Managing for resilient sagebrush plant communities in the modern era: We're not in 1850 anymore

By Chad S. Boyd

On the Ground

- 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.
- In December 2020 a diverse group of managers, scientists, and government officials held a symposium to discuss existing and emerging options for ameliorating the annual grass threat and associated impacts in the Northern Great Basin region.
- I provide 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.
- My broad overview serves as an operational context framing the importance of and relationships between the papers in this Special Issue.

Keywords: annual grasses, wildfire, historical ecology, restoration.

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Introduction

The invasion of western US rangelands by invasive annual grasses presents a challenge of generational magnitude to contemporary rangeland managers, scientists, and governmental authorities. The size of the annual grass problem is currently measured in tens of millions of hectares and is growing. Equally daunting is the complexity of the problem; sagebrush landscapes are characterized by strong variability in precipitation, temperature, elevation, aspect, and soil factors, creating an ecological maze of interactions for scientists and managers to disentangle.[1] As invasive annual grasses spread across sagebrush landscapes, there are strong, and lasting negative impacts to a myriad of ecosystem values and services including forage for livestock, wildlife habitat, human safety and loss of structures to wildfire, and rangeland carbon sequestration.[2]

Because of its size and complexity, making progress on the invasive annual grass problem will, if anything, be a collective effort involving managers, scientists, agricultural producers, interested public, and political leadership. To help chart a path forward in annual grass management of the northern Great Basin, the High Desert Partnership (Burns, Oregon), the SageCon Partnership, and Oregon State University organized an invasive annual grass symposium in December 2020. This symposium brought together individuals from an array of disciplines to address a wide variety of issues directly and indirectly related to invasive annual grasses and within the context of a geographic strategy stressing defending the core intact plant communities, growing cores through restorative treatments, and mitigating impacts of disturbances such as wildfire. Topics included slowing the spread of annual grasses, restoring impacted plant communities, improving fuels and fire management, enhancing cross-jurisdictional management, addressing impacts on agricultural producers, and prioritizing limited restoration resources. The purpose of this paper is to take a brief, and fairly coarse look at annual grass-induced changes in the ecology of sagebrush ecosystems, discuss future directions for management of annual grasses, and provide context for the papers in this Special Issue.

A note on perennial bunchgrasses

Central to the discussion of annual grass management are the notions of maintaining and restoring perennial bunchgrasses. Perennial bunchgrasses are a foundational plant group for maintaining the integrity of northern Great Basin sage-

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brush plant communities in the face of invasive annual grass invasion.[3] In a nutshell, these species collectively occupy space that would or could otherwise be occupied by invasive annual grasses. From a competition standpoint, and as discussed below, perennial bunchgrass seedlings are not much of a competitive match for invasive annual grasses. The latter being designed for rapid root and leaf elongation so they can reproduce within their brief lifespan. That said, once established, perennial bunchgrasses develop extensive root systems that fully occupy the soil resources around them, and effectively compete with annual grass invaders. Thus, much of my focus and that of other papers in this special issue is on the maintenance and establishment of perennial bunchgrasses (for a more in-depth discussion of the ecology behind this topic, see Johnson et al.,[4] this issue).

It's not that other plant functional groups aren't important. Indeed, a sizeable number of papers and book chapters have been written on the ecological importance of sagebrush and other shrubs within the sagebrush biome, and these species do interact with disturbance factors like fire (discussed below) to influence annual grass abundance. However, most shrub species lack the near-surface root density to effectively compete with annual grasses. So, when it comes to ameliorating annual grass problems in the northern Great Basin, it is a little about managing against annual grasses, and a lot about managing for perennial bunchgrasses.

The Great Basin in 1850

In thinking about the future of Great Basin plant communities, it can be instructive to revisit the historical ecology of the region. Knowledge of historical plant communities and the associated ecology helps us to conceptualize the ecological relationships that have developed over the course of sagebrush plant community evolution, providing an intellectual anchor point to gauge contemporary ecology and the extent to which it deviates from the past. Knowing the extent of deviation is important because it informs the natural human tendency to assume that management for historical conditions is reasonable in the present day.

Over the last 2.5 million years or so, the Great Basin region of the sagebrush biome has undergone significant changes in climate and associated plant communities. To wit, the office in which I am currently writing this paper was, within this time frame, at the bottom of a pluvial lake (we are high and dry at the moment).[5] So, in the spirit of narrowing down the term "historical ecology," let's think within the current short-term climate oscillation, but before the arrival of significant European populations, about 1850. During this time period, plant communities would have been dominated by cool season shrubs, such as sagebrush in the overstory, and largely cool season perennial bunchgrasses in the understory, with a variety of perennial and annual forbs. In fact, the native Great Basin plant assemblage of 1850 may have been very similar to the native plant species present today, with constituent species having evolved in place for many thousands of years. Associated with perennial bunchgrasses occupying the understory, native annual grasses were likely limited both in number of taxa and local abundance. From a disturbance standpoint, the ecosystem during this time was certainly disturbance-prone, with periodic lightening and burning practiced by Native Americans.[6,7] Mean fire return intervals may have been as short as 20 years in relatively high elevation mountain big sagebrush (*Artemisia tridentate* spp. *vaseyana*) communities, while lower elevation Wyoming big sagebrush (*Artemisia tridentata* spp. *wyomingensis*) communities likely experienced fire every 50 to 100 years or longer on xeric sites.[8] Grazing pressure from native herbivores may have been episodically heavy (e.g., following fire disturbance) but was not generally so owing to a lack of large native herbivores.[9]

The rules have changed

In the present article and in other articles in this special issue, I discuss how the ecology of sagebrush plant communities in the modern era differs markedly from that of the recent past, and how these differences compel managers, scientists, and conservationists to re-evaluate the importance of historical ecology and to align management pathways along a very different contemporary path.

Rule change number 1

From a historical standpoint, we can assume that frequency of disturbance events such as fire was in "balance" with the capacity of sagebrush plant communities to recover their fundamental composition and structure. This pragmatic reality is what allowed for the evolution of sagebrush plant communities within a fire-prone environment. It is not that fire did not harm sagebrush plant communities. In fact, combustion of the aboveground portion of most species of sagebrush results in death of the plant.[10] Perennial bunchgrasses generally fare better with fire than sagebrush, however a fire event can kill 20% to 60% of bunchgrass plants in sagebrush plant communities depending on the conditions.[11] The historical frequency of fire disturbance was not sufficient to result in loss of these species from sagebrush/bunchgrass plant communities at meaningful scales. Additionally, the timing of historical fires would have necessarily been associated with desiccation of available fuels. In the case of grasses, this would have been after seasonal senescence (i.e., before that point in time in the growing season, the moisture of green, actively growing grasses may not have been conducive to fire ignition and spread). Given that these species are predominantly cool season grasses, senescence generally occurs during late spring and early summer.

Historical overgrazing of cattle and sheep was associated with a reduction in native perennial bunchgrasses, creating ecological space for invasive annual grass species to inhabit.[8,9] With the influx of annual grasses into the sagebrush biome starting in the latter 1800s, the basic structure of fuel loads underwent significant changes. Fuel continuity increased dra-

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matically and in rough proportion to annual grass abundance.[12] Additionally, as annual grasses increased, the timing of fuel dry down was substantially earlier in the growing season.[12] This change in timing is significant because it shifts fire into the latter portion of the active growth period (i.e., during reproduction) of native perennial grasses. With fires more frequent and earlier in the season, native species decreased in abundance, opening up additional space for annuals to colonize. More annual grasses leads to more fires.[13] This cycle has progressed to the point that, within the annual grass zone, the frequency of fire is no longer in "balance" with the capacity of sagebrush plant communities to recover their fundamental composition and structure.

Rule change number 2

Many or perhaps most of the perennial plant species that evolved in the sagebrush biome were selected for based on their ability to persist in an environment with low, and variable resource availability in space and time.[14,15] Put another way, persistence was a currency of evolutionary success for native perennial plant species. Persistence in an environment with generally low (e.g., low soil nutrient levels) but variable (e.g., precipitation) resource availability requires phenotypic structures that allow exploiting large volumes of soil and maximizing capture of resources when available. Native perennial bunchgrass species common to sagebrush plant communities are a great example of this capability (see Baughman et al.,[16] this issue). Most of the biomass of individual bunchgrasses and of sagebrush/bunchgrass plant communities in general is comprised of below-ground roots.[17] These expansive root networks represent an efficient strategy for exploiting low levels of soil nutrients and for episodic capture of nutrients such as water when available. That efficiency, however, comes at a cost, and that cost is associated with the amount of energy and nutrients needed to grow and maintain root biomass, leaving fewer resources for development of above ground reproductive structures. Not surprisingly, native perennial grasses often have nonfilled seeds (i.e., no embryonic structures within the glumes), and when they do produce seeds, those seeds often beget seedlings that perform poorly at important demographic stages.[18,19] In short, native perennial bunchgrasses are infrequently successful at reproducing from seed. But then again, why should they be when they have evolved over millennia in an environment where the ability to persist was rewarded?

Invasive annual grasses changed everything. Success of the annual plant life form is not a matter of persistence. Instead, the metric of success for annual plants is to reproduce in the year of germination. Thus, invasive annual grasses such as cheatgrass (*Bromus tectorum*) and medusahead (*Taeniatherum caput-medusae*) have evolved seeds that germinate, emerge, and mature quickly and reliably within a wide amplitude of soil moisture and temperature conditions in either in fall or spring.[20] Invasive annual grasses outcompete native perennial grasses from a seedling establishment standpoint, and they also change the metrics of evolutionary success by altering the disturbance regime of sagebrush ecosystems. Specifically, as annual grasses become dominant in a plant community, they increase fuel continuity and fire frequency.[21] And when sagebrush plant communities burn, the nutrient rich postfire environment is ideally suited to the annual life form. In the modern era, the preceding factors have combined to create an environment in which rapid establishment following disturbance has now become the defining metric of success for plants within the annual grass zone of the sagebrush steppe. This represents a departure of significant magnitude from an evolutionary history of sagebrush plant communities that favored persistence. In short, we are now faced with a fundamentally different ecosystem, with different metrics of success than which our native perennial species evolved under. We're not in 1850 anymore.

In this new ecosystem, these two rule changes have synergistically combined to create a challenging and time-limited restoration environment. Pragmatically speaking, when a historical sagebrush/bunchgrass plant community burned, protracted recovery of perennial bunchgrasses had less consequence than today because invasive annual grasses were not present to fill the vacant niche. In annual grass prone areas of the modern sagebrush biome, if perennial grasses do not rapidly fill niche vacancies created by fire, those niches will likely be filled by invasive annual grasses. Thus, in the modern era, postfire restorationists need to be successful in reestablishing or bolstering remaining populations of perennial bunchgrasses right now if conversion to invasive annuals is to be avoided. This is a significant deviation from historical ecology and, as illustrated by rule change #2 (see above), is the equivalent of restorationists asking native perennial grasses to do something they are not evolutionarily designed to do well.

Moving forward in a new ecosystem

Hanging on to what's left

Given the difficulties associated with restoring native perennial grasses from seed, the most pragmatic approach to conserving sagebrush plant communities is to focus conservation efforts on those plant communities that are still relatively intact (i.e., "hang on to what's left," or "protect the core"). Not all sagebrush plant communities are created equal. For example, a sagebrush plant community with low resilience to fire and low resistance to annual grass invasion (collectively "R&R") is much harder to restore after fire than a plant community with high R&R.[22] This is important because sagebrush plant communities exist in fire prone environments such that burning is more of an eventuality than a probability. Thus, when an intact sagebrush community with low R&R burns, restoration of the plant community is going to be difficult at best, so the optimal management scenario is to prevent burning in the first place (i.e., "protect the core"; see Creutzberg et al.[23] and Maestas et al.,[24] this issue) and to prioritize preventative measures for low R&R plant communities.

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Keeping sagebrush plant communities from burning involves reducing fire ignition probability and fire spread. At the landscape scale, management efforts to address the occurrence of large fires have largely focused on construction of fuel breaks, which generally translates into eliminating woody fuels within strategically located linear treatments of variable width, ideally with a road running through the long axis of the treatment. These features not only help impede fire spread by reducing fuels, but, importantly, they provide locations for safely deploying firefighters and fire suppression equipment[25] (referred to as "manmade winnable ground" in Wollstein et al.[26]).

Although the efficacy of fuel breaks has been demonstrated in many case study examples, there is a strong need to manage the vast sea of fuels occurring between fuel breaks. Research shows that probability of fire ignition increases with increasing continuity and amount of herbaceous fuels.[27] Thus, livestock grazing can play an important role in reducing ignition potential and limiting initial fire spread in these areas (Davies et al.,[28] this issue). Livestock grazing also plays an indirect role in reducing the severity of fire by decreasing fuel continuity, which can lead to decreased shrub combustion.[29] Think of it this way, grasses carry fire from shrub to shrub, but combustion of calorically dense shrubs is what makes fire hot enough to kill perennial bunchgrasses. Previous research shows that up to 90% of perennial bunchgrasses killed by fire were beneath the dripline of sagebrush.[30] The lower the perennial bunchgrass mortality, the lower the odds of significant annual grass invasion post-fire. Given the near ubiquity of livestock grazing across sagebrush rangelands and its demonstrable importance in influencing both the presence of fire and fire outcomes, increased use of spatially strategic and temporally flexible grazing strategies can and should play an important role in creating fuel landscapes consistent with a diversity of management expectations.

Although fire plays an obvious and dominant role in conversion of native sagebrush plant communities to annual grass dominance, other factors favoring annual grasses, such as rising carbon dioxide and climate change, are increasing the potential for the spread of annual grasses and productivity of these species at a given location.[31] Additionally, recent research shows that over the last few decades annual grasses are moving into higher elevation sites (i.e., sites previously considered immune to invasion by annual grasses).[32] Thus, multiple lines of evidence suggest we are experiencing an increase in the potential abundance of annual grasses, over an expanding range of ecological contexts. These relationships underscore the importance of proactive management to decrease the probability of transition for existing intact native plant communities.

Fixing what's broken

Hanging on to what's left (i.e., "protecting the core") is a solid strategy because, if successful, it helps to preclude the need for more resource intensive restoration efforts (see Creutzberg et al.,[23] this issue). It is not always successful, and the magnitude of the annual grass problem has become large enough that hanging on to a functional sagebrush ecosystem at large scales will involve taking back some of what we've lost. Put another way, we've got to "grow the core." Growing the core or increasing fire resiliency through restoration of perennial vegetation is most likely to be successful on high R&R sites, where such activities should be prioritized. For nonintact plant communities (e.g., low abundance of perennial grasses) on lower R&R sites, restoration of perennials is less likely to be successful. However, managers may be able to use prefire fuels management to reduce likelihood of fire ignition and spread, which in turn could increase the odds of successful restoration of perennials on higher R&R sites within the same landscape. Thus, spatially allocating management resources within large rangeland landscapes will involve decisions that balance the likelihood of restoration success with likelihood of habitat loss in future disturbances.

Restoring perennials

Restoring sagebrush/bunchgrass plant communities is a two-part process involving getting rid of the unwanted annual grasses, followed by restoration of desired perennials. The first part is the "easy" part, and is supported by a wide variety of tools including contact herbicides, pre-emergent herbicides, and targeted grazing strategies.[2] As for the second part, success in restoring perennial grass abundance in depleted understories has generally been very low within the annual grass zone.[14] There are several factors at play here including a lack of vigor of native perennial seeds, the extreme spatial and temporal variability in abiotic factors important to seedling establishment, and a general lack of effective restoration tools for overcoming those factors.

There is some light on the horizon. First, a growing number of case studies can help understand factors leading to restoration success and our ability to share and synthesize lessons learned from those efforts is increasing (see Schroeder et al.,[33] this issue). The value of traditional experimental designs can become limited with problems as complex as restoring perennial bunchgrasses, and case studies can be an important tool for understanding both management successes and failures.[34] Second, in the last decade or so there has been a concerted research effort to determine what demographic stages are most limiting to perennial bunchgrasses and what environmental factors are killing their seedlings.[35] This led to the development of seed amendment technologies aimed at overcoming these environmental barriers.[36] Lastly, a growing awareness of the importance of seed source and planting of locally adapted varieties has shown promise for increasing restoration success of perennial grasses (see Baughman et al.,[16] this issue).

Prefire fuels modifications

Prefire fuels modifications include reducing the continuity and amount of herbaceous fuels, as described above, as well as reducing shrub abundance. The theory behind reducing (i.e., not eliminating) shrub abundance is, as previously discussed, that shrub fuels produce the prolonged high temperatures when combusted that are largely responsible for fire-associated perennial bunchgrass grass mortality. However, this is an area where nuance matters, particularly within the context of sagebrush obligate wildlife species, such as sage grouse whose habitat requirements vary both spatially and through time in accordance with life history stage.[37] Currently, research has not progressed to the point where general management recommendations on when shrub reduction is needed, or what might constitute appropriate levels of shrub reduction, are available.

Whether the focus is herbaceous or woody fuels modification, deciding when and where to conduct fuels modification treatments can be difficult in large sagebrush landscapes that vary strongly over space and through time. Recent advances in remote sensing, such as the Rangeland Analysis Platform,[38] are helping demystify that process by providing large-scale cover and biomass estimates for major plant functional groups. Additionally, new concepts, such as Potential Operational Delineations (a.k.a. "PODs", see Wollstein et al.,[26] this issue) are creating a spatial framework for fuels management decision-making in ecologically and sociologically complex rangeland landscapes.

Conclusions

As I stated at the outset of this paper, management of invasive annual grasses is truly a generational problem, and there is, and should be, significant gravity in that statement. Our current efforts to address this problem will amount to perhaps the most significant chapter to date (and let us hope, ever) in the history of management of Great Basin natural resources. Rangeland users and professionals have faced big challenges in the past, the most obvious being a simultaneous reformation of historic grazing practices, and development of science/principal-based rangeland management. These are major and historic milestones to be proud of for sure, but the invasive annual grass problem is different. The complexities of annual grass management, perennial plant restoration, and fire management are not going away and should be addressed through proactive, thoughtful, and science-based approaches to dealing with what amounts to a chronic problem for Great Basin rangelands.[34] The papers in this Special Issue discuss a variety of important aspects of such an approach, and it is our hope that they will foster ongoing and productive discussions that help us to better cope with invasive annual grasses and wildfire in the new Great Basin ecosystem.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Author is from: US Department of Agriculture, Agricultural Research Service, Burns, OR 97720, USA