ARTICLE IN PRESS

Rangeland Ecology & Management xxx (2016) xxx–xxx

Contents lists available at ScienceDirect

Rangeland Ecology & Management

journal homepage: http://www.elsevier.com/locate/rama

Using Resilience and Resistance Concepts to Manage Persistent Threats to Sagebrush Ecosystems and Greater Sage-grouse

Jeanne C. Chambers [a,*], Jeremy D. Maestas [b], David A. Pyke [c], Chad S. Boyd [d], Mike Pellant [e], Amarina Wuenschel [f]

[a] *Research Ecologist, US Forest Service, Rocky Mountain Research Station, Reno, NV 89509, USA*
[b] *Sagebrush Ecosystem Specialist, USDA Natural Resources Conservation Service, Redmond, OR 97756, USA*
[c] *Research Ecologist, US Geological Survey, Forest & Rangeland Ecosystem Science Center, Corvallis, OR 97331, USA*
[d] *Rangeland Ecologist, US Department of Agriculture—Agricultural Research Service, Burns, OR 97720, USA*
[e] *Rangeland Ecologist, USDI Bureau of Land Management, Boise, ID 83709, USA*
[f] *Presidential Management Fellow, US Forest Service, Rocky Mountain Regional Office, Golden, CO 80401, USA*

ARTICLE INFO

Article history:
Received 1 February 2016
Received in revised form 7 August 2016
Accepted 9 August 2016
Available online xxxx

Key Words:
conifer expansion
conservation
invasive annual grasses
population persistence
soil temperature/moisture regimes
wildfire

ABSTRACT

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. The approach links biophysical indicators of ecosystem resilience and resistance with species-specific population and habitat requisites in a risk-based framework to identify priority areas for management and guide allocation of resources to manage persistent ecosystem-based threats. US federal land management and natural resource agencies have adopted this framework as a foundation for prioritizing sage-grouse conservation resources and determining effective restoration and management strategies. Because threats and strategies to address them cross-cut program areas, an integrated approach that includes wildland fire operations, postfire rehabilitation, fuels management, and habitat restoration is being used. We believe this approach is applicable to species conservation in other largely intact ecosystems with persistent, ecosystem-based threats.

Published by Elsevier Inc. on behalf of The Society for Range Management.

Introduction

Conservation of imperiled species worldwide often demands curtailing a complex suite of threats that undermine species viability. Regulatory approaches, such as the US Endangered Species Act of 1973 (ESA) (United States Government, 2002), provide necessary stopgap protection but are largely reactive. The focus tends to be on addressing anthropogenic threats through adoption of policies and regulatory mechanisms such as restricting hunting or banning harmful pesticides (Boyd et al., 2014). Persistent ecosystem-based threats, such as invasive species and altered disturbance regimes, remain chronic issues for most at-risk species considered to be conservation reliant and require sustained conservation effort (Scott et al., 2010; Goble et al., 2012). Creative solutions based on an understanding of ecosystem resilience can be used to integrate science, management, and policy and help ecologists embrace uncertainty, manage risk, and adapt in rapidly changing environments (Curtin and Parker, 2014; Pope et al., 2014; Angeler et al., 2016).

Greater sage-grouse (*Centrocercus urophasianus,* hereafter sage-grouse) is a high-profile species facing a myriad of anthropogenic and persistent ecosystem threats that has been considered for federal regulatory protections under the ESA multiple times (USFWS, 2015). Sage-grouse and more than 350 other species rely on sagebrush (*Artemisia* spp.) ecosystems (Suring et al., 2005). These ecosystems now comprise only about 59% of their historical area, and the primary patterns, processes, and components of many of these systems have been significantly altered since Euro-American settlement in the mid-1800s (Knick et al., 2011; Miller et al., 2011). Primary threats driving continued loss and fragmentation of sagebrush habitat include large-scale wildfire, invasion of exotic annual grasses, conifer expansion, energy development, conversion to cropland, and urban and exurban development (USFWS, 2013). In 2010, concern over sagebrush habitats and the potential for listing sage-grouse under the ESA set in motion sweeping federal and state land management plan changes and proactive conservation actions to address threats within the realm of management control

* Correspondence: Jeanne Chambers, US Forest Service, Rocky Mountain Research Station, 920 Valley Road, Reno, NV 89509, USA.
E-mail address: jchambers@fs.fed.us (J.C. Chambers).

http://dx.doi.org/10.1016/j.rama.2016.08.005
1550-7424/Published by Elsevier Inc. on behalf of The Society for Range Management.

(USFWS, 2015). In fall 2015, federal regulators determined that sage-grouse did not warrant protection under the ESA due to ongoing efforts to address threats but that the species status would be reevaluated again in 2020 (USFWS, 2015). Invasive species and altered fire regimes remain persistent challenges, and changes in precipitation coupled with increased temperatures due to climate change are already magnifying effects of these threats and adding urgency to implementing strategic solutions (Chambers and Pellant, 2008; Abatzoglou and Kolden, 2011; Bradley et al., 2016). For example, climate change is likely linked to recently observed "mega-fires" through an increased propensity for and severity of climatic extremes (Stephens et al., 2014).

Application of ecological resilience and resistance concepts to species and ecosystems of conservation concern has emerged as a unifying framework for managing persistent threats in a variety of ecosystems (Curtin and Parker, 2014; Pope et al., 2014; Angeler et al., 2016). We define resilience as the capacity of ecosystems to reorganize and regain their fundamental structure, processes, and functioning (i.e., to recover) when altered by stressors like drought and disturbances like inappropriate livestock grazing and altered fire regimes (Holling, 1973). Resistance is the capacity of ecosystems to retain their fundamental structure, processes, and functioning when exposed to stresses, disturbances, or invasive species (Folke et al., 2004). Resistance to invasion by nonnative plants is increasingly important in rangeland ecosystems; it is a function of the abiotic and biotic attributes and ecological processes of an ecosystem that limit the population growth of an invading species (D'Antonio and Thomsen, 2004). Because resilience and resistance are functions of the biophysical characteristics of ecosystems, they vary over environmental gradients, are quantifiable, and can be used to manage risks and predict outcomes of management decisions (Chambers et al., 2014a, 2014b; Allen et al., 2016; Angeler et al., 2016). Linking biophysical indicators of ecosystem resilience and resistance with species-specific population and habitat requisites can yield an ecologically based framework for managing complex ecosystem problems threatening at-risk species at multiple scales (Chambers et al., 2014c, in press).

Here we illustrate how resilience and resistance concepts are being operationalized to reduce impacts of persistent threats from invasive annual grasses and altered fire regimes on sagebrush ecosystems and sage-grouse, particularly in the western portion of the species range (i.e., Columbia Basin, Snake River Plain, and Northern and Southern Great Basin ecoregions; USEPA, 2016). We begin by describing persistent ecosystem and anthropogenic threats to sagebrush ecosystems and discussing the resilience and resistance of these ecosystems based on their biophysical characteristics and known responses to disturbances and management actions. We present objectives and management strategies to support resilience management in sagebrush ecosystems and then link our understanding of sagebrush ecosystem resilience and resistance with sage-grouse habitat requirements in a decision matrix that supports habitat management. Finally, we show how this framework can be used to identify priority areas for management and guide allocation of scarce resources to manage risks across scales. We believe this approach is applicable to species conservation in other largely intact ecosystems with persistent, ecosystem-based threats.

Persistent threats to sagebrush ecosystems and impacts on sage-grouse

Euro-American arrival in sagebrush ecosystems in the mid-1800s initiated a series of changes in vegetation composition and structure that altered fire regimes and had negative consequences for sagebrush habitats. First, improper grazing (type and season of use that results in a phase at risk or departure from reference conditions) by livestock led to a decrease in native perennial grasses and forbs and effectively reduced abundance of fine fuels (Miller et al., 2011). Decreased competition from perennial herbaceous species, in combination with ongoing climate change and favorable conditions for woody species establishment at the turn of the 20th century, resulted in increased abundance of shrubs (primarily *Artemisia* species) and trees, including juniper (western juniper, *Juniperus occidentalis;* Utah juniper, *J. osteosperma*) and piñon pine (singleleaf piñon, *Pinus monophylla*), at mid to high elevations (Miller et al., 2011). The initial effect of these changes in fuel structure was a reduction in fire frequency and size.

Second, exotic annual grasses (e.g., cheatgrass, *Bromus tectorum;* medusahead, *Taeniatherum caput-medusa*) were introduced from Eurasia in the late 1800s and spread rapidly into relative warm and dry ecosystems at low to mid elevations with understories depleted by inappropriate livestock grazing (Pyke et al., 2016). These grasses increased the amount and continuity of fine fuels in many lower-elevation sagebrush habitats and initiated annual grass/fire cycles characterized by shortened fire return intervals and larger, more contiguous fires (Miller et al., 2013). Many warmer and drier sagebrush ecosystems at low to mid elevation have been converted to a new alternative state dominated by cheatgrass and other nonnative invasive annuals that is exceedingly difficult to restore (Germino et al., 2016). Cheatgrass and other invasive annuals now dominate at least 6% of the 650,000 km^2 central Great Basin (Balch et al., 2013) and have potential to spread across many of the remaining low to mid elevation sagebrush ecosystems in the sagebrush biome (Bradley et al., 2016).

Third, ongoing expansion of juniper and piñon pine trees into relatively cool and moist sagebrush types at mid to high elevations reduced the grass, forb, and shrub species associated with these types as a result of resource competition (Miller et al., 2011, 2013). Expansion and infilling of trees increased woody fuel loads, risk of high severity crown fires, and potential for conversion to an alternative state dominated by invasive annual grasses on relatively warm sites with depleted understories (Chambers et al., 2014b; Miller et al., 2014). Tree dominance also increased risk of soil loss and conversion to an eroded alternative state on erodible soils and steep slopes that may be largely irreversible (Chambers et al., 2014b; Miller et al., 2014). On the basis of tree-ring analyses at several Great Basin sites, it is estimated that the extent of piñon and/or juniper woodland increased twofold to sixfold since settlement and most of that area will exhibit canopy closure within the next 50 years (Miller et al., 2008).

Sage-grouse and other sagebrush-obligate species that require large and intact sagebrush landscapes without trees have been negatively impacted by these ongoing land cover changes (Schroeder et al., 2004). Regional analyses using remotely sensed data repeatedly confirm the importance of sagebrush-dominated landscapes as a key constraint on sage-grouse population persistence within a 5- to 30-km radius of leks or breeding sites (Aldridge et al., 2008; Wisdom et al., 2011; Knick et al., 2013). Landscapes with < 25% of the land area dominated by sagebrush cover have a low probability of sustaining lek activity. When sagebrush landscape cover exceeds 25%, the probability of maintaining active sage-grouse leks increases with increasing amounts of sagebrush landscape cover. With 50–85% of the landscape in sagebrush cover, the probability of sustaining sage-grouse leks increases further and then becomes relatively constant (Aldridge et al., 2008; Wisdom et al., 2011; Knick et al., 2013).

Progressive invasion of exotic annual grasses has reduced sage-grouse habitat quantity and quality. Most active leks have little annual grass cover (2.2%) within a 5-km radius (Knick et al., 2013), and lek use decreases as cover of invasive annual species increases at both the 5-km and 18-km scales (Johnson et al., 2011). Active leks that are not impacted by annual grasses can exhibit recruitment rates nearly twice as high as the population average and nearly six times greater than leks affected by annual grasses during years favorable for reproduction (Blomberg et al., 2012). At the scale of the nest site, female sage-grouse avoid nesting in areas with cheatgrass cover > 8% (Kirol et al., 2012).

Piñon and juniper expansion in sagebrush ecosystems at mid to upper elevations reduces sage-grouse habitat availability and suitability over large areas through decreases in sagebrush cover and perennial native grasses and forbs (Miller et al., 2013). Sage-grouse avoid or are

Please cite this article as: Chambers, J.C., et al., Using Resilience and Resistance Concepts to Manage Persistent Threats to Sagebrush Ecosystems and Greater Sage-grouse, Rangeland Ecology & Management (2016), http://dx.doi.org/10.1016/j.rama.2016.08.005