after fire in a native-dominated Wyoming big sagebrush ecosystem at Hart Mountain National Antelope Refuge, Oregon, United States. **Ecosystem resilience is evident 17 years after fire in Wyoming big sagebrush ecosystems.** L. M. ELLSWORTH, D. W. WROBLESKI, J. B. KAUFFMAN, AND S. A. REIS

Ecological restoration often attempts to promote native species while managing for disturbances such as fire and non-native invasions. The goal of this research was to investigate whether restoration of a non-native, invasive *Megathyrsus maximus* (guinea grass) tropical grassland could simultaneously promote native species and reduce fire potential. *Megathyrsus maximus* was suppressed with herbicide, and three suites of native species—each including the same groundcover and shrub, and one of three tree species—were outplanted in a randomized, complete block design that also included herbicide control (herbicide with no outplantings) and untreated control treatments. **Restoration impacts on fuels and fire potential in a dryland tropical ecosystem dominated by the invasive grass Megathyrsus maximus.** Lisa M. Ellsworth, Creighton M. Litton, James J. K. Leary

With invasive grasses increasing wildfire occurrence worldwide, a better understanding of the relationships between native plants, fire, and invasive grass is needed to help restoration plans facilitate ecosystem resilience. Invasive grasses are particularly problematic for altering fire regimes in the tropics, yet in Hawai‘i, restoration sites are often planted with monocultures of the native tree Acacia koa, which can promote grass growth via nitrogen fixation. This, combined with the difficulty of estimating pre-fire grass cover under thick canopies, complicates attempts to restore Hawaiian ecosystems. **Understanding Grass Invasion, Fire Severity, and Acacia koa Regeneration for Forest Restoration in Hawai‘i Volcanoes National Park.** Natalia P. Hamilton, Stephanie G. Yelenik, Tara D. Durboraw, Robert D. Cox and Nathan S. Gill

Many ecosystems are rapidly being transformed into new, non-historical configurations owing to a variety of local and global changes. We discuss how new systems can arise in the face of primarily biotic change (extinction and/or invasion), primarily abiotic change (e.g., land use or climate change) and a combination of both. Some changes will result in hybrid systems retaining some original characteristics as well as novel elements, whereas larger changes will result in novel systems, which comprise different species, interactions, and functions. We suggest that these novel systems will require significant revision of conservation and restoration norms and practices away from the traditional place-based focus on existing or historical assemblages. **Novel ecosystems: implications for conservation and restoration.** Richard J. Hobbs, Eric Higgs and James A. Harris

Ecological restoration in the United States is growing in terms of the number, size, and diversity of projects. Such efforts are intended to ameliorate past environmental damage and to restore functioning ecosystems that deliver desired levels of ecosystem services. In nine current restoration case studies from across the continental United States, this paper details (1) the impacts of the original disturbance and compounding secondary issues that compel restoration, (2) the corrective practices applied to advance restoration goals, and (3) the prospects for recovery of ecosystem services, including those involving associated animal populations. **Impacts on ecosystems, corrective restoration practices, and prospects for recovery: nine case studies in the continental United States.** T. A. Jones

Native species that are abundant and persistent across disturbance-succession cycles can affect recovery and restoration of plant communities, especially in drylands. In the sagebrush-steppe deserts of North America, restoring deep-rooted perennial bunchgrasses (DRPBGs) is key to the strategy for breaking an increasingly problematic cycle of wildfire promoted by exotic annual grasses (EAGs) and displacement of perennials by post-fire increases in EAGs. We asked how Sandberg bluegrass (*Poa secunda*, POSE)—a common native grass that shares traits with EAGs such as resilience to disturbance and rapid, shallow-rooted, early season growth (1) recovered after wildfire, (2) responded to different combinations of native-plant seedings of DRPBGs and EAG-targeting herbicides; and (3) in turn, related to DRPBG recovery. **A nontarget, disturbance-resilient native species influences post-fire recovery and multiphasic herbicide-seeding outcomes in drylands threatened by exotic annual grasses.** Chad R. Kluender, Matthew J. Germino

Top-down and bottom-up factors affecting invasive populations are rarely considered simultaneously, yet their interactive responses to disturbances and management interventions can be essential to understanding invasion patterns. We evaluated postfire responses of the exotic perennial forb *Chondrilla juncea* (rush skeletonweed) and its biocontrol agents to landscape factors and a post-fire combined herbicide (imazapic) and bacteria (Pseudomonas fluorescens strain MB906) treatment that targeted invasive annual grasses in a sagebrush steppe ecosystem. **Post-fire management targeting invasive annual grasses may have inadvertently released the exotic perennial forb *Chondrilla juncea* and suppressed its biocontrol agent.** Brynne E. Lazarus, Matthew J. Germino

Increasing drought and changing temperatures drive researchers to seek more efficient and effective means to aid management of coniferous forests across the western United States. Thinning allows for effective removal of biomass, but with few options to remove the residual slash from the treatment unit after saleable timber is taken away, pile burning has become a favored method of debris removal. Pile burning has greater efficiency and reduced removal cost as compared to air curtain burning or whole tree removal. In this review, we synthesize the current knowledge on the effects of slash pile burning on soil physical properties, soil nutrients, impacts to understory vegetation and tree regeneration, animal responses to pile burning, and the variety of remediation techniques for burn scar areas. **Post-harvest slash burning in coniferous forests in North America: A review of ecological impacts**. Christine M. Mott, Richard W. Hofstetter, Anita J. Antoninka

Ecosystem restoration efforts are carried out by a variety of individuals and organizations with an equally varied set of goals, priorities, resources and time-scales. Once restoration of a degraded landscape or community is recognized as necessary, choosing which species to include in a restoration programme can

be a difficult and value-laden process. Species choice in restoration is often carried out with limited ecological information, particularly in regard to species interactions, successional processes and resource-use patterns. on. We present a method for species selection in restoration, based on the collection of plant functional trait data. Using this method, managers can develop species mixtures with desired properties, including expected predictions of interspecific interactions and potential changes in biotic and abiotic conditions. **Using plant functional traits to restore Hawaiian rainforest**. Rebecca Ostertag, Laura Warman, Susan Cordell and Peter M. Vitousek

To outline important considerations and options for post-fire seeding, including the selection of seed mixes and seeding equipment for restoring sagebrush communities following fire. The emphasis is on lower-elevation communities where restoration needs are greatest. References and resources are offered for greater detail and guidance on specific topics. **Seeding Techniques for Sagebrush Community Restoration After Fire.** Jeff Ott, Anne Halford, Nancy Shaw

Seed mixes used for postfire seeding in the Great Basin are often selected on the basis of short-term rehabilitation objectives, such as ability to rapidly establish and suppress invasive exotic annuals (e.g., cheatgrass, Bromus tectorum L.). Longer-term considerations are also important, including whether seeded plants persist, continue to suppress invasives, and promote recovery of desired vegetation. To better understand long-term effects of postfire seed mixes, we revisited study sites in Tintic Valley, Utah, where seeding experiments had been initiated after the 1999 Railroad wildfire. Four different mixes, including two comprised entirely of native species, had been applied using rangeland drills at a shrubland site and aerial seeding followed by one-way Ely chaining at a woodland site. **Long-Term Vegetation Recovery and Invasive Annual Suppression in Native and Introduced Postfire Seeding Treatments.** Jeffrey E. Ott, Francis F. Kilkenny, Daniel D. Summers, Tyler W. Thompson

Re-establishing native communities that resist exotic weed invasion and provide diverse habitat for wildlife are high priorities for restoration in sagebrush ecosystems. Native forbs are an important component of healthy rangelands in this system, but they are rarely included in seedings. Understanding competitive interactions between forb and grass seedlings is required to devise seeding strategies that can enhance establishment of diverse native species assemblages in degraded sagebrush communities. We conducted a greenhouse experiment to examine seedling biomass and relative growth rate of common native forb species when grown alone or in the presence of a native bunchgrass or an exotic annual grass. **Impact of Native Grasses and Cheatgrass (Bromus tectorum) on Great Basin Forb Seedling Growth.** Hilary Parkinson, Cathy Zabinski, and Nancy Shaw

Habitat loss is the most prevalent threat to biodiversity in North America. One of the most threatened landscapes in the United States is the sagebrush (Artemisia spp.) ecosystem, much of which has been fragmented or converted to non-native grasslands via the cheatgrass-fire cycle. Like many sagebrush obligates, greater sage-grouse (Centrocercus urophasianus) depend upon sagebrush for food and cover and are affected by changes to this ecosystem. We investigated habitat selection by 28 male greater sage-grouse during each of 3 years after a 113,000-ha wildfire in a sagebrush steppe ecosystem in Idaho and Oregon. During the study period, seeding and herbicide treatments were applied for habitat restoration. We evaluated sage-grouse responses to vegetation and post-fire restoration treatments. **Greater sage-grouse respond positively to intensive post-fire restoration treatments.** Sharon A.

Poessel, David M. Barnard, Cara Applestein, Matthew J. Germino, Ethan A. Ellsworth, Don Major, Ann Moser, Todd E. Katzner

Invasions by non-native plant species after fire can negatively affect important ecosystem services and lead to invasion-fire cycles that further degrade ecosystems. The relationship between fire and plant invasion is complex, and the risk of invasion varies greatly between functional types and across geographic scales. Here, we examined patterns and predictors of non-native plant invasion following fire across the western United States. We specifically analyzed how the abundance of nonnative plants after fire was related to fire characteristics and environmental conditions, such as climate, soil, and topography, in 26,729 vegetation plots from government networks and individual studies. **Non-native plant invasion after fire in western USA varies by functional type and with climate.** Janet S. Prevéy, Catherine S. Jarnevich, Ian S. Pearse, Seth M. Munson, Jens T. Stevens, Kevin J. Barrett, Jonathan D. Coop, Michelle A. Day, David Firmage, Paula J. Fornwalt, Katharine M. Haynes, James D. Johnston, Becky K. Kerns, Meg A. Krawchuk, Becky A. Miller, Ty C. Nietupski, Jacquilyn Roque, Judith D. Springer, Camille S. Stevens-Rumann, Michael T. Stoddard, Claire M. Tortorelli

Hawaiian dryland ecosystems are important for global biodiversity conservation and contain numerous species threatened with extinction. Over the past century, wildfire frequency and size have increased dramatically because of invasion by fire-promoting non-native invasive species, greatly threatening these ecosystems. Native species restoration is a tool that can disrupt the cycle of increased fire and invasion in lowland dry forest communities, but restoration prescriptions have not been studied systematically in other dryland plant communities. We examined the restoration of three Hawaiian dryland plant communities. **Shifting Limitations to Restoration across Dryland Ecosystems in Hawai ‘i.** Erin J. Questad, Amanda Uowolo, Samuel Brooks and Susan Cordell

Current paradigm suggests that spatial and temporal competition for resources limit an exotic invader, cheatgrass (Bromus tectorum L.), which once established, alters fire regimes, and can result in annual grass dominance in sagebrush steppe. Prescribed fire and fire surrogate treatments (mowing, tebuthiuron, and imazapic) are used to reduce woody fuels and increase resistance to exotic annuals but may alter resource availability and inadvertently favor invasive species. We used four study sites within the Sagebrush Steppe Treatment Evaluation Project (SageSTEP) to evaluate 1) how vegetation and soil resources were affected by treatment, and 2) how soil resources influenced native herbaceous perennial and exotic annual grass cover before and following treatment. **Soil Resources Influence Vegetation and Response to Fire and Fire-Surrogate Treatments in Sagebrush-Steppe Ecosystems.** Benjamin M. Rau, Jeanne C. Chambers, David A. Pyke, Bruce A. Roundy, Eugene W. Schupp, Paul Doescher, and Todd G. Caldwell

Imperiled sagebrush (Artemisia spp.) ecosystems of western North America are experiencing unprecedented conservation planning efforts. Advances in decision-support tools operationalize concepts of ecosystem resilience by quantitatively linking spatially explicit variation in soil and plant processes to outcomes of biotic and abiotic disturbances. However, failure to consider higher trophic-level fauna of conservation concern in these tools can hinder efforts to operationalize resilience owing to spatiotemporal lags between slower reorganization of plant and soil processes following disturbance, and faster behavioral and demographic responses of fauna to disturbance. Here, we provide multi-scale

examples of decision-support tools for management and restoration actions that evaluate general resilience mapped to variation in soil moisture and temperature regimes through new lenses of habitat selection and population performance responses for an at-risk obligate species to sagebrush ecosystems, the greater sage-grouse (Centrocercus urophasianus). We then briefly describe general pathways going forward for more explicit integration of sagegrouse fitness with factors influencing variation in sagebrush resilience to disturbance and resistance to invasive species (e.g., annual grasses). **Integrating Ecosystem Resilience and Resistance into Decision Support Tools for Multi-Scale Population Management of a Sagebrush Indicator Species.** Mark A. Ricca and Peter S. Coates

Managers require quantitative yet tractable tools that identify areas for restoration yielding effective benefits for targeted wildlife species and the ecosystems they inhabit. As a contemporary example of high national significance for conservation, the persistence of Greater Sage-grouse (Centrocercus urophasianus) in the Great Basin is compromised by strongly interacting stressors of conifer expansion, annual grass invasion, and more frequent wildfires occurring in sagebrush ecosystems. Associated restoration treatments to a sagebrush-dominated state are often costly and may yield relatively little ecological benefit to sage-grouse if implemented without estimating how Sage-grouse may respond to treatments, or do not consider underlying processes influencing sagebrush ecosystem resilience to disturbance and resistance to invasive species. Here, we describe example applications of a spatially explicit conservation planning tool (CPT) to inform prioritization of: (1) removal of conifers (i.e., pinyon-juniper); and (2) wildfire restoration aimed at improving habitat conditions for the Bistate Distinct Population Segment of Sage-grouse along the California–Nevada state line. **A conservation planning tool for Greater Sage-grouse using indices of species distribution, resilience, and resistance.** MARK A. RICCA, PETER S. COATES, K. BENJAMIN GUSTAFSON, BRIANNE E. BRUSSEE, JEANNE C. CHAMBERS, SHAWN P. ESPINOSA, SCOTT C. GARDNER, SHERRI LISIUS, PILAR ZIEGLER, DAVID J. DELEHANTY, AND MICHAEL L. CASAZZA

Dryland ecosystems in the western United States are affected by invasive species, wildfires, livestock grazing, and climate change in ways that are difficult to distinguish. Biocrusts perform important ecological roles in these systems and are sensitive to all of these pressures. **Long-term biocrust responses to wildfires in Washington, USA.** Heather T. Root, Julian Chan, Jeanne Ponzetti, David A. Pyke, Bruce McCune

The increasing frequency of wildfires in Southern California's Mediterranean-type habitats has been facilitating the displacement of native plants by invasive annuals. Black mustard (Brassica nigra) is an abundant, allelopathically harmful, invasive forb, which readily colonizes soil niches following most disturbances. Wildfires, however, are unlike other forms of disturbance because they can fundamentally alter plant–soil interactions through both physical and chemical changes in the soil. Here, a comparative field study of burned and unburned sites suggests that the Woolsey Fire—the largest wildfire ever recorded in California's Santa Monica Mountains—inhibited dispersal of B. nigra and changed how it interacts with other plant species in the second year of post-fire recovery. **Wildfire disturbance affects species interactions of a harmful invasive annual in second year of post-fire vegetative recovery.** Benjamin Marcus Schlau

Identifying management actions required to maintain desired ecological conditions in response to high intensity disturbance events remains a critical question, especially as disturbance regimes and species composition shift due to human activities and climate change. Feedbacks between novel fire disturbance and invasive species on islands, in particular, have resulted in the degradation and conversion of native ecosystems into more alien species-dominated communities. Further, monitoring and evaluation of management responses to these events remains sparse. We draw on 14 years of monitoring to assess the effects of fire and management response (weed removal and experimentally controlled out planting of native plants), on the structure, composition and diversity of a native, mesic tropical forest in Hawai'i. **Active restoration enhances recovery of a Hawaiian mesic forest after fire.** Clay Trauernichta, Tamara Ticktin, Hoala Fraiola, Zoe Hastings, Amy Tsuneyoshi

Ecological restoration is beneficial to ecological communities in this era of largescale landscape change and ecological disruption. However, restoration outcomes are notoriously variable, which makes fine-scale decision-making challenging. This is true for restoration efforts that follow large fires, which are increasingly common as the climate changes. Post-fire restoration efforts, like tree planting and seeding have shown mixed success, though the causes of the variation in restoration outcomes remain unclear. Abiotic factors such as elevation and fire severity, as well as biotic factors, such as residual canopy cover and abundance of competitive understory grasses, can vary across a burned area and may all influence the success of restoration efforts to re-establish trees following forest fires. **Elevation, canopy cover and grass cover structure patterns of seedling establishment in a subtropical post-fire restoration.** Christopher Warneke, Lars A. Brudvig, Makani Gregg, Sierra McDaniel, Stephanie Yelenik

Dry forest ecosystems in Hawai'i once supported a rich diversity of native and endemic species. However, the diversity, composition, distribution, ecosystem structure, and function of dry forests have been significantly altered due to human impacts, invasive species, and wildfires. As such, there is a great need for landscape-level restoration of dry forests, and the development and testing of methods for reintroducing native species in altered habitats. Wildfire, in particular, is a significant threat to vulnerable Hawaiian dry forests, with thousands of acres burned annually. These burned areas have high restoration potential through the use of methods such as native seed broadcasting, yet few studies have investigated the effectiveness of direct seeding for ecological restoration following wildfire in Hawaiian lowland dry forests. A broadcast seeding experiment was established at the Waikōloa Dry Forest Preserve in 2018 after a 18,000-acre wildfire burned through a portion of the preserve (22 acres). **SUCCESS OF POST-FIRE BROADCAST SEEDING AS A TOOL FOR RESTORATION OF A HAWAI'I DRY FOREST.** Taylor Warner

Geographic ranges of Greater Sage-Grouse (Centrocercus urophasianus) and Gunnison SageGrouse (C. minimus) have contracted across large areas in response to habitat loss and detrimental land uses. However, quantitative analyses of the environmental factors most closely associated with range contraction have been lacking, results of which could be highly relevant to conservation planning. Consequently, we analyzed differences in 22 environmental variables between areas of former range (extirpated range), and areas still occupied by the two species (occupied range). **Factors Associated with Extirpation of Sage-Grouse.** Michael J. Wisdom, Cara W. Meinke, Steven T. Knick, and Michael A. Schroeder

Genetic Studies

Invasive species are often initially restricted to a narrow range and may then expand through any of multiple mechanisms including phenotypic plasticity, in situ evolution, or selection on traits preadapted for new habitats. Our study used population genetics to explore possible processes by which the highly selfing invasive annual grass Bromus tectorum has expanded into montane environments. The wide geographic distribution of several common haplotypes almost completely restricted to montane habitats suggests that dominant lineages in montane populations may possess adaptive syndromes that are preserved through reduced outcrossing rates or negative selection on outcrossed progeny. However, conclusive evidence of such local adaptation requires reciprocal seeding experiments and further characterization of adaptive traits and breeding system characteristics. Other lineages have likely risen to dominance in montane populations through selectively neutral processes. **Population genetic structure of Bromus tectorum in the mountains of western North America.** Spencer Arnesen, Craig E. Coleman, and Susan E. Meyer

Molecular markers prove to be an invaluable tool in assessing the introduction dynamics, pattern of range expansion, and population genetics of an invasive species. Ventenata dubia (Leers) Coss. (Aveneae; ventenata) is a diploid, primarily self-pollinating, annual grass native to Eurasia and Northern Africa. The grass has a detailed herbarium collection history in the western United States since its discovery in eastern Washington in 1952. Genetic analysis of 51 invasive populations (1636 individuals) of V. dubia, coupled with historical records, suggests moderate propagule pressure from multiple introductions, followed by local or regional range expansion. **Genetic analysis of invasive populations of Ventenata dubia (Poaceae): an assessment of propagule pressure and pattern of range expansion in the Western United States.** Inna Pervukhina-Smith, Rene´ F. H. Sforza, Massimo Cristofaro, James F. Smith, Stephen J. Novak

Understanding why some, but not other, plant communities are vulnerable to alien invasive species is essential for predicting and managing biological invasions. Darwin proposed two seemingly contradictory hypotheses on how native-invader relatedness influences invasion success, emphasizing, respectively, the importance of environmental filtering and competition between natives and invaders. Despite much recent empirical research on this topic, reconciling these two hypotheses, known as Darwin's naturalization conundrum, remains a challenge. Our results suggest that the impact of species phylogenetic relatedness on invasion success varies distinctly along resource versus non-resource environmental gradients. These results help to reconcile Darwin's naturalization conundrum, thereby improving the ability to predict the success of alien plant invasions in a changing world. Our study stresses the need to consider adjusting forest species composition to strengthen their resistance to invasion, while taking into account resource and non-resource environmental gradients, particularly after wildfires. **The impact of species phylogenetic relatedness on invasion varies distinctly along resource versus non-resource environmental gradients.** Guoyan Wang, Xiaojuan Zhang, Florencia Yannelli, Jing-Ji Li, Songlin Shi, Tingbin Zhang, Xiaojuan Bie, Xu Chen, Pei-Hao Peng, Lin Jiang

Social Issues

Wildfire frequency and intensity has increased across the Southern Great Plains of the United States and other similar landscapes worldwide in part due to climate change. It is important that policymakers, practitioners, and the agricultural community better understand the impact from increased wildfire

incidence and severity across different agricultural landscapes. The purpose of this study is to examine the impact of wildfires across an agricultural landscape of the Southern Great Plains. Using primary data collected from semi-structured interviews of farmers and ranchers in the study region, we quantitatively explore farmers' and ranchers' perceptions and experiences about wildfires in the Southern Great Plains of the U.S. **Wildfire across agricultural landscapes: farmer and rancher experiences and perceptions in the southern great plains.** Jason S. Bergtold, Marcelus M. Caldas, Audrey Joslin and Mariam Gharib

Multi-jurisdictional rangeland "mega-fires" are becoming more common. Using interview data, we examined cross boundary collaboration after the Soda Fire that burned approximately 113,312 ha (280,000 acres) of southwestern Idaho and southeastern Oregon. We found relationships established in other management contexts were activated by individuals within agencies to share funding and resources to rehabilitate the landscape after the Soda Fire. **Effects of Wildfire on Collaborative Management of Rangelands: A Case Study of the 2015 Soda Fire.** Gwendwr R. Meredith and Mark W. Brunson

Climate change is expected to influence the frequency and severity of biological invasions in a variety of ways, including creating novel introduction pathways, decreasing the resilience of native habitats, inducing range shifts and expansions, and altering phenologies. As such, it is important to gain a better understanding of how invasive species managers incorporate climate change in their management strategies and identify the invasive species that are expected to pose the greatest threat under climate change. To address these questions, the Regional Invasive Species and Climate Change Management Network surveyed invasive species researchers and managers across four regions of the continental U.S. (the Northeast, Southeast, North Central, and Northwest) to determine the invasive species of greatest concern. This analysis will identify and compare the invasive species most frequently reported by researchers and managers for each region and describe their ecologies. **Integrating Climate Change into Invasive Species Management: a Risk Assessment Survey Analysis to Identify Species of Concern.** Nicole Read, Annette Evans, Carrie Brown-Lima, Rachel Gregg, Deah Lieurance, R. Chelsea Nagy, Lindsey Thurman, Toni Lyn Morelli

Bringing diverse groups together in collaboration to solve complex landscape-scale issues presents opportunities and challenges. Collaborating at the planning stage of restoration projects can be slow. It takes time to build relationships, and meeting people "where they are at" is often the accomplishment. Success in collaboration comes from gathering the local knowledge to move forward with implementing projects. Long-standing collaborative groups often face challenges with keeping stakeholders and partners involved particularly when tracking past projects. Finding continued funding to maintain the projects implemented years earlier takes effort usually on behalf of the convening organization. **Prioritizing limited resources in landscape-scale management projects.** Brenda S. Smith, Julie K. Unfried, Dallas K. Hall Defrees, and Debbie J. Wood

Research continually adds to our understanding of the ecological factors and biophysical processes driving frequent, large-scale fires on Great Basin rangelands in the western United States. Yet even with advances in forecasting rangeland fire probabilities and likely ecological outcomes of fire, it remains difficult for individuals, communities, or organizations to coordinate their actions across jurisdictions and at an ecologically relevant scale to address collective wildfire risk. In this forum, we discuss current

institutional arrangements that perpetuate scale mismatches in this system; that is, institutional objectives, authorities, and capacities that limit coordinated actions to mitigate collective wildfire risk. **Integrating Rangeland Fire Planning and Management: The Scales, Actors, and Processes.** Katherine Wollstein, Dustin D. Johnson

Grazing Management and Rangelands

In spite of overwhelming experimental evidence to the contrary, rotational grazing continues to be promoted and implemented as the only viable grazing strategy. The goals of this synthesis are to 1) reevaluate the complexity, underlying assumptions, and ecological processes of grazed ecosystems, 2) summarize plant and animal production responses to rotational and continuous grazing, 3) characterize the prevailing perceptions influencing the assessment of rotational and continuous grazing, and 4) attempt to direct the profession toward a reconciliation of perceptions advocating support for rotational grazing systems with that of the experimental evidence. The ecological relationships of grazing systems have been reasonably well resolved, at the scales investigated, and a continuation of costly grazing experiments adhering to conventional research protocols will yield little additional information. **Rotational Grazing on Rangelands: Reconciliation of Perception and Experimental Evidence.** D. D. Briske, J. D. Derner, J. R. Brown, S. D. Fuhlendorf, W. R. Teague, K. M. Havstad, R. L. Gillen, A. J. Ash, and W. D. Williams

Understanding fire and large herbivore interactions in interior western forests is critical, owing to the extensive and widespread co-occurrence of these two disturbance types and multiple present and future implications for forest resilience, conservation and restoration. However, manipulative studies focused on interactions and outcomes associated with these two disturbances are rare in forested rangelands. We investigated understory vegetation response to 5-year spring and fall prescribed fire and domestic cattle grazing exclusion in ponderosa pine stands and reported long-term responses, almost two decades after the first entry fires. **Long-term frequent fire and cattle grazing alter dry forest understory vegetation.** Becky K. Kerns, Michelle A. Day

Rangeland landscapes occupy roughly 662 million acres in the coterminous U.S. and their vegetation responds quickly to climate and management, with high relative growth rates and inter-annual variability. Current national decision support systems in the U.S. such as the Interagency Fuels Treatment Decision Support System (IFT-DSS) require spatially explicit information describing production, fuels, grazing capacity, and successional trajectory. However, no single system presently offers this information. In addition, issues of increasing national attention, such as preservation of lekking birds, has prompted new management guidelines such as stubble height standards, but ecological tools for predicting this type of management outcome on rangelands are quite limited in their ability to predict these variables. Therefore, a system is needed that quantifies these vegetation and fuel characteristics in sufficient detail to permit estimations of annual production, treatment success, grazing capacity, and fire behavior and effects. This situation inspired our project to develop a comprehensive program for simulating succession, productivity, and fuels in non-forest environments. This system is called the Rangeland Vegetation Simulator (RVS). **The Rangeland Vegetation Simulator: A User-Driven System for Quantifying Production, Succession, Disturbance and Fuels in Non-Forest Environments.** Matt Reeves and Leonardo Frid

A longer growing season with climate change is expected to increase net primary productivity of many rangeland types, especially those dominated by grasses, although responses will depend on local climate and soil conditions. Elevated atmospheric carbon dioxide may increase water use efficiency and productivity of some species. In many cases, increasing wildfire frequency and extent will be damaging for big sagebrush and other shrub species that are readily killed by fire. The widespread occurrence of cheatgrass and other nonnatives facilitates frequent fire through annual fuel accumulation. **Effects of Climate Change on Rangeland Vegetation in the Northern Rockies.** Matt C. Reeves, Mary E. Manning, Jeff P. DiBenedetto, Kyle A. Palmquist, William K. Lauenroth, John B. Bradford, and Daniel R. Schlaepfer

Management for invasive species is usually done with the intent of maintaining or enhancing one or several ecosystem services. On rangeland landscapes, management is often focused on provisioning services (e.g., livestock) but can also include maintaining biodiversity. Rangeland landscapes are often large and complex, suggesting understanding the invasion and management efforts is best done at multiple scales. The objective of this study was to assess the effectiveness of sericea lespedeza (Lespedeza cuneata [Dum-Cours] G. Don) management practices on two study areas that were focused on managing livestock and promoting biodiversity simultaneously. **Managing an Invasive Species While Simultaneously Conserving Native Plant Diversity.** C.W. Sherrill, S.D. Fuhlendorf, L.E. Goodman, R.D. Elmore, R.G. Hamilton

Management of areas invaded by cheatgrass (*Bromus tectorum*) continues to be one of the greatest challenges for US Great Basin ecosystems. Targeted cattle grazing in the fall and winter has shown positive results as a management tool to reduce dormant fine fuel biomass within cheatgrass-invaded areas, but management of targeted grazing within large pastures can be challenging. We evaluated the use of strategically placed liquid protein supplement stations over a 4-wk period in the fall to focus cattle grazing along a linear transect stretching away from water to reduce residual cheatgrass biomass on a production-scale, working ranch from 2014 to 2017. **Strategic Supplementation to Manage Fine Fuels in a Cheatgrass (Bromus tectorum) – Invaded System.** Mitchell B. Stephenson, Barry L. Perryman, Chad S. Boyd, Brad W. Schultz, Tony Svejcar, Kirk W. Davies

Limiting fire in Wyoming big sagebrush (*Artemisia tridentata* ssp*. wyomingensis* [Beetle & A. Young] S.L. Welsh) steppe is often a management priority as fires threatens its ecological integrity and rural economies that depend on it. However, the Wyoming big sagebrush steppe is vast and occurs in different community states from intact (sagebrush-bunchgrass dominated) to exotic annual grass dominated. Grazing has been suggested as the only tool that is likely feasible to apply across such large landscapes to manage fine fuels, but there is concern that over time grazing may induce undesirable shifts in plant community composition (e.g., increases in exotic annuals) that increase fire risk. Therefore, we evaluated the longer-term (+10 yr) effects of contemporary, moderate grazing by cattle compared with grazing exclusion on fuel characteristics in three community states: intact, degraded, and exotic annual grass states. **Grazing Effects on Fuels Vary by Community State in Wyoming Big Sagebrush Steppe.** T.W. Thomas, K.W. Davies

Appendix II – Agency Plans and Literature Search Papers

Climate Change

In the last decades, more than six hundred exotic species have become established throughout the region of the southwestern United States and northwestern Mexico, including the African buffelgrass (Cenchrus ciliaris L.). Buffelgrass often causes negative impacts on natural ecosystems, and it is considered a highly invasive species in many parts of the world. We used 18,550 records from 260 datasets and species distribution modeling (SDM) to provide support for the climatically based and topographic hypotheses, which claim that current climate and topography affect species distribution patterns of plants. **Climate change and the potential expansion of buffelgrass (Cenchrus ciliaris L., Poaceae) in biotic communities of Southwest United States and northern Mexico.** Fabio Suzart de Albuquerque, Miguel Angel Macıas-Rodrıguez, Alberto Burquez, Yaiyr Astudillo-Scalia

The Northeastern California Plateaus Bioregion Science Synthesis reviews literature relevant to the ecology and management of the Great Basin ecosystems and dry pine forests of the Lassen and Modoc National Forests. Critical factors on these national forests are reduced water availability—expected to become more challenging as levels and patterns of precipitation and temperature change under climate variability—coupled with a high proportion of rangeland and open woodland whose vegetation community is influenced by grazing of livestock and wild animal populations. **Northeastern California plateaus bioregion science synthesis.** Dumroese, R.K.; Moser, W.K., eds.

Preventing the spread of range-shifting invasive species is a top priority for mitigating the impacts of climate change. Invasive plants become abundant and cause negative impacts in only a fraction of their introduced ranges, yet projections of invasion risk are almost exclusively derived from models built using all non-native occurrences and neglect abundance information. We compiled abundance records for 144 invasive plant species from five major growth forms. We fit over 600 species distribution models based on occurrences of abundant plant populations, thus projecting which areas in the eastern United States (U.S.) will be most susceptible to invasion under current and +2°C climate change. **Shifting hotspots: Climate change projected to drive contractions and expansions of invasive plant abundance habitats.** Annette E. Evans, Catherine S. Jarnevich, Evelyn M. Beaury, Peder S. Engelstad, Nathan B. Teich, Jillian M. LaRoe, Bethany A. Bradley

Forest and Rangeland Soils of the United States Under Changing Conditions - A Comprehensive Science Synthesis. Richard V. Pouyat, Deborah S. Page-Dumroese, Toral Patel-Weynand, Linda H. Geiser (Editors) 2020

Restoration

Plant communities vary both abruptly and gradually over time but differentiating between types of change can be difficult with existing classification and ordination methods. Structural topic modeling (STRUTMO), a text mining analysis, offers a flexible methodology for analyzing both types of temporal trends. Objectives Our objectives were to (1) identify postfire dominant sagebrush steppe plant association types and ask how they vary with time at a landscape (multi-fire) scale and (2) ask how often major association changes are apparent at the plot-level scale. Methods We used STRUTMO and plant species cover collected between 2002–2022 across six large burn areas (1941 plots) in the Great Basin, USA to characterize landscape change in dominant plant association up to 14 years post-fire. **Analysis**

adapted from text mining quantitively reveals abrupt and gradual plant-community transitions after fire in sagebrush steppe. Cara Applestein, Christopher Anthony, Matthew J Germino

This report details a systematic literature review that evaluated how well peer-reviewed journal articles and formal technical reports published between January 1, 2015, and December 31, 2020, addressed 10 needs (hereinafter "Needs") identified under the Restoration topic in the Plan. Our searches resulted in the inclusion of 371 science products that at least partially addressed a Need identified in the Restoration topic. **Integrated Rangeland Fire Management Strategy Actionable Science Plan Completion Assessment: Restoration Topic, 2015–20.** Christopher R. Anthony, Matthew J. Holloran, Mark A. Ricca, Steven E. Hanser, Sue L. Phillips, Paul F. Steblein, and Lief A. Wiechman

Land managers are responsible for developing effective strategies for conserving and restoring Great Basin ecosystems in the face of invasive species, conifer expansion, and altered fire regimes. A warming climate is magnifying the effects of these threats and adding urgency to implementation of management practices that will maintain or improve ecosystem functioning. This Factsheet Series was developed to provide land managers with brief summaries of the best available information on contemporary management issues to facilitate science delivery and foster effective management. **Great Basin Factsheet Series 2016: Information and tools to conserve and restore Great Basin ecosystems.** Edited by Jeanne C. Chambers

The Science Framework for the Conservation and Restoration Strategy of the Department of the Interior, Secretarial Order 3336 (SO 3336), Rangeland Fire Prevention, Management and Restoration, provides a strategic, multiscale approach for prioritizing areas for management and determining effective management strategies across the sagebrush biome. The emphasis of this version is on sagebrush ecosystems and greater sage-grouse. The Science Framework uses a six-step process in which sagebrush ecosystem resilience to disturbance and resistance to nonnative, invasive annual grasses are linked to species habitat information based on the distribution and abundance of focal species. **Science Framework for the Conservation and Restoration Strategy of the Department of the Interior Secretarial Order 3336.** Jeanne C. Chambers, Jeffrey L. Beck, Steve Campbell, John Carlson, Thomas J. Christiansen, Karen J. Clause, Michele R. Crist, Jonathan B. Dinkins, Kevin E. Doherty, Shawn Espinosa, Kathleen A. Griffin, Steven E. Hanser, Douglas W. Havlina, Kenneth F. Henke, Jacob D. Hennig, Laurie L. Kurth, Jeremy D. Maestas, Mary Manning, Kenneth E. Mayer, Brian A. Mealor, Clinton McCarthy, Mike Pellant, Marco A. Perea, Karen L. Prentice, David A. Pyke, Lief A. Wiechman, and Amarina Wuenschel

Science Framework for Conservation and Restoration of the Sagebrush Biome: Linking the Department of the Interior's Integrated Rangeland Fire Management Strategy to Long-Term Strategic Conservation Actions Part 1. Science Basis and Applications. Jeanne C. Chambers, Jeffrey L. Beck, John B. Bradford, Jared Bybee, Steve Campbell, John Carlson, Thomas J. Christiansen, Karen J. Clause, Gail Collins, Michele R. Crist, Jonathan B. Dinkins, Kevin E. Doherty, Fred Edwards, Shawn Espinosa, Kathleen A. Griffin, Paul Griffin, Jessica R. Haas, Steven E. Hanser, Douglas W. Havlina, Kenneth F. Henke, Jacob D. Hennig, Linda A. Joyce, Francis F. Kilkenny, Sarah M. Kulpa, Laurie L. Kurth, Jeremy D. Maestas, Mary Manning, Kenneth E. Mayer, Brian A. Mealor, Clinton McCarthy, Mike Pellant, Marco A. Perea, Karen L. Prentice, David A. Pyke, Lief A. Wiechman, and Amarina Wuenschel

Science Framework for Conservation and Restoration of the Sagebrush Biome: Linking the Department of the Interior's Integrated Rangeland Fire Management Strategy to Long-Term Strategic Conservation Actions Part 2. Management Applications. Michele R. Crist, Jeanne C. Chambers, Susan L. Phillips, Karen L. Prentice, and Lief A. Wiechman

A working group of experts with diverse backgrounds and disciplinary expertise was assembled to conceptualize a spatially explicit conservation design to support and inform the Sagebrush Conservation Strategy Part 2. **A Sagebrush Conservation Design to Proactively Restore America's Sagebrush Biome.** Kevin Doherty, David M. Theobald, John B. Bradford, Lief A. Wiechman, Geoffrey Bedrosian, Chad S. Boyd, Matthew Cahill, Peter S. Coates, Megan K. Creutzburg, Michele R. Crist, Sean P. Finn, Alexander V. Kumar, Caitlin E. Littlefield, Jeremy D. Maestas, Karen L. Prentice, Brian G. Prochazka, Thomas E. Remington, William D. Sparklin, John C. Tull, Zachary Wurtzebach, and Katherine A. Zeller

Conservation and Restoration of Sagebrush Ecosystems and Sage-Grouse: An Assessment of USDA Forest Service Science. Deborah M. Finch, Douglas A. Boyce, Jr., Jeanne C. Chambers, Chris J. Colt, R. Kasten Dumroese, Stanley G. Kitchen, Clinton McCarthy, Susan E. Meyer, Bryce A. Richardson, Mary M. Rowland, Mark A. Rumble, Michael K. Schwartz, Monica S. Tomosy, and Michael J. Wisdom

Greater Sage-Grouse Science (2015–17)—Synthesis and Potential Management Implications. Steven E. Hanser, Patricia A. Deibert, John C. Tull, Natasha B. Carr, Cameron L. Aldridge, Travis D. Bargsten, Thomas J. Christiansen, Peter S. Coates, Michele R. Crist, Kevin E. Doherty, Ethan A. Ellsworth, Lee J. Foster, Vicki A. Herren, Kevin H. Miller, Ann Moser, Robin M. Naeve, Karen L. Prentice, Thomas E. Remington, Mark A. Ricca, Douglas J. Shinneman, Richard L. Truex, Lief A. Wiechman, Dereck C. Wilson, and Zachary H. Bowen

An Assessment of Native Seed Needs and the Capacity for their Supply – Final Report. Committee on an Assessment of Native Seed Need and Capacities. SUSAN P. HARRISON (Chair), University of California, Davis DELANE ATCITTY, ROB FIEGENER, RACHAEL GOODHUE, KAYRI HAVENS, CAROL C. HOUSE, RICHARD C. JOHNSON, ELIZABETH LEGER, VIRGINIA LESSER, JEAN OPSOMER, NANCY SHAW, DOUGLAS E. SOLTIS, SCOTT M. SWINTON, EDWARD TOTH, STANFORD A. YOUNG, ROBIN SCHOEN, KRISZTINA MARTON, JENNA BRISCOE, SARAH KWON, PAIGE JACOBS, SAMANTHA SISANACHANDENG

Postfire Restoration Framework for National Forests in California. Marc D. Meyer, Jonathan W. Long, and Hugh D. Safford, Editors. 2021

A Field Guide for Selecting the Most Appropriate Treatment in Sagebrush and Piñon-Juniper Ecosystems in the Great Basin. **Evaluating Resilience to Disturbance and Resistance to Invasive Annual Grasses and Predicting Vegetation Response.** Richard F. Miller, Jeanne C. Chambers, and Mike Pellant 2014/2015

A Review of Fire Effects on Vegetation and Soils in the Great Basin Region: Response and Ecological Site Characteristics. Richard F. Miller, Jeanne C. Chambers, David A. Pyke, Fred B. Pierson, and C. Jason Williams. 2014

Downy Brome Control and Impacts on Perennial Grass Abundance: A Systematic Review Spanning 64 Years. Thomas A. Monaco, Jane M. Mangold, Brian A. Mealor, Rachel D. Mealor, Cynthia S. Brown

Exotic plant invasions present a global threat to natural ecosystems, yet the efficacy of management efforts in mitigating invader impacts remains unclear. A rapidly emerging problem is that of secondary invasion — an increase in abundance of non-target exotics following treatment of targeted invasive plants. Here, we present **a global literature** review and meta-analysis directed at quantifying the magnitude of secondary invasion effects and identifying possible causes. Of 168 studies examining the efficacy of exotic plant management in terrestrial habitats, 29% quantified community responses sufficiently to evaluate secondary invasion. Meta-analysis of 60 cases from 38 studies showed that control efforts strongly reduced target invader abundance overall, but secondary invaders increased, with a mean effect size double what was found for native plants, which increased only weakly. Moreover, 89% of the secondary invaders identified were classified as noxious or invasive plants. Increases in secondary invaders were correlated with target invader reductions, but control method and target invader growth form failed to explain variation in secondary invader responses. **Secondary invasion: The bane of weed management**. Dean E. Pearson, Yvette K. Ortega, Justin B. Runyon, Jack L. Butler

Restoration Handbook for Sagebrush Steppe Ecosystems with Emphasis on Greater Sage-Grouse Habitat— Part 1. Concepts for Understanding and Applying Restoration. David A. Pyke, Jeanne C. Chambers, Mike Pellant, Steven T. Knick, Richard F. Miller, Jeffrey L. Beck, Paul S. Doescher, Eugene W. Schupp, Bruce A. Roundy, Mark Brunson, and James D. McIver

Restoration Handbook for Sagebrush Steppe Ecosystems with Emphasis on Greater Sage-Grouse Habitat— Part 2. Landscape Level Restoration Decisions. David A. Pyke, Steven T. Knick, Jeanne C. Chambers, Mike Pellant, Richard F. Miller, Jeffrey L. Beck, Paul S. Doescher, Eugene W. Schupp, Bruce A. Roundy, Mark Brunson, and James D. McIver

Restoration Handbook for Sagebrush Steppe Ecosystems with Emphasis on Greater Sage-Grouse Habitat— Part 3. Site Level Restoration Decisions. David A. Pyke, Jeanne C. Chambers, Mike Pellant, Richard F. Miller, Jeffrey L. Beck, Paul S. Doescher, Bruce A. Roundy, Eugene W. Schupp, Steven T. Knick, Mark Brunson, and James D. McIver

Sagebrush Conservation Strategy—Challenges to Sagebrush Conservation. Prepared in cooperation with the Western Association of Fish and Wildlife Agencies, the Bureau of Land Management, and the U.S. Fish and Wildlife Service (2021) Thomas E. Remington, Patricia A. Deibert, Steven E. Hanser, Dawn M. Davis, Leslie A. Robb, and Justin L. Welty

A Sagebrush Conservation Design to Proactively Restore America's Sagebrush Biome. Kevin Doherty, David M. Theobald, John B. Bradford, Lief A. Wiechman, Geoffrey Bedrosian, Chad S. Boyd, Matthew Cahill, Peter S. Coates, Megan K. Creutzburg, Michele R. Crist, Sean P. Finn, Alexander V. Kumar, Caitlin E. Littlefield, Jeremy D. Maestas, Karen L. Prentice, Brian G. Prochazka, Thomas E. Remington, William D. Sparklin, John C. Tull, Zachary Wurtzebach, and Katherine A. Zeller

Fire Management and Invasive Species

Fire management can help maintain natural habitats, increase forage for wildlife, reduce fuel loads that might otherwise lead to catastrophic wildfire and maintain natural succession. Today, there is an emerging challenge that fire managers need to be aware of: invasive plants. Fire management activities can create ideal opportunities for invasions by nonnative plants, potentially undermining the benefits of

fire management actions. This manual provides practical guidelines that fire managers should consider with respect to invasive plants. **Fire Management and Invasive Plants: A Handbook.** Matthew Brooks and Michael Lusk

This study was conducted to provide timely scientific information regarding the effects of wildfire on greater sage-grouse (*Centrocercus urophasianus*) demography within the Great Basin over the last 30 years. Findings are provided to fill a prominent information gap in the threat assessment for greater sage-grouse populations as part of the listing decision process by the U.S. Fish and Wildlife Service under the Endangered Species Act of 1973. The primary purpose of the current report is to present a Bayesian approach to estimate the effects of wildfire on greater sage-grouse population rate of change while accounting for influential interactions with climatic conditions (that is, precipitation). **Long-Term Effects of Wildfire on Greater Sage-Grouse—Integrating Population and Ecosystem Concepts for Management in the Great Basin.** Peter S. Coates, Mark A. Ricca, Brian G. Prochazka, Kevin E. Doherty, Matthew L. Brooks, and Michael L. Casazza

Much of what we currently know about using fire to manage vegetation—and to control invasive plant species in particular—has been derived from studies of cropland systems. However, there are many fundamental differences between cropland and wildland settings, and our ability to use effects observed in croplands to predict effects that may occur in wildlands is limited. The goal of this report is to capture the current state of knowledge on the use of fire as a tool to manage invasive plants in wildlands. It summarizes current literature and observations on: the risks and challenges of conducting prescribed burns; the types of systems where burning, used alone or as part of an integrated approach, can be effective for the management of invasive plants; the impacts of prescribed burning on the broader plant community and soils. **The Use of Fire as a Tool for Controlling Invasive Plants.** DiTomaso, J.M. and D.W. Johnson (eds.)

Wildland managers need detailed information about the responses of invasive species to fire and the conditions that increase site invasibility in order to effectively manage fire without introducing or increasing populations of invasive plants. Literature reviews and syntheses of original research are important sources of this information, but the usefulness of a review is limited by the quantity, quality, and geographic coverage of information available when it is written. This study analyzed the information available for 61 syntheses published in the Fire Effects Information System (www.fs.fed.us/database/feis) between 2008 and 2011, covering 74 species of invasive plants in the eastern United States. **Characteristics of information available on fire and invasive plants in the eastern United States.** Corey L. Gucker, Kris Zouhar, Jane Kapler Smith, and Katharine R. Stone

Science plays a critical role in natural resource management, and the use of science in decision-making is mandated by several policy initiatives. Other disciplines have documented the challenges associated with applying science to management and possible solutions to overcoming challenges, but the evaluation of science use in wildland fire management is relatively immature. In this paper, we reviewed the available literature that evaluates science use in wildland fire management and common barriers and facilitators to science use in decision-making. **The Use of Science in Wildland Fire Management: a Review of Barriers and Facilitators.** Molly E Hunter, Melanie M Colavito, Vita Wright

The Integrated Rangeland Fire Management Strategy Actionable Science Plan. Integrated Rangeland Fire Management Strategy Actionable Science Plan Team

Effectiveness of Fuel Treatments at the Landscape Scale: State of Understanding and Key Research Gaps (2021). Theresa B. Jain, Ilana Abrahamson, Nate Anderson, Sharon Hood, Brice Hanberry, Francis Kilkenny, Shawn McKinney, Jeffrey Ott, Alexandra Urza, Jeanne Chambers, Mike Battaglia, J. Morgan Varner, Joseph J. O'Brien

The ecosystems along the border between the United States and Mexico are at increasing risk to wildfire due to interactions among climate, land-use, and fuel loads. A wide range of fuel treatments have been implemented to mitigate wildfire and its threats to valued resources, yet we have little information about treatment effectiveness. To fill critical knowledge gaps, we reviewed wildfire risk and fuel treatment studies that were conducted near the US-Mexico border and published in the peer-reviewed literature between 1986 and 2019. **Wildfire Risk and Hazardous Fuel Reduction Treatments Along the US-Mexico Border: A Review of the Science (1986-2019).** Katherine M Laushman, Seth M Munson and Miguel L Villarreal

Wildfire and Invasive Species in the West: Challenges That Hinder Current and Future Management and Protection of the Sagebrush-steppe Ecosystem: A Gap Report. Western Association of Fish and Wildlife Agencies. December 2013

Invasive Species in Forests and Rangelands of the United States. A Comprehensive Science Synthesis for the United States Forest Sector. Therese M. Poland, Toral Patel-Weynand, Deborah M. Finch, Chelcy Ford Miniat, Deborah C. Hayes, Vanessa M. Lopez (Editors) 2021

Annotated Bibliography of Scientific Research on Ventenata dubia Published from 2010 to 2020. Erin E. Poor, Nathan J. Kleist, Heidi L. Bencin, Alison C. Foster, and Sarah K. Carter. 2021

Invasive Alien Species. T. Pullaiah and Mikael R. Ielmini (2021) p. 1455

Fire is unlikely to be a simple, deterministic process that will result in increased rates of invasion by nonnative plants. Relative dominance of nonnative plants at any postfire site likely results from a combination of factors, including propagule pressure (aboveground and belowground), time since invasion, interspecific competition, disturbance history, rainfall patterns, soil nutrients, environmental heterogeneity, land use, plus the actual fire dynamics. Consequently, the role different factors play in nonnative plant invasion is still relatively unexplained, and the possibility that wildfire may promote nonnative plant species remains a concern. Our aim was to evaluate the state of knowledge concerning how nonnative plant species establish, survive, and spread following wildfire in wildland areas for the main vegetation types of the Intermountain West. The initial literature search was conducted in the U.S. Forest Service Rocky Mountain Research Station (Missoula, MT) using Agricola,1 TreeCD,2 and EcoDisc3 databases to identify literature on fire and weeds published since 1990. Various combinations of the key words burn, fire, weed, noxious, invasive, exotic, alien, and the names of the Intermountain West states were used. **Reviewing the Role of Wildfire on the Occurrence and Spread of Invasive Plant Species in Wildland Areas of the Intermountain Western United States.** Lisa J. Rew and Mara P. Johnson

Compendium to Invasive Annual Grass Spatial Products for the Western United States, January 2010–February 2021. Data Report 1152. D. Joanne Saher, Jessica E. Shyvers, Bryan C. Tarbox, Nathan D. Van Schmidt, Julie A. Heinrichs, and Cameron L. Aldridge

Wildfire and Invasive plants in Alaska's Boreal Forest - State of the Science Report. Taylor J. Seitz, Katie V. Spellman, and Christa P. H. Mulder

Recent research has emphasized the need to advance fuel knowledge and management through (1) improving the speed and accuracy of techniques for characterizing fuel properties, such as fuel moisture and arrangement; (2) evaluating how fuel properties respond to management and disturbance events; and (3) integrating these techniques to improve the mapping of fuel characteristics and hazards across space and time. This Special Issue represents a collection of papers that highlight the diversity in fuel dynamics, characterization approaches, and mapping strategies from around the world. **Preface: Special Issue on Advances in the Measurement of Fuels and Fuel Properties.** Wade T. Tinkham, Lauren E. Lad and Alistair M. S. Smith

Invasive plants can alter fuels and fire regimes in ways that facilitate their spread and dominance through a process known as the invasion-fire cycle. This phenomenon can result in considerable fire and ecosystem impacts, but mechanisms, habitat susceptibility, and prevalence of invasion-fire cycles are poorly understood. Here, we reviewed literature on invasion-fire cycles and describe how mechanisms by which and habitats in which invasion-fire cycles occur are influenced by invader growth form, including woody versus herbaceous and perennial versus annual species, among other factors, and highlight research needs to better understand invasion-fire cycles. From these publications, we compiled a list of invasive plant species that could potentially initiate invasion-fire cycles by altering fuels and/or fire behavior, and compiled information on how each species has been observed to complete each step of the invasion-fire cycle. **Research gaps limit understanding of invasion-fire cycles** (2022). Giovanna Tomat-Kelly and S. Luke Flory

SPREADING LIKE WILDFIRE THE RISING THREAT OF EXTRAORDINARY LANDSCAPE FIRES – 2022. Spreading like Wildfire: The Rising Threat of Extraordinary Fires is the first report by UNEP and GRID-Arendal to take stock of the scale and extent of the global wildfire crisis and has been commissioned in support of the UN Decade of Ecosystem Restoration. Over 50 experts from research institutions, government agencies, and international organizations from around the globe have contributed to this report. Their findings are that while the situation is certainly extreme, it is not yet hopeless.

Strengthening Syntheses on Fire: Increasing the Usefulness for Managers. Jane Kapler Smith

Wildland Fire in Ecosystems – Fire and Nonnative Invasive Plants. Kristin Zouhar, Jane Kapler Smith, Steve Sutherland, Matthew L Brooks