Defend the core: Maintaining intact rangelands by reducing vulnerability to invasive annual grasses

By Jeremy D. Maestas, Mark Porter, Matt Cahill, and Dirac Twidwell

On the Ground

- 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.

Keywords: Cheatgrass, Sagebrush, Resilience, Resistance, Invasive annual grasses, Wildfire.

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A new battle cry is being heard from the Great Plains to the Great Basin in the fight to save America's grasslands and shrublands: "*Defend the Core*".[1] This concept refers to an emerging strategy for conserving rangelands that emphasizes proactive and preventative management of large-scale threats within otherwise intact landscapes comprised mostly of native plant communities, or 'cores.' In the Plains, such a strategy is being applied to halt woody encroachment and grassland loss to trees like eastern redcedar (*Juniperus virginiana* L.).[1,2] Farther west, partners in sagebrush (*Artemisia* L. spp.) country are beginning to adopt this approach to more effectively curb shrubland conversion to invasive annual grasses, such as cheatgrass (*Bromus tectorum* L.), medusahead (*Taeniatherum caput-medusae* (L.) Nevski), and ventenata (*Ventenata dubia* (Leers) Coss.).[1,3-6] Despite differences across geographies, the approach uses the same spatially-explicit planning process to help prioritize management in and around rangeland cores where it is still possible to prevent state transitions that result from invasive plants.

While conservationists are embracing this new threat-reduction strategy, applications of it are relatively new and questions remain about how to implement it effectively at meaningful scales. Vulnerability-based models are used around the world to manage risks associated with a variety of large-scale and intractable threats, such as, climate change and woody plant encroachment.[2,7] Vulnerability is typically defined as a function of three factors: sensitivity, exposure, and adaptive capacity (Fig. 1). In general, sensitivity refers to the inherent characteristics of a system that determine the degree to which it is impacted by a threat or stressor. Exposure refers to the magnitude of threat or stressor the system is exposed to. Sensitivity and exposure combine to determine risk. For instance, Great Plains grasslands historically had low risk of woody encroachment because regular fire improved vigor of native grasses reducing sensitivity to woody invasion and exposure to woody seed sources was rare in expansive grasslands. Adaptive capacity refers to the potential of human communities to adapt to a threat with minimal disruption, such as a community within a watershed that comes together to more effectively confront woody encroachment across property lines (e.g., landowner prescribed burn associations) rather than working alone.

Converging scientific and technological advancements over the last decade provide a better understanding of sagebrush ecosystem vulnerability to annual grass invasion. Partners in the sagebrush biome have built out a robust science framework describing biotic and abiotic drivers of ecosystem resilience to disturbance or stress and resistance to invasive annual grasses.[8,9] Resilient ecosystems have the capacity to reorganize and regain their basic characteristics when altered by stressors such as invasive plants and disturbances like fire, while resistant ecosystems have attributes limiting establishment and expansion of the invader.[9,10] For example, cooler and wetter sagebrush sites supporting healthy perennial plant communities exhibit greater resilience to wildfire and resistance to annual grass invasion than warmer and drier sites with depleted perennial plant communities.[10] Our under-

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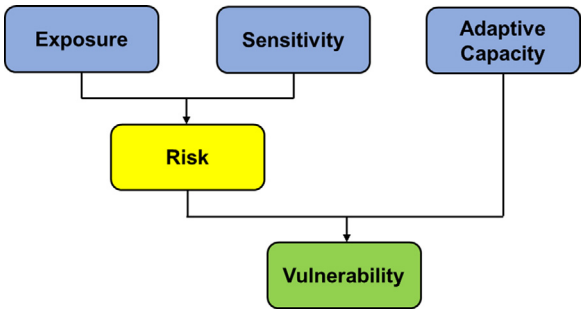

Figure 1. The classic vulnerability-based model for reducing large-scale ecosystem threats.

standing of the biology and ecology of invasive annual grasses has also improved,[11] along with the tools needed to disrupt invasive species reproduction processes.[12] Recent breakthroughs in remotely-sensed rangeland vegetation mapping provide heightened awareness of where annual grass invasions are occurring and how they are changing through time,[13] providing context for communities and partners to rally around a coordinated strategy to tackle this evolving threat.[3,4,6] When combined, these advancements provide a basis for reducing vulnerability of sagebrush ecosystems to annual grass invasion by allowing us to more effectively address sensitivity, exposure, and adaptive capacity.

We elaborate on what it means to proactively "defend the core" by applying the vulnerability-based model to reduce the threat of invasive annual grasses. First, we review the critical role of landscape context in informing management options and expectations and discuss how geographic strategies help managers understand this context. Next, we highlight three guiding actions needed to reduce vulnerability of sagebrush rangeland cores to annual grass conversion: 1) reduce exposure to invasive annual grass seed sources, 2) improve resilience to disturbance/stress and resistance to invasion by promoting perennial plants, and 3) build capacity of communities and partnerships to adapt to changing conditions and respond to the problem with appropriate actions in a timely manner.

Importance of landscape context

We often wait too long to address resource issues, deferring management until problems are obvious. However, principles of invasion ecology teach us that control is more effective and cost-efficient when done early before infestations become widespread. Indeed, Early Detection and Rapid Response (EDRR) has long been a key tenet of invasive species management. The field of landscape ecology teaches us that scale and context matter too as invasions tend to be spatially contagious. This "landscape context" is essential to understand as ecosystem composition, structure, and function partially depend on what is happening around that location at multiple scales (e.g., watershed, region, biome) through time.

Combining these principles in a simple example illustrates the importance of understanding the severity and extent of invasions when evaluating management options and expectations. Contrast a largely intact hypothetical rangeland core with few annual grass infestations (Fig. 2a) with a landscape that is heavily invaded by annual grasses with few uninvaded lands remaining (Fig. 2b). In which of these landscapes do you think annual grass control will be more effective over the long run? Clearly, success in stopping annual grass conversion depends not only on what is happening within a particular site on the ground, but also what is happening in the surrounding area.

Understanding this landscape context enables managers to focus the right actions, in the right places, at the right time, and set realistic expectations for potential outcomes. In the relatively uninvaded core area (Fig. 2a), the emphasis is on risk management to proactively prevent invasions and erad-

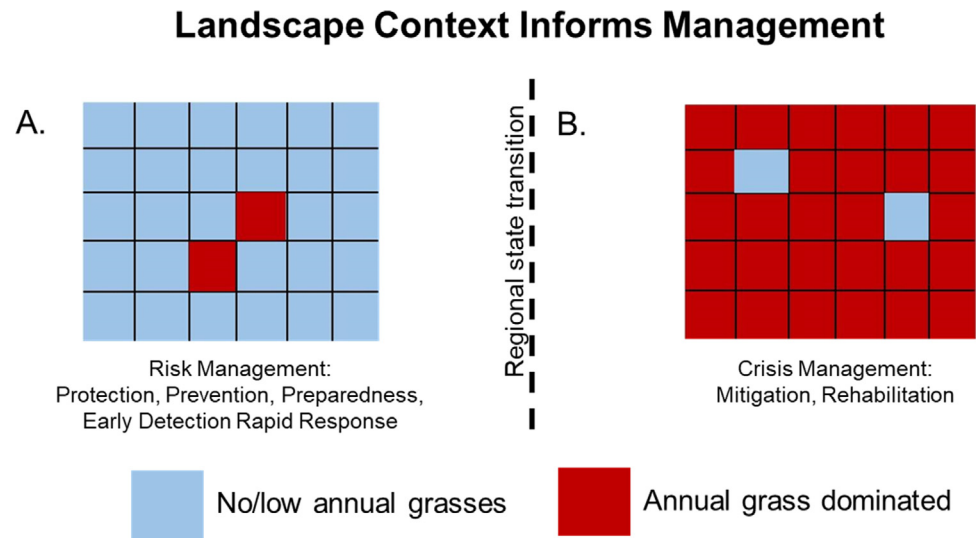

Figure 2. Conceptual example illustrating the importance of landscape context. A landscape that is largely intact with few annual grass infestations (a) is contrasted with a landscape that is heavily invaded by annual grasses (b). As more of the landscape transitions to annuals, regional state shifts occur limiting management response and options.

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Figure 3. Three guiding actions needed to reduce vulnerability of sagebrush rangeland cores to annual grass invasion.

ication of new infestations. In the heavily invaded landscape (Fig. 2b), prevention is no longer an option as invasive annuals are widespread and difficult to control. Here, crisis management is needed to mitigate the most severe impacts of the annual grass-fire cycle on life and property. Given the widespread nature of the annual grass problem and invasibility of sagebrush rangelands (see Boyd et al., this issue),[14] land managers should be asking themselves: 1) What kind of landscape do I live or work in?; 2) Am I already in a crisis or should I be working to prevent one?

Remotely-sensed vegetation maps help managers know the condition of the landscape they are working in, enabling partners to develop geographic strategies for prioritizing appropriate management actions in the right places (see Creutzburg et al., this issue).[3,4,6] Identifying and defending cores from annual grass invasion is a top priority for management as it is more likely to be effective and cost-efficient than waiting to act until problems are acute. In cores, opportunities remain to reduce risks before difficulty and costs go up exponentially as the scale and severity of invasions increase. Yet, cores cannot be defended in isolation so transitioning lands situated between cores and more degraded regions are also important areas for aggressive management and restoration. Finally, focusing triage tactics (e.g., targeted fine fuels reduction, enhanced fire suppression) in degraded regions can help mitigate and contain crises resulting from widespread invasive annuals and frequent fire (see Wollstein et al. and Davies et al., this issue).[15,16] We focus here on further describing the proactive management needed to defend cores.

Reducing vulnerability of cores to invasion

With common geographic strategies providing context for management, partners are better positioned to focus specific actions needed to reduce vulnerability of sagebrush rangeland cores to invasive annual grasses. Putting the vulnerability-based model into practice, we discuss three guiding actions needed to "defend the core" from annual grass conversion: 1) reduce exposure of cores to invasive annual grass seed sources, 2) improve resilience to disturbance/stress and resistance to invasion by promoting perennial plants, and 3) build capacity of communities and partnerships to adapt to changing conditions and respond to the problem with appropriate actions in a timely manner (Fig. 3).

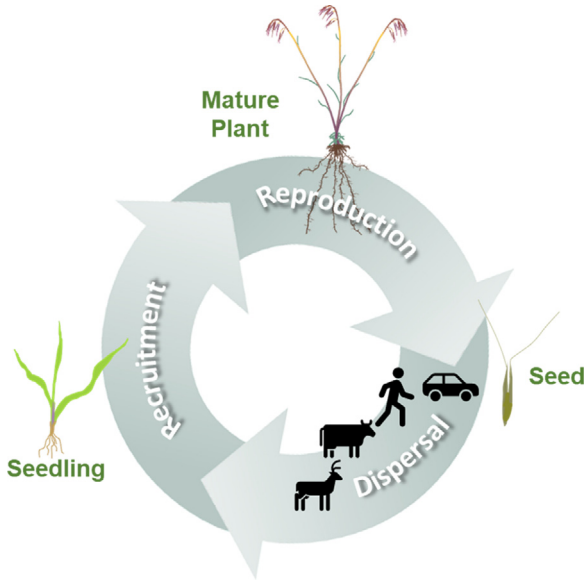

Figure 4. Invasive annual grass life cycle. Limiting exposure of rangeland cores to invasive seed sources is essential to breaking the cycle.

1). *Reduce exposure to invasive seed sources*

Simply put, annual grass invasion of rangeland cores cannot occur without seed sources. Stopping these weeds means stopping their seeds to prevent subsequent dispersal, recruitment, and reproduction (Fig. 4). Exposure of cores to seeds and subsequent reproduction is a primary point of vulnerability leading to annual grass conversion. As annual plants, invasive annual grasses have one job: produce seed every year. And they are exceptionally good at it. Cheatgrass and other non-native annuals produce vast amounts of seed annually. Furthermore, annual grass seeds are well-adapted for dispersal making it difficult to contain seed spread. Once introduced, viable seeds accumulate on site and contribute to re-establishment after initial control which is often inconsistently or ineffectively implemented. But we are not helpless, and applying our understanding of the pathways of invasion can inform specific actions we may need to take to stop the spread.

Annual grass invasion is a spatially contagious process whereby new seed introductions often come from nearby invaded areas. These are the front lines of annual grass control where managers can take steps to reduce exposure of uninvaded cores, such as, eradicating or containing small infes-

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tations, controlling timing of livestock and human access to invaded areas during seed production to limit dispersal opportunities, and heightened vigilance using EDRR in uninvaded areas. Wildlife and free-roaming equids also contribute to annual grass seed dispersal, so monitoring and treatment of known travel corridors may be required to reduce introductions from these sources. Seed can also come from faraway places through contaminated hay or seed, recreationists, vehicles, and livestock transportation. In these cases, other measures may be needed, such as regional regulation of agricultural seed contamination, use of certified weed and annual grass free forage and restoration materials, seasonal travel restrictions, and clean-out periods for livestock moving from place to place.

Where introductions have already occurred, seedbank depletion is key to reducing exposure.[12] Insights into cheatgrass seed viability and longevity provide the biological basis for long-term control. Science shows over 96% of first-year seeds germinate the fall after hitting the ground, with few persisting more than 2-5 years in the soil.[17,18] A multi-year approach to seedbank depletion using selective herbicides provides a critical tool for reducing seed exposure over time,[12] assuming a residual community of desirable perennial vegetation exists or a reseeding effort is successful to re-occupy previously infested sites. Another consideration in seedbank depletion is decreasing seed viability by reducing 'safe sites' for germination, such as thatch or litter that facilitates annual grass seed germination and growth.[19] These early response techniques can be successful if they disrupt the short-lived seedbank dynamics of annual grasses and then focus on prevention of reinvasion.

Long-term efficacy of efforts to reduce exposure to annual grass seed sources is not well understood and is an area in need of future research. In the interim, management actions should be coupled with regular monitoring and adaptive management. Multiple interventions are required to deplete seed sources once introduced, so land managers should consistently incorporate adaptive, multi-year treatments into annual grass management plans.

2). *Improve resilience and resistance by promoting perennial plants*

The sensitivity of sagebrush rangelands to invasive annual grasses has been well-described in terms of ecosystem resilience to disturbance/stress and resistance to invasion.[10] While much of the Intermountain West is well-suited to invasion by winter annual grasses,[11] relative resilience to disturbance/stress and resistance to invasion varies along an environmental gradient based on certain abiotic and biotic factors.[8,9,10] Warmer and drier sites are more susceptible to cheatgrass invasion than cooler and wetter sites (e.g., lower vs. higher elevations). Vegetation composition and productivity also determine resilience to disturbance/stress and resistance to invasion. Perennial grasses are particularly important for keeping invasive annuals out by occupying above and belowground niches that might otherwise be available for weeds

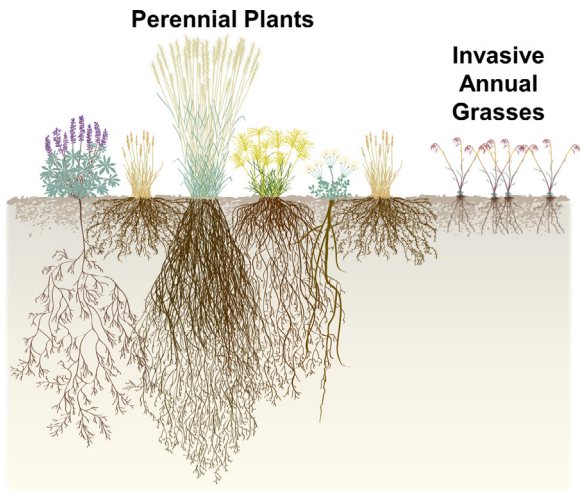

Figure 5. Maintaining a sufficient density of healthy perennial plants is a key factor in reducing sensitivity to annual grass invasion. Illustration credits: Jeremy Maestas and Maja Smith, Sage Grouse Initiative

(Fig. 5).[10] For certain species, like medusahead, soils strongly influence susceptibility to invasion.

Invasive species management only focusing on killing the weed, without considering mechanisms of invasion and what will take its place when it's removed, is akin to playing "whack-a-mole"—a metaphor used to describe a situation in which attempts to solve a problem are piecemeal, resulting only in temporary or minor improvement. Long-term solutions lie in integrated approaches that manage both for desired perennials and against invasive annuals. Since abiotic factors are beyond our control, improving resilience and resistance boils down to managing for the health and vigor of perennial plants, especially bunchgrasses. This includes tactics, such as grazing management favoring desired perennial plants, restoration seeding (see Baughman et al., this issue),[20] herbicide treatments to release perennials from invasive competition and deplete the invasive seedbank,[12] and reducing ground-disturbing activities that weaken perennial vegetation.[3] Johnson et al. (this issue) describe in more detail specific actions for improving ecosystem resilience and resistance.[21]

3). *Build capacity to adapt to changing conditions*

Increasing society's capacity to respond to complex and dynamic problems with appropriate actions in a timely manner is essential to minimizing loss of critical ecosystem functions and services into the future. The ever-expanding niche for invasive annual grasses with climate change[11,22,23] underscores the importance of land and resource managers in sagebrush county to be prepared to confront this problem, even if invasive annuals are not a clear and urgent threat locally today. Managing vulnerability to a dynamic threat is a socio-ecological systems problem requiring not only ecological knowledge but also political and cultural will to take an 'all hands, all lands' approach. Building adaptive capacity includes increasing the ability of institutions and agencies to learn and

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transfer knowledge quickly (see Schroeder et al., this issue),[24] while also providing creative flexibility in decision-making and accountable power structures to ensure action. Innovative organizational infrastructure, such as collaboratives and special management units, can also empower local communities to more effectively respond to changing management needs. Garnering support for reliable long-term funding and resources is another key element of enhancing adaptive capacity at the local level that enables willing stakeholders to act (see Smith et al. and Cahill et al., this issue).[25,26]

Community-based cooperatives are a proven mechanism for building the capacity for adaptation. Cooperatives share equipment, experience, staff, and resources to conduct treatments across property lines which increases their collective abilities to manage resource issues. County Weed Control Districts and Cooperative Weed Management Areas (CWMAs) are such existing structures for diverse partners to address invasive species in a particular area. Other innovative examples include organizations like the High Desert Partnership which brings people together to solve diverse rural challenges from wildfire to economic development (see: https://highdesertpartnership.org/). Unique learning networks are also emerging, like the University of Wyoming's Institute for Managing Annual Grasses Invading Natural Ecosystems (IMAGINE) which is connecting scientists and land managers to improve data sharing and communications about how to effectively manage invasive annuals. Human capacity in the form of boots-on-the-ground to coordinate collaborative efforts is vital to ensuring willing groups have the support needed to function.

The co-mingled nature of public-private rangelands in sagebrush country requires land and natural resource management agencies, private landowners, and other partners to row in the same direction toward a shared vision and goal at multiple scales. Biome-wide frameworks, such as, the NRCS Working Lands for Wildlife Framework for Conservation Action,[1] Western Governors Association Toolkit for Invasive Annual Grass Management,[4] and Western Association of Fish and Wildlife Agencies' Sagebrush Conservation Strategy,[5] help align federal and state partners with a common "defend the core" strategy for proactively protecting rangeland cores from invasive annuals. Stepping this down to state-wide or area-wide plans co-produced by local stakeholders provides an actionable roadmap for coordination and investment in human capacity, management, and monitoring. Models, such as, Idaho's Cheatgrass Challenge,[3] Oregon's SageCon Invasives Initiative (Creutzburg et al., this issue),[6] and Wyoming Governor's Invasive Species Initiative illustrate flexibility in how state and local partners can work towards the same the shared vision.

A proactive path forward

As we consider a new path forward to address the annual grass problem, it is instructive to evaluate the effectiveness of past efforts and priorities and acknowledge shortcomings. While we spend most of our resources dealing with the latest crisis in heavily impacted regions, previously uninvaded rangelands continue to transition to invasive annuals every day. Climate change only adds to the urgency as cheatgrass and other invasive annuals are on the move, increasingly occupying new niches and challenging management assumptions and paradigms.[11,21,22]

However, new vegetation mapping technology provides us with a better understanding of the spatial distribution of the problem which has enabled partners to lay out proactive and comprehensive strategies for tackling it. Roughly 70% of the sagebrush biome still has relatively low amounts of invasive annuals, providing land managers with abundant opportunities for proactive risk management.[27] Putting maintenance of intact rangeland cores at least on par with our investment in crisis management provides an opportunity to save the vast majority of remaining rangelands that are still functional. Successfully defending cores will require a shift in mindset and the sustained resources needed to build adaptive capacity of landowners and managers to reduce exposure to annual grass seed sources and continually improve rangeland resilience to disturbance/stress and resistance to invasion in the face of change.

Declaration of Competing Interest

None.

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