Society for Range Management

RANGELAND ECOSYSTEM SERVICES:

CONNECTING NATURE AND PEOPLE

A SOCIETY FOR RANGE MANAGEMENT TASK FORCE REPORT

WILDLIFE BIODIVERSITY CARBON WATER FOOD/FIBER

EXECUTIVE SUMMARY

USDA

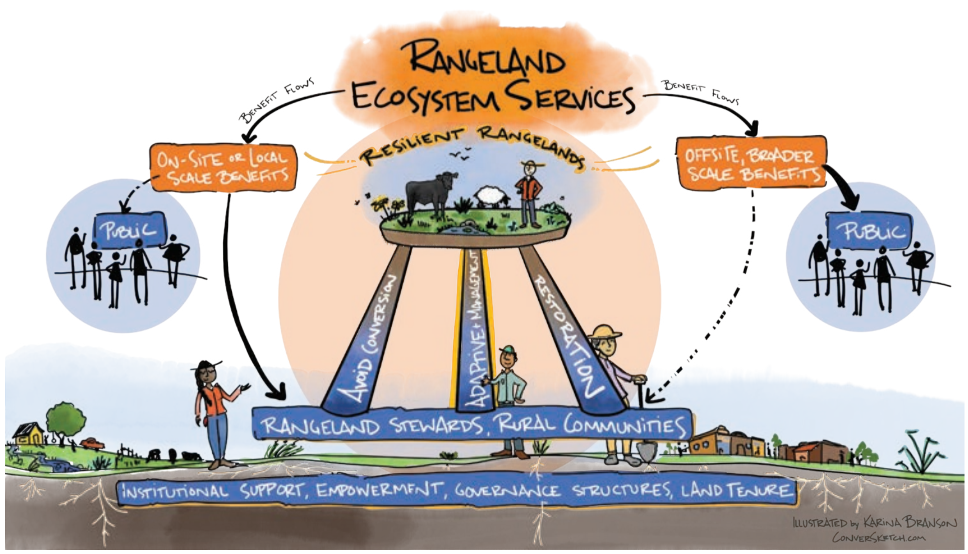
A Society for Range Management Task Force Report

Rangelands support a myriad of ecosystem services and associated benefits for human society, including food and fiber production, wildlife habitat, pollination, water infiltration, and much more.

Over the past fifteen years, the ecosystem services framework has spurred countless scholarly efforts and policy initiatives and has also been criticized. Despite its faults, the ecosystem services framework continues to provide a shared language about the flow of benefits from nature to people. Today, rangeland social-ecological systems and the ecosystem services they support are threatened by both broad-scale and fine-scale drivers, ranging from climate change and market shifts to invasive species and aging producer populations. These pressures increase the likelihood of land use change and the loss of livestock production operations, which in turn can lead to permanent losses in a wide array of ecosystem services and associated benefits provided to people by rangelands.

The Society for Range Management (SRM) works closely with rangeland stakeholders of all types and advances science and policy related to the sustainable, productive management of rangelands as complex social-ecological systems. SRM commissioned a Task Force to study the role of the Society on the topic of ecosystem services in rangelands. In this report, the Task Force seeks to: 1) outline several of the ecosystem services that we consider most central to rangelands, including who benefits from the service and what factors currently threaten the service, 2) discuss ways in which rangeland stewardship helps support the services, 3) outline current opportunities for rangeland stakeholders to gain direct benefits from actions taken to support the services, and 4) describe potential ways SRM could engage in this process. Although we included global examples and context wherever possible in this report, we emphasize that our perspectives and expertise are geographically limited. We would encourage SRM to recruit additional task forces to expand this document's geographic scope. Importantly, the role of this Task Force and its report was to collect information and outline potential roles for SRM in the conversation around ecosystem services. The Task Force does not have any role in advocating for or undertaking specific activities or policy recommendations.

Figure 1. A framework for identifying and supporting rangeland ecosystem services. The activities of rangeland stakeholders and rural communities are central to supporting resilient rangelands and associated ecosystem services. These services produce both on-site, local-scale benefits and off-site, broader-scale benefits. Linkages between on-site benefits and rangeland stakeholders are relatively well-developed (as represented by a thicker black arrow), but stakeholders generally receive little credit or compensation for creating or sustaining off-site, broader-scale benefits. This fragmented linkage is represented by the thin, broken arrow. Institutions and governance structures play a strong role in shaping the ability and willingness of rangeland stakeholders to sustain or enhance services.



In the first part of the report, we focus on five topic areas, each of which include multiple ecosystem services and associated benefits. The topic areas are food and fiber, water, carbon, biodiversity, and wildlife.

For each topic area, we describe:

01 The relevant ecosystem services and benefits, including interconnections among services.

02 Current threats to these services.

03 The ways human management and stewardship can help to enhance, sustain, or erode these services.

04 Opportunities for producers and managers to obtain material benefits from supporting the services.

We also recognize the important role of culture in defining linkages between ecosystem services and human benefits across all topic areas. In a separate section of the report, we discuss the role of culture and multiple knowledges in shaping the conversation around ecosystem services and their benefits. In this section we also discuss many of the less tangible, yet often highly meaningful, benefits associated with a healthy, productive rangeland ecosystem and associated ecosystem services. At the end of the human dimensions section, we provide multiple stakeholder perspectives on the topic of ecosystem services. Finally, we identify several potential roles for SRM in the conversation about rangeland ecosystem services. This part of the document incorporates not only our own expertise, but also insights from a broad swath of SRM membership, gathered via an in-person and a virtual Campfire Conversation during the 2022 SRM Annual Meeting.

Our compilation of the literature and of existing SRM member perspectives found that active rangeland stewardship is essential for maintaining and enhancing the ecosystem services and associated benefits provided by resilient rangeland social-ecological systems. In other words, not only do benefits flow from nature to people, but also from people to nature. At the same time, some forms of human management can lead to the degradation of rangeland ecosystem services. Sanderson et al. (2020) proposed three facets of rangeland stewardship that help support ecosystem services in rangelands: avoiding conversion, restoration of degraded lands, and adaptive management. Here, we adapt these three categories and argue that they form a "three-legged stool" supporting resilient rangeland systems, in that without attention to all three, the system cannot maintain health and function. Although the presence and actions of rangeland managers, producers, and other stakeholders are critical for supporting a broad array of rangeland ecosystem services and benefits, there are currently few opportunities or mechanisms for rangeland stakeholders to receive direct benefits for many of the services they support.

There are multiple ways that SRM can engage in the conversation around rangeland ecosystem services. Broadly, potential SRM roles include discovery, sharing, engagement, advocacy, and acting as a trusted liaison. Unlike many government agencies, SRM has the ability to advocate strongly and publicly for activities, policies and practices that benefit rangeland ecosystem services as well as rangeland stakeholders and communities. This Task Force report does not advocate for any particular action but presents various potential options and opportunities for the Society to consider.

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OBJECTIVES OF THIS REPORT

Rangelands provide many ecosystem services and associated benefits (e.g., livestock production, wildlife habitat, plant diversity, and water infiltration) which benefit society (Havstad et al., 2007). Although the presence and actions of rangeland managers, producers, and other stakeholders support many of these services, rangeland stakeholders only receive direct benefits for a small subset of services. The Society for Range Management (SRM) works closely with rangeland stakeholders of all types and advances science and policy related to the sustainable, productive management of rangelands as complex social-ecological systems. In this report, our objectives are to:

Outline several of the ecosystem services that we consider most central to rangelands, including who benefits from the service and what factors currently threaten the service.

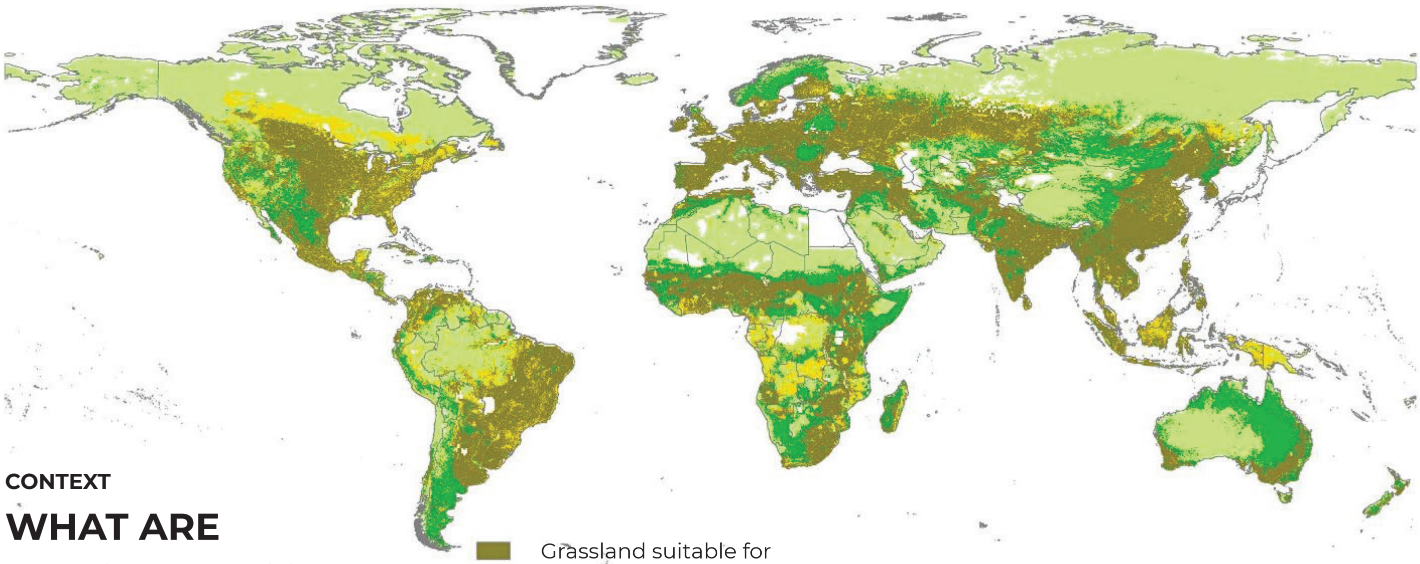
Discuss ways in which rangeland stewardship helps support the services.

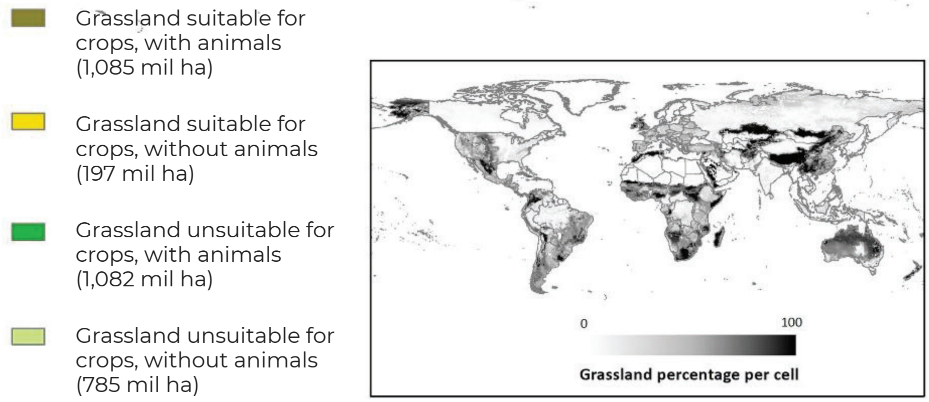
Outline current opportunities for rangeland stakeholders to gain direct benefits from actions taken to support the services.

Describe ways in which SRM could engage in this process.

Importantly, the role of this Task Force and its report was to collect information and outline potential roles for SRM in the conversation around ecosystem services. The Task Force does not have any role in advocating for or undertaking specific activities or policy recommendations.

Figure 2. Global map of rangeland/grassland production systems (from Mottet et al., 2017).
(Please note that the inset map depicts grassland extent, while the main map focuses on rangeland type.)





CONTEXT

WHAT ARE RANGELANDS?

Rangelands are lands on which the indigenous vegetation is predominantly grasses, grass like plants, forbs or shrubs and are managed as natural ecosystems. If plants are introduced, they are managed similarly. These lands include natural grasslands, savannas, shrublands, many deserts, tundra, alpine communities, marshes and meadows. Rangelands cover about 50% of the earth's land surface (Holechek et al., 2011) and provide 70% of the forage for ruminant livestock (Holechek, 2013). Livestock production systems using global rangelands provide the ability for humans to effectively harvest animal protein and fiber from plants. Rangelands occur on six of the seven continents (Antarctica is the exception) and are highly diverse, ranging from low-input, pastoral production systems on communally owned lands to highly intensive production systems on private land (Mottet et al., 2017, **Figure 2**). Domesticated livestock grazing often occurs on lands which are ill suited for crop production, but some rangelands occur in mesic areas where the majority of land has already been converted to cropland or other uses. In North America, for example, 40% of the Great Plains have been converted to row crop agriculture (Augustine et al., 2017), and the pace of cropland conversion continues to be high (Wright and Wimberly, 2013; Gage et al., 2016). Cropland conversion has led to widespread fragmentation of remnant rangelands in this ecoregion (**Figure 3**), and this fragmentation has associated environmental costs, such as steep declines in grassland bird populations (Herkert, 1994; With et al., 2008; Rosenberg et al., 2019).

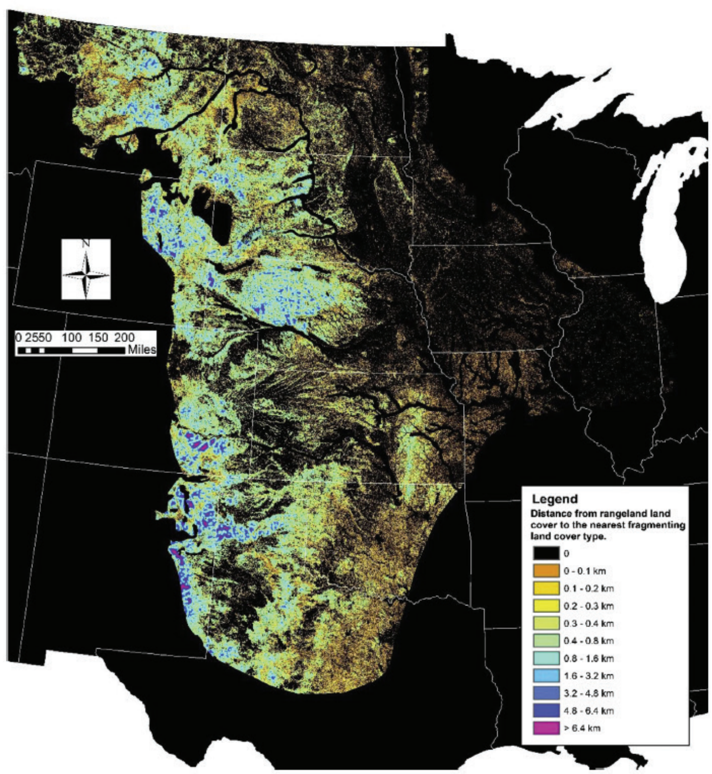


Figure 3. Fragmentation of rangelands in the North American Great Plains (from Augustine et al., 2020).

Across the globe and for thousands of years, humans have interacted in complex, intricate, and dynamic ways with natural processes in rangelands; this is also called a social-ecological system, or a complex adaptive system. Indigenous peoples have long had management and stewardship relationships with rangelands and native large herbivores, such as bison in the North American Great Plains and reindeer in the Sápmi region of northern Europe. Today, people who identify as rangeland stakeholders include not only Indigenous peoples, but also ranchers, pastoralists, other livestock producers, public land and natural resource managers, nongovernmental organizations working in rangelands, local government groups (e.g., conservation districts, weed and pest groups), and more. Management of rangelands presents many challenges because 1) they are frequently managed for multiple objectives and 2) they are biophysically complex, and exhibit high levels of variation in topography, soils, plant communities, and annual and seasonal patterns of precipitation and temperature (Boyd and Svejcar, 2009). Inherent complexity and high rates of variability make planning and prediction difficult for rangeland managers and stewards.

USDA

All of these pressures are increasing the likelihood of land use changes as policies and markets shift and traditional operations are lost.

The loss of producers generally leads to land conversion and fragmentation, which in turn leads to permanent losses in a wide array of ecosystem services and associated benefits provided to people by rangelands. Conserving sustainable ranching as a land use means conserving ranching ways of life and cultures, supporting rural resource-dependent communities and livelihoods, and promoting the management and stewardship of large tracts of land with considerable environmental value and habitat for iconic species, such as the Greater Sage-Grouse in the western United States (U.S.). Here, we argue that the concept of ecosystem services may provide an avenue for:

A better understanding of the benefits created by rangeland systems

Enhancing those benefits

Helping to avoid the loss and degradation of rangeland ecosystems

PRESSURES ON RANGELAND PERSISTENCE AND HEALTH

Rangeland social-ecological systems are experiencing increasing pressures from both broad-scale and fine-scale drivers. At broad scales, the ecological health and persistence of rangelands are currently threatened by climate change, invasive species, woody expansion, altered fire regimes, and land use conversion (for example, to residential developments or croplands). Climate change can negatively affect rangelands and rangeland livelihoods in multiple ways, including amplifying precipitation variability, increasing the likelihood of extreme events (e.g., floods and droughts), reducing soil moisture, increasing wildfire frequency, severity and extent, increasing the abundance of undesirable species (including both woody encroachment and invasive species), increasing heat stress, and affecting livestock disease dynamics, though we note that some rangelands may benefit from climatic shifts in the future (Reidmiller et al., 2018). Invasive species and woody encroachment can increase management costs and reduce the productivity and stability of desired plant communities on both public and private rangelands.

Rangeland livelihoods depend on rangeland health and are also vulnerable to societal perceptions, price cycles, scarcity of inputs during drought and/or large wildfire events, and the value of land for other uses (e.g., crop production, or residential development driven by population growth). Sayre et al. (2013) outlines political and economic dimensions of rangeland stewardship. Political dimensions include land tenure or access insecurity, and the degree of democratic representation, transparency and accountability in rangeland governance. Tenure or governance insecurities shape how social and cultural aspects of rangelands can be destroyed, stolen, monetized, commodified, appropriated, or traded in various ways along with rangeland resources, and are particularly reliant on the legal access of rangeland residents, stewards, and users to rangelands. Economic dimensions of rangeland stewardship include livestock production changes and challenges, and land use conversion pressure.

These and other broad-scale threats interact with finer-scale ecological and social changes that also threaten ecological, cultural, and social aspects of rangelands. In the western U.S., legacies of historically high stocking rates, fire suppression, energy development, and other post-European settlement human activities have contributed to reduced productivity and function across many rangelands. Many areas are in need of regeneration. In some places, current rangeland management practices (including the absence of management) continue to drive degradation of natural resources. These practices are often motivated by financial necessity due to episodes of very low profit margins on private lands or result from the lack of adequate staffing and resources on public lands. Finally, many rangelands have aging producer populations and limited opportunities for succession of the land or business operation to future generations. For example, lack of recruitment of young people into rangeland livelihoods, often exacerbated by economic conditions in ranching or limited amenities, economic opportunities or cultural wellbeing in rural areas, is identified by ranchers as a major threat to the future of ranching and related rangelands (Mundon-Dixon et al., 2018).

RANGELAND ECOSYSTEM SERVICES

What are rangeland ecosystem services?

Rangelands benefit people in many different ways. These benefits are generated by a subset of ecological processes known as ecosystem services. In 2005, the Millennium Ecosystem Assessment (MEA) introduced the concept of ecosystem services for communicating a global assessment of life on Earth (Millennium Ecosystem Assessment, 2005). The idea that Earth's resources are finite and rapidly degrading, and diminishing was not new, but because such a large proportion of humans and global centers of power live in places relatively disconnected from nature, not enough was being done. More clear, urgent, and targeted individual, community, and governmental action would be needed. Ecosystem services are foundationally defined as "benefits people obtain from ecosystems" (Millennium Ecosystem Assessment, 2005). More recently, another international group, the International Platform on Biodiversity and Ecosystem Services (IPBES) modified and expounded upon the MEA to pervasively integrate the role of culture and social values, replacing the ecosystem services term with Nature's Contributions to People (NCP) (Díaz et al., 2015). The NCP framework moves beyond traditional conceptualizations of ecosystem services and recognizes that contributions can be both positive and negative, and whether a given contribution is considered positive or negative may depend on cultural, economic, spatial, or temporal context (Díaz et al., 2018).

Over the past fifteen years, the ecosystem services concept has spurred countless research and scholarly efforts, policy initiatives, educational programs, and has also been heavily criticized (Carpenter et al., 2009; Chan et al., 2012; Díaz et al., 2018; Jacobs et al., 2016; Kremen, 2005; Pascual et al., 2017; Peterson et al., 2018). The utility of the concept is that it makes direct linkages between ecology and society. It directly addresses human beings' relationship with nature and demystifies the idea that human action is directly tied to the state of the environment. In his preface to a special journal issue, Richard Knight asserted that the ecosystem services concept captures the "dynamic interplay of an expanding human population and rising standards of living on a finite planet in which land and waters continue to degrade" (Knight et al., 2011).

REPORT FOCUS TOPICS

In the first part of this report, we focus on five topic areas: food and fiber, water, carbon, biodiversity, and wildlife. We then address human well-being as a sixth topic area that crosscuts all the others. Each topic area includes multiple ecosystem services and associated benefits. For each topic area, we address four central themes.

FIRST THEME
The relevant ecosystem services and benefits, including interconnections among services.

SECOND THEME
Current threats to these services.

THIRD THEME
The ways human management and stewardship can help to enhance, sustain, or erode these services.

FOURTH THEME
Opportunities for producers and managers to obtain material benefits from supporting the services.

BIODIVERSITY

Medicinal, ceremonial, and cultural products
Income, consumer surplus

Genetic variation, native plant, seed production
Income, intellectual property

Pollination
Income, consumer surplus

WATER

Erosion reduction
Surface water quality improvement

Water infiltration
Reduced irrigation costs, forage production, drinking water

Water storage
Flood damage attenuation

FOOD/FIBER

Food (livestock)
Income, sustenance, cultural identity

Fiber (hay/forage)
Income, clothing, cultural identity

WILDLIFE

Wildlife habitat provision
Outdoor recreation

CARBON — Topic Area

Carbon storage and sequestration — Ecosystem Service

Climate change mitigation — Topic Benefit Example

The concept has also developed concrete terminology to describe, categorize, and quantify the benefits humans derive from nature in order to include their value in policy and decision-making. A downside to this is that it shifts the nature-human relationship to an anthropogenic one, and there has been considerable debate around this issue (Hermelingmeier & Nicholas, 2017). Regardless, the ecosystem services concept continues to provide a shared language about the flow of values from nature to people. Society cannot be forced into biospheric altruism, so ecosystem services capitalize on self-interest as an aspect of human nature to shift and encourage a conservationist/stewardship rationale (Fisher, 2015).

We recognize that the terminology around ecosystem services is potentially divisive. Strict use of one framework or another (MEA or NCP) risks polarization of an interdisciplinary scientific community, instead of bridging knowledge and synthesis (Peterson, 2018). Therefore, we take a holistic approach to the idea of rangeland ecosystem services, recognizing the intricate connections among, and context-dependence of, services provided by rangelands. Some contributions can be both positive and negative at the same time (for example, carnivores may both control wild ungulate populations and threaten livestock populations). Moreover, while a service generates benefits in its own right, it can also affect other services positively or negatively, with implications for those associated benefits. Relatedly, management scenarios affect the provision of services to varying degrees. Thus, any change in management can negatively or positively affect one or more services. These dynamics among ecosystem services, especially in regards to the management of them, are often referred to as tradeoffs and synergies (Bennett et al., 2009).

The NCP framework (Diaz et al., 2018) also centers the role of culture in defining all links between people and nature and focuses on the need to include Indigenous and Traditional Ecological Knowledge and local knowledge in understanding nature's contributions to people. In line with these ideas, we recognize the important role of culture in defining linkages between ecosystem services and human benefits across all topic areas. Our discussion of benefits in the topic areas above is based on our specific worldviews and perspectives. In a dedicated section ("Human Well-being and Human Dimensions of Ecosystem Services"), we further discuss the role of culture and multiple knowledges in shaping the conversation around ecosystem services and their benefits. In this section we also discuss many of the less tangible, yet often highly meaningful, benefits associated with a healthy, productive ecosystem and associated ecosystem services. These benefits relate to the satisfaction of knowing that an ecosystem exists, as well as the relevance of the ecosystem to identity and culture. Unlike food production or even outdoor recreation, such benefits are not readily revealed by market interactions. Moreover, they may accrue for individuals who never directly interact with and are distant from rangelands. For example, food and fiber services provide not only material benefits (e.g. meat, wool), but also cultural and identity benefits for producers who identify with animal stewardship and food production.

Jeff Goodwin, Texas A&M Natural Resources Institute

A FRAMEWORK FOR RANGELAND ECOSYSTEM SERVICES

The central role of rangeland stewardship

Humans play a management and governance role in virtually all of the world's rangelands. It is important to recognize that management and governance structures operate even in areas set aside as "protected" or "un-managed". Here, we argue that active rangeland stewardship is often essential for maintaining and enhancing the ecosystem services provided by resilient rangeland social-ecological systems. In other words, not only do benefits flow from nature to people, but also from people to nature (Diaz et al., 2018). At the same time, some forms of human management can lead to the degradation of rangeland ecosystem services. Sanderson et al. (2020) proposed three facets of rangeland stewardship that help support ecosystem services in rangelands: avoiding conversion, restoration of degraded lands, and adaptive management. Here, we adapt these three categories and argue that they form a "three-legged stool" supporting resilient rangeland systems, in that without attention to all three, the system cannot maintain healthy functioning (See **Three Stewardship Pillars** box and **Figure 4**). For each topic area in this report, we focus on how producers and other rangeland stakeholders can and do apply these three pillars to maintain or enhance ecosystem services and their benefits in rangelands. We focus especially on the central pillar, Adaptive+ Management, which encompasses a large portion of the day-to-day decision-making and activities undertaken by rangeland managers.

Governance and institutions

Although we focus on the role of individual rangeland stakeholders in this report, we recognize that governance, institutions, markets, and policy structures can also play a critical role in how rangeland stewardship operates. In order for stewardship to operate effectively, institutional structures need to be in place that empower and support rangeland stewardship. For example, rangeland stewardship and, by extension, rangeland ecosystem services can be threatened in situations where modern institutions do not account for the value of local knowledge and practices, such as the sedentarization of traditionally mobile pastoralists.

Who benefits?

Ecosystem services produce both local and public benefits. For example, a rangeland system supporting higher water infiltration will often have less erosion and produce more herbaceous plant material. This outcome results in direct, on-site benefits to producers

Table 2. Hypothesized relationships between ecosystem services, rangeland stewardship, and net benefits

	Costs Incurred		Net Benefits Received		
	General Public	**Rangeland Steward**	**Rangeland Steward**	**Rangeland Steward**	**General Public**
Topic area in this report	Level of support for on-site services	Level of support for on-site services	Level of direct on-site monetary benefits from services	Level of indirect on-site benefits from services	Level of benefit from services
Food/fiber	HIGH	HIGH	HIGH	HIGH	HIGH
Water	LOW	HIGH	LOW	MODERATE	HIGH
Carbon	LOW	HIGH	LOW	MODERATE	HIGH
Biodiversity	LOW	HIGH	LOW	MODERATE	HIGH
Wildlife	MODERATE	HIGH	MODERATE	MODERATE	HIGH
Human Well-being	LOW	HIGH	MODERATE	HIGH	HIGH

such as enhanced forage availability and quality for livestock. However, water infiltration on rangelands also produces off-site, broader-scale benefits for the public, for example by reducing flood and erosion risk in downstream areas. Although the actions of rangeland stakeholders can have direct effects (both positive and negative) on a wide array of ecosystem services, stakeholders are not well-compensated for many of the ecosystem service benefits that can accrue to the general public (**Table 2**). A primary ecosystem service and objective of government-owned rangeland management is public recreation. Here the question of "who benefits?" is directly linked to "who has access?" or "who has the opportunity?" These questions quickly enter the realms of equity and environmental justice, and illustrate the infusion of societal values, structures, and barriers that complicate ecosystem services management on rangelands (Buchel & Frantzeskaki, 2015). The situation of who benefits can also get complicated in situations where rangeland stakeholders take actions that affect ecosystem service outcomes on lands that they do not own (for example, conservation NGOs doing projects on public or private lands, or ranchers leasing public lands for grazing). Therefore, management decisions are not only about ecological tradeoffs, but tradeoffs of who benefits from ecosystem services or not (Winkler & Nicholas, 2016). In this report we draw attention to several questions with respect to ecosystem services in rangelands: Who benefits from them? Who does the work to maintain them? Who pays for them? Who "gets the credit" for beneficial stewardship actions performed?

Opportunities to better link ecosystem service benefits with rangeland stewardship activities

As we have summarized above, many factors have led to and continue to increase the likelihood of rangeland conversion, fragmentation, and degradation, and subsequent losses in ecosystem services. Not least of these is the fact that it is increasingly difficult for rangeland producers to maintain viable livelihoods. If enhancing or maintaining ecosystem services requires additional resources on the part of producers and managers, it may be difficult to accomplish these tasks in the face of resource scarcity. To combat this trend, SRM and other organizations concerned with rangeland health and ranching livelihoods can potentially increase producer benefits by finding ways to highlight and advocate for stewardship activities, such as adaptive management and restoration. Additionally, they can potentially cultivate and advocate for opportunities for producers and managers to benefit from rangeland stewardship in other ways. An ecosystem services framework can help elucidate and organize these other sources of income and wellbeing.

We provide thoughts on opportunities for rangeland stakeholders to derive additional benefits from ecosystem service provision within each topic area, but more broadly, examples may include government incentives or cost-share opportunities, ecosystem service markets, and more. For example, the emergence of markets that have the potential to expand the application of conservation across rangeland ecosystems may bolster the production of ecosystem services for land stewards and society alike. We recognize that ecosystem services are context-specific, and the potential for improvement in ecosystem services therefore differs based on context (e.g., spatial, temporal, economic, etc.).

Economic value assessment of ecosystem services elucidates our understanding of the economic drivers of ecosystem use, the relative effects of alternative actions, raising awareness and interest, analyzing policy, engaging in land use planning, and understanding our common assets (Costanza et al., 2014; Millennium Ecosystem Assessment, 2005). Ideally, ecosystem service markets and other mechanisms that seek to reward or incentivize rangeland stakeholders for management decisions that enhance ecosystem service benefits would be driven by a net benefit calculus (Olander et al., 2018), i.e., what action has the largest positive effect on human well-being. However, the degree to which individuals benefit from services is predicated on their knowledge and preferences, which are influenced by culture and value systems. As a result, benefit estimation for decision making can pose a significant challenge. A reasonable alternative is to measure changes in ecosystem service provision, which can be measured in the field, irrespective of beneficiary populations. Thus, like goods and services more generally, an ecosystem service can be more easily monetized if it is amenable to quantification.

Payments for ecosystems services (PES) has been the most widely applied approach to enhance ecosystem service management through monetization. The international stage for PES program case studies continues to expand, and is not without debate (Chan et al., 2017; Cleveland et al., 2006; Garbach et al., 2012). Monetization is just one of the many tools available to us to better incorporate what humans value into our decision-making as a society. Attaching economic value to ecosystem services potentially shifts the nature-human relationship to a strongly anthropogenic one (Hermelingmeier & Nicholas, 2017), and the idea of commodifying nature is wrought with moral and ethical dilemmas. The commodification of nature also conflicts with certain cultural worldviews.

On the other hand, some argue that without quantitative investigation of ecosystem service value, we frequently assign low or zero value and correspondingly low policy or decision-making priority to many services despite their high value to society (Costanza, 1997). This tendency can also result in undervaluing the work done by people who protect and enhance these services.

In light of the fact that monetizing benefits generated by ecosystem services often presents a challenge (Olander et al., 2018), one promising set of metrics used to measure changes in ecosystem service provision includes the use of indicators (Fox et al., 2009; Olander et al., 2018; Ojima et al., 2020; Ahlering et al., 2021). For example, grassland bird occupancy or abundance data (associated with the wildlife habitat service) might be used to reflect the marginal effect that an intact and healthy tract of rangeland has on non-consumptive outdoor recreation, existence values, and biodiversity goals. Use of the ecosystem service framework, incentive programs, and relevant indicators can inform and can lead to adjustments in management and stewardship activities in order to support, sustain, or enhance this larger set of ecosystem services. Here, we highlight several important rangeland ecosystem services and the role of people in supporting them.

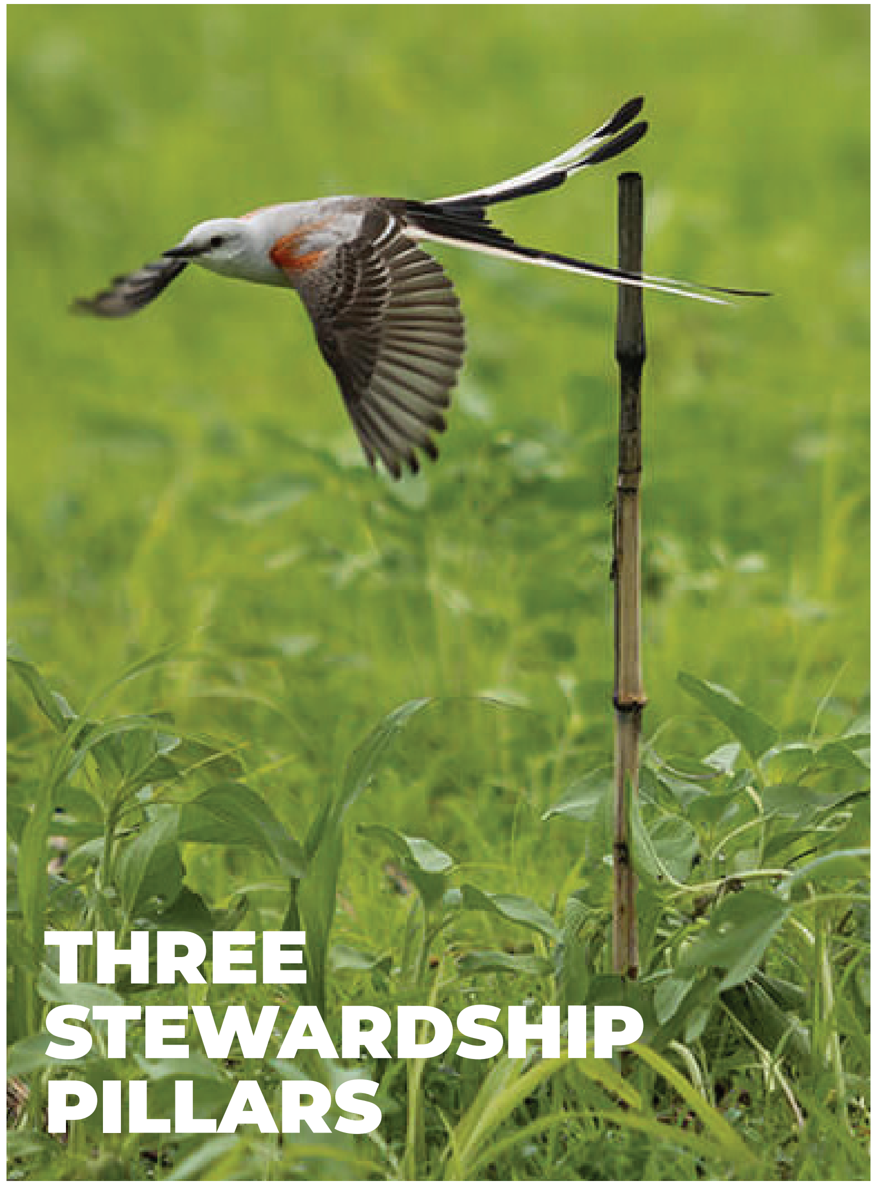
SCOPE

GEOGRAPHIC.

We are a group of natural resource managers and scientists who have worked mostly in North American rangelands located in the United States. Although we included global examples and context wherever possible in this report, we emphasize that our perspectives and expertise are geographically limited. Many of our examples are from the United States, where we have the most knowledge. Our comments on opportunities for producers to benefit from ecosystem services are especially limited, as we know little about ecosystem service markets or opportunities in other countries and regions. We would encourage SRM to recruit additional task force(s) to expand this document's geographic scope.

CONTENT:

The list of ecosystem services provided by rangelands is long. Many other documents have worked to synthesize this topic, and various different groupings of services have been presented. Here, we have not attempted to catalog and describe every possible service provided by rangelands. Rather, we have limited our remarks to topic areas that were most central to the objectives of this report. Moreover, rather than recreating the work others have done to evaluate and value these different services, we provide a high level overview and then direct readers to other resources where they can find additional information.



THREE STEWARDSHIP PILLARS

Rob Mattson, Noble Research Institute

Avoiding Conversion

Conversion refers to activities leading to losses of ecosystem services that are permanent or costly to reverse, and usually includes crossing biotic or abiotic thresholds. Over the last century rangelands have declined worldwide mostly because of conversion to croplands (Bengtsson et al., 2019), but urbanization, severe and intense wildfires or megafires, invasive species, and climate change also contribute to the loss or conversion from rangelands (Samson et al., 2004; Foley et al., 2005; Briske, 2017). Conversion is still occurring at rapid rates in many rangelands (e.g., https://www.worldwildlife.org/projects/plowprint-report). Conversion from "healthy" rangelands to urban areas, row crop agriculture, annual grasslands, or woody encroachment are detrimental to ecosystem services because of the removal or change in dominance of the native plants. These conversions lead to less resilient rangeland ecosystems that are unable to respond to erosion, drought, disease or insect outbreaks, and fire.

There is a need more than ever to restore rangelands because of the multitude of pressures on rangeland persistence and health.

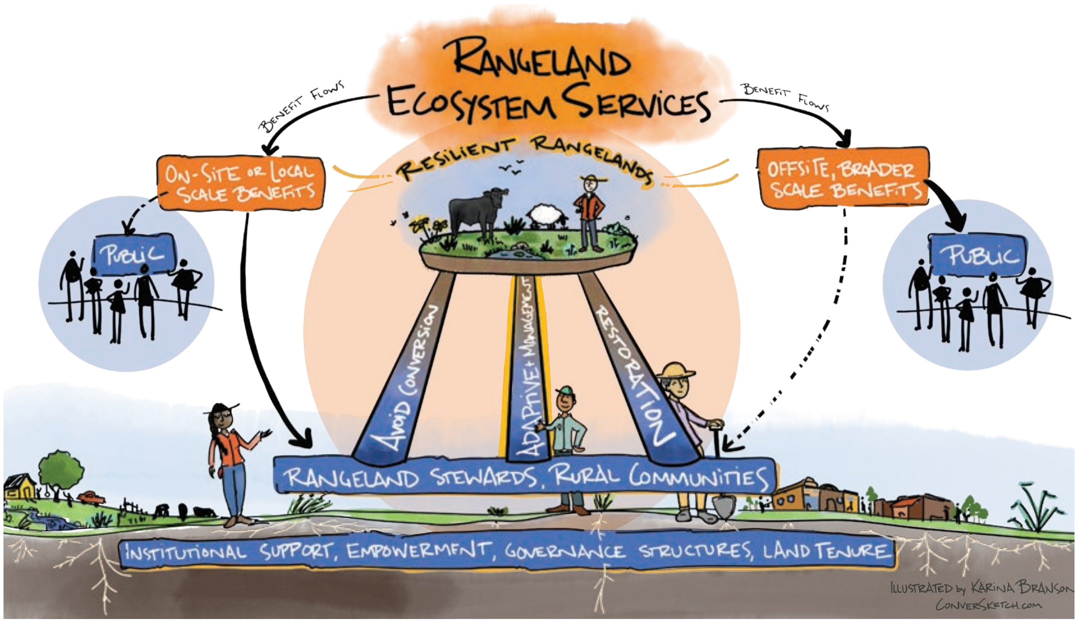


Figure 4. A framework for identifying and supporting rangeland ecosystem services. The activities of rangeland stakeholders and rural communities are central to supporting resilient rangelands and associated ecosystem services. These services produce both on-site, local-scale benefits and off-site, broader-scale (public) benefits. Linkages between on-site benefits and rangeland stakeholders are relatively well-developed (as represented by a thicker black arrow), but stakeholders generally receive little credit or compensation for creating or sustaining off-site, broader-scale benefits. This fragmented linkage is represented by the thin, broken arrow. Institutions and governance structures play a strong role in shaping the ability and willingness of rangeland stakeholders to sustain or enhance services.

Restoration

There is a need more than ever to restore rangelands because of the multitude of pressures on rangeland persistence and health. Rangeland restoration has not had high success rates at the landscape scale under current restoration methods, and restoration efforts may become increasingly difficult in a changing climate (Shriver et al., 2018). Rangeland restoration projects that focus on the regeneration of compromised ecosystem processes (for example, energy flow, water cycle, nutrient cycle, community dynamics) and addressing the root cause of degradation should be prioritized. However, new methods and technologies along with increased native seed sources are starting to show potential for improving restoration success. In addition, it is necessary to understand that restoration takes multiple years if not decades and requires a multi-year approach of restorative activities for rangelands to return to a functioning state.

Adaptive, Context-Specific, Inclusive, Outcome-based (Adaptive+) Management:

A critical pillar of our stewardship stool is a concept we are calling Adaptive+ Management. We believe this type of management will be integral to the sustainability of resilient rangelands and the ecosystem services they provide. Many rangeland producers and managers make daily management decisions about grazing, and rangeland stakeholders also commonly work to manage fire, invasive species, wildlife habitat, and other aspects of rangelands that are directly related to ecosystem services. Livestock grazing management involves complex interactions among livestock, rangeland ecosystems and humans resulting in an infinite number of potential outcomes. In other words, the effects of grazing are many and varied and cannot be effectively considered by oversimplified approaches that consider only grazed versus ungrazed conditions (Davies and Boyd, 2020; Meiman et al., 2016). How livestock grazing is managed is far more important than whether or not an area is being, or has been, grazed by livestock. That said, there is broad consensus that careful consideration of both overall stocking rate and rest periods are central to grazing management approaches that support a broad array of ecosystem services. For the purposes of this report, Adaptive+ Management includes:

ADAPTIVE

Adaptive management involves strategic planning and goal setting, monitoring, and frequent evaluation of management success in which managers learn from previous actions and make adjustments when needed (Holling, 1978; Wang et al., 2020). Adaptive management is more transparent and defensible when it includes clear objectives linked to processes, well-defined monitoring thresholds, and objective actions triggered by these monitoring thresholds (Fischman & Ruhl, 2015). Here we emphasize the importance of learning as a key component of the adaptive management process (e.g., Fernandez-Gimenez et al., 2019).

CONTEXT-SPECIFIC

Rangelands are wildly variable, and we recognize that there is no silver bullet when it comes to management strategies that will sustain or enhance desired ecosystem services. Management activities need to be tailored to social-ecological contexts. For example, reducing grazing intensity can reduce plant invasion in some ecosystems, but increase invasion in other systems. For a given context, we need an understanding of how management actions relate to desired ecological or social outcomes. However, we should not assume that what works in one context will also work in other contexts.

INCLUSIVE

Here we emphasize the importance of including local knowledge, indigenous knowledge, and other diverse perspectives and knowledges when designing management actions and evaluating outcomes. Collaborative adaptive management (Innes & Booher, 2010; Caves et al., 2013) is one example of this type of approach.

OUTCOME-BASED

Although goal-setting is an implicit part of adaptive management, here we emphasize the importance of managing with desired outcomes in mind. This type of management centers goals, objectives, and monitoring as key elements of the process, and holds managers accountable for not only applying practices, but achieving the desired outcomes (Perryman et al., 2021, Derner et al., 2022).

KEY RANGELAND SERVICE TOPIC AREAS

In the following five sections, we consider topic areas that encompass many (but not all) rangeland ecosystem services, threats specific to these topic areas, the role of rangeland stewardship within each area, and potential opportunities for rangeland producers and managers to derive benefits from ecosystem services in each topic area. Topic areas include: food and fiber, water, carbon, biodiversity, and wildlife. Following these sections, we address a sixth crosscutting topic: Human Well-being and Human Dimensions of Ecosystem Services.

FOOD AND FIBER

What are the services and benefits?

Rangelands produce a renewable dietary source of forage (cellulose) in biomass from a diverse set of grasses, forbs, and woody plants. This cellulose is uniquely converted by ruminant livestock into animal protein and fiber production (e.g., wool, mohair) for human consumption. Ruminant livestock (cattle, bison, sheep, and goats), by hosting specialized microbes in their digestive system, serve as energy brokers between cellulose in plant biomass and animal protein and fiber production (Derner et al., 2017). Livestock and fiber production from rangelands is a provisioning service that can have economic and/or subsistence value (Sayre et al., 2013; Lindstater et al., 2016; Lind et al., 2020) for individuals and local communities (Havstad et al., 2007). For example, 31.3 million beef cows on 729,000 operations contribute to the $77 billion annual sales for the U.S. beef cattle industry (USDA-NASS, 2019, 2020). Sustainably increasing global animal protein and fiber production for human consumption is needed as global human populations increase (Greenwood, 2021). Climate projections for dryland environments are estimating increased frequency of extreme events (e.g., deluges, droughts) with some of these geographic areas currently experiencing significant population growth (Ruppert et al., 2015). Thus, there is a need to understand the threats to the conservation of rangelands and pastures as sustainable producers of critical ecosystem services, including livestock production.

Effects of rangeland stewardship on the service

AVOID CONVERSION

Land use changes from rangeland to other uses (e.g., cropland, urban development) markedly alter the food and fiber from rangelands (Holechek et al., 2020; Lark, 2020). Keeping rangelands intact is the primary action to providing food and fiber from rangelands (Lark, 2020), as well as for conservation such as

OPPORTUNITIES

Relative to other ecosystem services, opportunities for producers and managers to benefit from food and fiber production are already widely available in developed markets for many countries due to existing livestock markets, including local, national, and international trade. While supported to some degree through private or government conservation programs, the current and potential land-stewardship ecosystem services co-benefits provided by ranching operations to society may not be adequately recognized and supported relative to the societal value this stewardship provides.

Jeff Goodwin, Texas A&M Natural Resources Institute maximizing soil carbon stocks that could be lost when converted to other uses (Sanderson et al., 2020). Large spatial extents of rangeland with associated natural disturbances are needed for biodiversity conservation in rangeland landscapes rather than pastures/paddocks (Augustine et al., 2021).

RESTORATION

Rangeland restoration efforts need to be explicitly linked to ecological outcomes (e.g., structure, function, and productivity) to enhance food and fiber production (Brown & MacLeod, 2018). Precision restoration efforts can target critical abiotic and biotic barriers to restoration success, and specific tools, methods, and practices can be applied in a targeted manner in a site-based construct rather than ubiquitous landscape level efforts (Copeland et al., 2021). Augustine et al. (2021) highlights the critical contributions of restoration of Conservation Reserve Program (CRP) lands to the production and conservation of the Great Plains. They outline opportunities to spatially prioritize restoration efforts and the recoupling of fire and grazing for livestock grazing and conservation.

ADAPTIVE+ MANAGEMENT

To accomplish sustainably increasing global animal protein and fiber production for human consumption, land managers of rangeland ecosystems can use adaptive grazing management (Derner & Augustine, 2016). One key adaptive approach is flexible stocking (Torrell et al., 2010), which can improve economic returns in response to a changing climate by capturing forage during wet periods, while also reducing negative environmental outcomes associated with high stocking rates during dry periods and drought. Another adaptive management approach involves incorporation of knowledge about large-scale and local climatic controls on forage (Chen et al., 2017; Hartman et al., 2020) and livestock (Raynor et al., 2020; Derner et al., 2020) production. Inclusion of climate information and regional forecasts can support science-informed adaptive decision-making to better balance forage demand with available forage. This can increase efficiency of livestock weight gain on rangelands and may provide additional economic benefits for production enterprises. In addition, concurrent reductions can occur in the negative environmental outcomes associated with excessively high stocking rates during dry periods and drought. Moreover, adaptive grazing management can capture additional livestock gain during wet periods, potentially increasing net economic returns to production enterprises, although institutional structures and/or environmental factors may constrain this opportunity. However, due to investment costs, knowledge gaps, the time it may take for forage benefits to be realized, and the time value of money, financial support may be required for producers to at least break even when investing in practices and technology that enhance conservation (Dyer et al., 2021), including adaptive management. With this support in mind, adaptive management has the potential to support the sustainable management of forage production, fiber production and livestock production, in addition to a suite of other ecosystem services on rangelands around the world.

Livestock can be managed as tools to sustain or enhance other ecosystem services, while providing food and fiber.

In more mesic environments, integrated livestock-crop forage systems represent another innovative management strategy that can be used to improve feed efficiency, consume crop residues and cover crops, and increase rates of nutrient cycling. Integrated livestock-crop production systems can also reduce enterprise risk, restore degraded land, increase productivity, diversify production, and enhance resiliency of the land (Palmer, 2014; Smart et al., 2021). In addition, by integrating livestock with crops as well as with forests, manure from livestock can be used as fertilizer to improve soil nutrient status and soil organic matter (Sulc & Franzluebbers, 2014; Smart et al., 2021).

Finally, livestock can also be managed as tools to sustain or enhance other ecosystem services, while simultaneously providing food and fiber production. Conceptual advances in livestock production systems have expanded the utility of livestock in conservation-oriented approaches that include (1) efforts to "engineer ecosystems" by altering vegetation structure for increased habitat and species diversity, and structural heterogeneity (Derner et al., 2009); (2) use of targeted grazing to reduce invasive species abundance, and to reduce fuels and associated wildfires (Bailey et al., 2019); and (3) improvement of the distribution of livestock grazing across the landscape (Raynor et al., 2021).

THREATS

Climatic variability is an area of considerable concern for rangelands (Polley et al., 2013), including forage (Petrie et al., 2018; Reeves et al., 2021) and livestock production (Derner et al., 2018; Klemm et al., 2020), and profitability (O'Reagain et al., 2011) as well as the influence of increasing atmospheric carbon dioxide (CO_2) on forage quality (Augustine et al., 2018). A high degree of climatic variability is a key feature of arid and semiarid rangelands worldwide, and droughts are a major cause of land degradation and economic loss (Coppock, 2011). But this climatic variability as well as the severity and frequency of extreme disturbance events (e.g., droughts) are expected to increase in many areas around the globe and negatively affect livelihoods (Goode et al., 2020). Preparedness of land managers, including livestock producers, for such events and their adaptive responses are crucial to minimizing financial losses and negative effects on rangeland resources (Kachergis et al., 2014; Espeland et al., 2020).

Changing climate and legacy effects can alter species composition on rangelands with two primary concerns to date: 1) continuing encroachment of woody species into rangelands in many areas of the world (Estell et al., 2012), and 2) increasing invasive plants (e.g., non-native annual grasses like cheatgrass) that alter phenology of the plant community, forage quality and quantity, fire regimes (frequency and severity), and fire extent (Brooks et al., 2004; Chambers et al., 2014; Williamson et al., 2020). These structural and functional changes to plant communities can affect forage production, fiber production, and livestock production from rangelands around the world, as well as other ecosystem services.

Additional threats include global population growth increasing pressure on land resources and environmental quality (Greenwood, 2021), changing consumer preferences including a desire for higher quality beef (Felderhoff et al., 2020), land ownership patterns and institutional changes that affect conservation and management (Robinson et al., 2019; Swette & Lambin, 2021), investments in ranch properties by amenity buyers (Gosnell & Travis, 2005; Epstein et al., 2021), tracking ranch-level sustainability in the beef industry (Ahlering et al., 2021), and structural aspects of the beef supply chain in a post-pandemic world (Peel, 2021).

Anna Kuhne

WATER AS AN ECOSYSTEM DRIVER IN RANGELANDS

What are the services and benefits?

As the dominant land cover type on earth, rangelands account for over half of the land surface area, and the vast majority of these areas occur in water-limited environments (Millennium Ecosystem Assessment, 2005). So, water scarcity is the norm for rangelands, the plants and animals they support and the humans who work and live in these ecosystems. The scarcity of water in rangeland systems emphasizes its importance. In fact, rangeland managers often strive to capture every raindrop where it falls, maximizing the amount of water that is available to plants and minimizing the amount that runs off of the soil surface. Maximizing the amount of water available to plants supports many different ecosystem services and benefits on rangelands because so many are closely linked to vegetation (e.g., forage for both wild and domestic herbivores, habitat for a wide range of animals, biodiversity, carbon dynamics/sequestration, and nutrient cycling; see other Topic Areas in this report). Some have even stated that water is the ecosystem service that underpins all other ecosystem services (Cotes et al., 2013). Even if "all" is too strong of a word, most would probably agree that water availability is necessary to support the vast majority of ecosystem services on rangelands.

Even though water is scarce on many arid and semi-arid rangelands, the supply and storage of clean water is a fundamental ecosystem service provided by these lands.

Warming temperature will increase evaporative demand, accelerating the loss of water from soils and surface waters through higher evaporation and transpiration.

It is also important to recognize that some rangelands occur in wetter, cooler regions or have soil and geologic characteristics that increase the ability of these lands to provide or store water. Surface and ground water on rangelands provide crucial benefits in the form of habitat for aquatic organisms, drinking water for humans, wildlife, and livestock. Although they represent a small percentage of the land area, most wetlands and riparian areas are also rangelands. These are the areas found close to dependable supplies of water (streams, rivers, ponds, lakes, depressions, etc.). These ecosystems are inextricably linked to the watersheds in which they occur, and their importance is disproportionate to the land area they occupy. They provide key habitats for plants and animals and support many other ecosystem services (Wilcox et al., 2017; Wohl et al., 2012).

Effects of rangeland stewardship on the service

AVOID CONVERSION

Converting rangelands to irrigated croplands or urban lands will increase demands on surface and groundwater supplies, straining water resources, particularly in drier regions. Groundwater resources, such as the Ogallala Aquifer, are being depleted at alarming rates to provide water for agriculture and urban areas, with recharge limited on any meaningful timeline for human use (Deines et al., 2020). Globally, livestock production is primarily dependent on local precipitation, with only 6% coming from surface and groundwater (Heinke et al., 2020). Avoiding rangeland conversion to other land uses can decrease water demand in many regions. Similarly, preventing the conversion of native rangelands to alternate states dominated by exotic, invasive species will maintain hydrologic function and the ability of rangelands to provide water as an ecosystem service. Rangeland managers and users must remain constantly vigilant in order to detect and manage invasive plants.

RESTORATION

Converting croplands back to rangelands can decrease water demands and increase the infiltration rates and water holding capacity of the soils. However, the recovery of soil hydraulic properties can be slow (Zhang et al., 2013). Similarly, restoration of rangelands that have been invaded by exotic plants likely represents an opportunity to restore the hydrologic function of those rangelands and their ability to provide water as an ecosystem service.

Many approaches to livestock grazing management have been used successfully to maintain or restore the condition of riparian areas (Swanson et al., 2015). These approaches can reduce streambank erosion and nutrient loads into streams and prevent other unwanted outcomes associated with livestock activity.

THREATS

Land cover and land use conversions in rangelands can increase the demand for surface water and groundwater as well as alter the partitioning among components of the hydrological cycle (for example, runoff, evaporation, and groundwater recharge). In the western U.S., 34% of historic rangeland area has been lost due to land cover change (Reeves & Mitchell, 2011). For example, between 1984 and 2008 over 195,000 ha of California rangelands were converted to urban (49%) or intensive agricultural (40%) land uses (Cameron et al., 2014). Conversion of rangelands as a result of exotic plant invasion is another important threat. Exotic plant invasions are considered one of the most pressing rangeland management issues and represent a significant threat to rangelands and their ability to provide ecosystem services including, but not limited to water.

USDA

Water quantity and quality can also be negatively affected by management (Havstad et al., 2007). Management that causes changes in vegetation structure and soil structure can affect runoff, erosion, groundwater recharge, and soil moisture for plant production. A primary consideration from the perspective of water-based services is whether or not livestock grazing management provides for the growth needs of plants, and vegetation responses to grazing and grazing management are well established (Briske et al., 2008). Therefore, if livestock grazing management negatively affects the growth needs of plants (for example, by ignoring considerations of season, duration, and intensity of use), it may constitute a threat to rangeland water dynamics. Similarly, livestock grazing managed in ways that negatively affect soil properties or biological soil crusts could represent a threat. For example, in certain dry rangelands of the Colorado Plateau, loss of biological soil crusts from historic livestock trampling likely led to accelerated wind and water erosion (Duniway et al., 2018; Miller, 2011). Under some approaches to management, water quality can also be affected by livestock in riparian zones by increasing sediments, nutrients (i.e., nitrogen and phosphorus), and bacteria levels.

While precipitation variability is often high in rangelands, climate change is predicted to further increase variability and extremes (e.g., droughts and floods), as well as shift the seasonal timing of precipitation in some regions (IPCC, 2013). Warming temperature will increase evaporative demand, accelerating the loss of water from soils and surface waters through higher evaporation and transpiration. Combined, these changes in climate will create novel hydrological regimes, altering water resources in rangelands.

ADAPTIVE+ MANAGEMENT

Managing livestock grazing to provide for the growth needs of plants by paying attention to season, duration and intensity of use is the tried-and-true recipe for success when it comes to sustaining water-based ecosystem services. For example, flexible stocking strategies and rotational grazing can allow producers to adapt to short-term variation in climate. Adjusting stocking rates with short-term weather forecasts can allow producers to match livestock numbers and periods of use to seasonal variability in precipitation. Rotational grazing that allows for resting pastures each year or "grass-banking", can result in stockpiled feed that is a crucial resource in drought years. Numerous tools (stockmanship, water developments, minerals, supplements, permanent fencing, temporary fencing, virtual fencing, etc.) enable livestock producers to manage the distribution of livestock on rangelands. Monitoring is a key component of successful adaptive management and provides information to the manager about how their inputs and Mother Nature's inputs relate to goals, objectives and the responses of rangeland ecosystems to management.

Adjusting stocking rates with short-term weather forecasts can allow producers to match livestock numbers and periods of use to seasonal variability in precipitation.

Current and projected opportunities for producers and managers

There are some voluntary, incentive-based programs for landowners to protect and restore rangelands to improve water quality and quantity. For example, there are opportunities within the USDA's Conservation Reserve Program to protect native rangeland or convert croplands with resource-conserving vegetation covers in exchange for yearly payments. These programs aim to improve water quality and reduce erosion. Other opportunities include conservation efforts, such as the Ducks Unlimited Preserve Our Prairies initiative, which aims to protect vital wetland habitat for waterfowl in the Prairie Pothole Region of North America.

Rob Mattson, Noble Research Institute

C

CARBON SEQUESTRATION AND SECURITY

What are the services and benefits?

Carbon is an essential element for life on our planet and is found all around us. For example the earth's atmosphere contains approximately 750 Pg C, total terrestrial vegetation contains 580 Pg C, and the top one meter of soil holds approximately 1,417 Pg C (not including soil inorganic carbon), thus just the top meter of our soil contains more carbon than the vegetation and atmosphere combined (FAO, 2017). Soil carbon is composed of both inorganic (SIC) and organic (SOC) fractions. Soil inorganic carbon is derived from weathering parent materials and carbonates, while soil organic carbon is derived from decomposing tissues from dead plants and animals, and soil

Soil carbon sequestration is the process by which carbon is fixed from the atmosphere through plants and microbial processes, then stored in the soil profile.

organisms. With rangelands comprising ~40% of the earth's terrestrial surface and storing 10-30% of global soil organic carbon (Conant, 2012), rangelands play a key role in global carbon cycling.

Soil carbon sequestration is the process by which carbon is fixed from the atmosphere through plants and microbial processes, then stored in the soil profile. The amount of soil carbon sequestration possible at a location is dependent on soil texture, the climate (temperature and precipitation regimes), and the type of vegetation present (perennial vs annual and woody plants vs grasses), however, the management being applied and weather can change short-term fluxes (Sanderson et al., 2020). Because these variables (among others) can affect soil carbon sequestration potentials, rangelands covering a vast area of the earth's terrestrial surface have considerable variability in their potential to sequester carbon. Mesic rangelands (>500 mm of annual precipitation) are poised to sequester more soil carbon annually than xeric rangelands (<500 mm of annual precipitation) (De Deyn et al., 2008). These differences in potential do not mean xeric rangelands are less important regarding soil carbon sequestration, it is actually the opposite: xeric rangelands are vast and can maintain and secure soil carbon if managed to maintain healthy soils and plant communities (FAO, 2017).

Thus, the sequestration of carbon has been recognized as a tool to mitigate climate change effects (Lal, 2016). The global potential of SOC sequestration and restoration of degraded soils is estimated at 0.6 to 1.2 Pg C/y for about 50 years with a cumulative sink capacity of 30 to 60 Pg (Lal, 2003). For these reasons, applying management in agricultural production systems to rebuild soil carbon concentrations could provide significant benefits to the production subsystem and society as a whole.

Effects of rangeland stewardship on the service

AVOID CONVERSION

For rangelands, maintaining soil structure and eliminating erosion will help to maintain the soil organic carbon. In the tallgrass prairie it took 35 years to get to 50% of the total C pool physically protected after cropping (Scott et al., 2017), but it is estimated to take 350 years for the total C pool to return to a native tallgrass prairie after being cropped (Rosenzweig et al., 2016). This timeframe shows that once we lose native rangeland it can take decades to centuries to return the carbon stocks to a "native condition". Ideally, we need to protect the remaining rangeland and keep it intact (Sanderson et al., 2020).

David Augustine

RESTORATION

Restoring rangeland soil carbon requires an understanding of site potential (i.e., soil type, climate, vegetation), and knowing that during droughts there will be a loss of soil carbon (Morgan et al., 2016). The largest increase in soil carbon during restoration occurs when restoring croplands back to rangelands; this process has been estimated to sequester almost a 0.87 Mg C per ha per yr (Conant et al., 2017). This large increase in sequestered carbon comes from the establishment of native perennial grass and forb species, which increase root carbon inputs at deeper depths than annual crop species, which in turn increases microbial activity (Rosenzweig et al., 2016, Scott et al., 2017). When it comes to establishing plant communities that will aid in the restoration of soil carbon in rangelands, however, it is critical to understand that not all plant species have equal potential to provide benefits. For example, native perennials grasses will continue to improve and sequester soil carbon over non-native annual grasses (Rau et al., 2011). Understanding how different plant species affect soil carbon and other soil processes is important to know for restoring rangeland soil carbon. Thus, to successfully restore rangelands, we need to use all the tools, techniques, and strategies available to minimize soil loss and increase native vegetation diversity.

ADAPTIVE+ MANAGEMENT

GRAZING MANAGEMENT

Grazing management in rangelands is often a contentious topic and it is crucial to understand the management goals. Rangelands have evolved with grazing pressures from both native and domesticated animals. Understanding how grazing and grazing management influences rangelands is crucial for being able to determine how much carbon can be stored, sequestered, and secured in the ecosystem. The effect of grazing management on soil organic carbon is highly variable due to the external influences of climate, heterogeneous vegetation communities, and spatial distribution of soil types, notwithstanding the influence of stocking rate, stock density, recovery period, etc. (McSherry and Ritchie 2013).

Multiple studies from various grassland environments have reported positive responses of soil organic carbon stocks due to improved grazing management (Conant et al., 2017). Light to moderate grazing intensities have been shown to increase fine root production, tillering and increase foliar growth rates of perennial grasses with minimal effects on soil erosion and infiltration rates (Follet et al., 2001), ultimately affecting the potential to sequester soil carbon. Other studies have reported that moderate grazing has been shown to have little to no effect on total soil carbon compared to ungrazed areas (Derner et al., 2006; Derner et al., 2019). Ultimately management can influence multiple ecological processes that may directly and/or indirectly affect soil carbon dynamics on rangelands. Although questions still remain, where C stocks have been reported to increase soil carbon sequestration in western rangelands, the rate has been low (0.05 to 0.50 Mg C ha-1) (Schuman et al., 2002). Although greater amounts have been reported in grasslands associated with adaptive grazing management in higher precipitation zones (3 Mg C ha-1) (Teague et al., 2016). Ultimately, in drier environments, where management influences on soil carbon stocks may be limited in concentration, they are still significant contributors to regional carbon dynamics due to their spatial magnitude.

What grazing can do for rangeland is help manage fine fuel loads to reduce the prevalence of severe wildfires (Davies et al., 2016; Davies et al., 2021). The reduction in herbaceous fuel loads from moderate grazing helps maintain and secure rangeland carbon from being lost through wildfires.

THREATS

Rangelands can lose carbon through change or loss of vegetation, erosion, tilling or breaking ground, or replacement by man-made infrastructure. It has been estimated that in the Midwest region of the United States of America that between 2008 and 2016, 2 million hectares of rangeland was converted to cropland which lost 11.8 Tg soil per year yielding a 673.8 Gg C loss per year (Zhang et al., 2021). In the western U.S., woody encroachment conversion to juniper woodlands can result in soil loss (erosion) of up to 1.12 Mg per hectare during a rain event (Miller et al., 2019). Loss of the surface soil, the O or A-horizon (depending on ecosystem), removes a large amount of carbon from a location, and makes it more difficult to restore the location because of the loss of the topsoil.

2M

It has been estimated that in the Midwest region of the United States of America that between 2008 and 2016, 2 million hectares of rangeland was converted to cropland which lost 11.8 Tg soil per year yielding a 673.8 Gg C loss per year.

Most rangelands have evolved with fire; however, fires are increasingly becoming larger and more frequent in xeric rangelands due to invasive grasses (Keane et al., 2008), and less frequent in mesic rangelands because of woody encroachment and human behavior towards fire (Ratajczak et al., 2016; Twidwell et al., 2016). These changes to rangeland fire disturbance dynamics ultimately change the rangelands' potential to store and secure carbon. Between 2001 and 2008 average greenhouse gas (GHG) emissions from fires in the western U.S. were 0.3-7.4 $TgCO_2$ eq/yr from the cold and warm deserts, and Mediterranean ecosystems of California (Zhu & Reed, 2012), while in the Great Plains GHG emissions ranged between 0.18-24.72 $TgCO_2$ eq/yr (Zhu et al., 2011).

These GHG values from the western U.S. have likely increased since the Zhu and Reed (2012) report because of megafires that are fueled by invasive annual grasses, but in the Great Plains they likely have stayed within the reported range because of grassland conservation efforts to allow prescribed fires (Twidwell et al., 2016). Even though fires give off carbon, rangelands' ability to store and secure carbon vastly exceeds the sources currently (~6,838 TgC stored) (Zhu et al., 2011; Zhu & Reed, 2012) and our ability to manage fire on our rangelands will dictate total potential for carbon sequestration and security.

Like fire, most rangelands have evolved with herbivores (i.e., grazers, browsers, mixed-feeders). However, the management of domestic livestock grazing can affect how rangelands function regarding their nutrient and water cycles. The degree to which livestock or native ungulates graze (light, moderate, or heavy) and the allowed recovery period dictates how the ecosystem will respond. Heavy grazing or overgrazing rangelands significantly affects the ecosystem in multiple ways. Such grazing 1) increases soil erosion which removes any soil organic matter in the upper soil profile; 2) reduces the amount of aboveground and belowground plant-based carbon through grass mortality, all of which reduces total carbon pools (Follet et al., 2001). Decreasing grazing intensity from heavy grazing in overgrazed grasslands to moderate or light grazing has the potential to sequester 45.7 Tg C yr-1 through a change in land management practice (Conant & Paustian, 2002). Entirely removing grazing from a system has shown no real change in the total soil carbon stocks (Derner et al., 2006; Derner et al., 2019).

Managing fire for rangeland carbon

Managing rangeland fire regimes can maintain if not increase carbon storage and security in rangelands. In rangelands dominated or co-dominated by grasses, fire is an essential ecosystem driver that can be used to maintain or increase grass vegetation and minimize woody plant densities or encroachment on the landscape (Briggs et al., 2005; Bond, 2008; Bates et al., 2019). Grasses have the potential to sequester and store more carbon belowground in roots and root exudates compared to woody plants in general (Zhu & Reed, 2012; Dass et al., 2018; Gherardi & Sala, 2020). Even though woody plants can store more carbon than grasses in aboveground biomass, the threat of loss through fire is greater than with grasses. However, savannas or co-dominant shrublands have the potential to store significant amounts of carbon because of the bimodality of the system with woody plants and grasses (Pendall et al., 2018), but it is vulnerable to carbon loss through fire (Rau et al., 2012; Sanderson et al., 2020). This is very apparent in the semi-arid shrubland ecosystems of the western U.S. where annual grass invasions are converting these ecosystems to annual grasslands through increased fire frequencies (Brooks et al., 2004). This conversion from a shrub and perennial grass co-dominated system to annual grassland causes a 50% reduction in stored above- and belowground carbon (Nagy et al., 2020). Thus, managing with fire to maintain healthy native plant communities is critical for carbon storage and security.

Current and projected opportunities for producers and managers

Opportunities for increasing soil carbon on rangelands are centralized around increasing soil organic matter, as soil organic matter consists of approximately 58% soil organic carbon (Waksman and Stevens, 1930). Although increasing soil organic matter in rangeland soils is dependent upon several abiotic factors (e.g., precipitation, soil type, etc.) many biotic factors contribute to its accumulation.

These biotic factors are often responsive to adaptive+management. Increased soil organic matter has been linked to increased soil water holding capacity, infiltration, and microbial biomass in rangeland systems, all increasing the potential resiliency of rangeland ecosystems.

58%

Soil organic matter includes approximately 58% soil organic carbon.

Although increasing the concentration of soil organic carbon on rangelands has the potential to benefit many ecosystem processes on-site, opportunities to financially capitalize further on these services are currently being developed through ecosystem service markets. These ecosystem-based markets are primarily centralized around the quantification and subsequent valuation of soil carbon sequestration. Currently, there are no centralized or nationally regulated soil carbon markets in the United States, as there are in other countries. There are however emerging opportunities for land managers to participate in agricultural/grassland-based soil carbon markets. These markets are novel and although most operate based on a peer reviewed standards there is little consistency among requirements or application. Thus, although soil carbon markets clearly pose an opportunity for enterprise diversification, caution should be taken when contractual agreements are required.

Jeff Goodwin, Texas A&M Natural Resources Institute

Landowners are encouraged to seek legal advice from council experienced in such markets. Here we outline a few primary concern(s) that could potentially affect producer and landowner participation:

01 Long term contracts, particularly anything in perpetuity, can be alarming to producers. Projects that focus on shorter term life spans are much more desirable.

02 The cost of monitoring can be overwhelming. The identification of transparent, cost-effective measurement, reporting, and verification strategies are needed.

03 A defined protocol outlining the opportunities for private and public rangelands would potentially increase the level of comfort in landowner/manager participation.

04 In an effort to increase trust, the project aggregator/broker should be a trusted, unbiased source mediating between the supplier and buyer.

For producers that are interested in pursuing soil carbon markets, several key questions should be asked prior to signing any contractual engagement. Many of these questions have been outlined and are available on the Texas Agricultural Land Trust website (www.txaglandtrust.org/determining-if-soil-carbon-storage-markets-are-right-for-you/).

Mary Ashby

PLANT AND INSECT BIODIVERSITY

What are the services and benefits?

Rangelands can vary dramatically in the degree to which they harbor plant and insect diversity. Highly managed, irrigated pasture systems and integrated cropland-livestock systems (e.g., fodder-based or silage-based systems) tend to support lower levels of plant diversity than extensive rangeland systems (Newbold et al., 2015). Unlike pastures and croplands, extensive rangelands often include relatively diverse plant communities and a high number of native plant species. For the purposes of this section, we will focus on the latter category, which includes the vast majority of global rangeland land area (Briske, 2017). Extensive rangelands support higher biodiversity than many alternative land use systems, even under relatively intensive management (Newbold et al., 2015). Diversity here is broadly conceived to include genetic diversity, taxonomic/species diversity, functional diversity, structural diversity, and trait diversity.

Rangelands often include relatively diverse plant communities and a high number of native plant species.

Plant diversity

Plant biodiversity supports a broad array of ecosystem services and benefits.

FORAGE AND LIVESTOCK PRODUCTION

There is broad consensus that higher plant diversity supports higher primary productivity, as well as more stability in production across space and time (Isbell et al., 2009; Isbell et al., 2011; Cardinale et al., 2012; Hooper et al., 2012). There are a number of different mechanisms through which diversity can support productivity and stability, including complementarity, facilitation, sampling effects, portfolio effects, invasion resistance, and more. Higher and more stable plant productivity can benefit humans directly, for example by providing a reliable source of hay or livestock forage. Higher and more stable plant production also has many indirect ecosystem service benefits, including erosion control, flood control, water purification, and carbon sequestration. Many of these co-benefits are discussed elsewhere in this document.

WILDLIFE

Plant species provide sources of food, shelter, and other resources for animals that humans benefit from, including pollinating insects, birds, large game species, and more. Insects often rely on specific host plants or plants that are active at a certain time of year. As a result, more diverse plant communities tend to support more diverse insect communities (e.g., Siemann et al., 1998; Knops et al., 1999; Wenninger et al., 2008; Zhang et al., 2016). That said, the total abundance of insects may be more related to moisture, plant quantity, or plant structure than plant diversity (e.g., Siemann et al., 1998; Wenninger et al., 2008). A growing body of research supports the idea that structural and functional plant diversity are critical for supporting diverse grassland and shrubland bird species (e.g., Knopf et al., 1996; Hovick et al., 2015; Pennington et al., 2016, Duchardt et al., 2018). There is limited evidence that plant diversity may also support higher quality diets for large ruminants, particularly if species with different phenological growth patterns are present (e.g. Soder et al., 2007; Briske, 2017). See the Wildlife section for more information on this topic.

NEW FORMS OF MEDICINE, TECHNOLOGY, FOOD, FLOWERS, AND OTHER RESOURCES.

In addition to supporting ecosystem processes and animal diversity, plant diversity can also provide direct benefits to humans in the form of raw materials that can be used or developed into medicines, new technologies, new food or fiber crops, new horticultural crops, and more. Because we do not yet know what benefits or technologies specific species will be able to contribute to in the future, the preservation of genetic diversity will maximize our chances of being able to use plant species for human needs in the future (Khoury et al., 2010).

INTRINSIC VALUE.

Diverse plants (e.g., wildflowers) are often valued by humans for their intrinsic beauty and cultural value (see Human Dimensions section).

THREATS

The largest threat to plant and insect biodiversity in rangelands is conversion of rangelands to other uses, including introduced pastures that are typically characterized by plantings of highly productive, non-native species with low biodiversity (Boughton et al., 2010; Boughton et al., 2018). Although introduced pastures may provide some biodiversity benefits, they are not as valuable for this service as native rangelands. Rangeland biodiversity can also be threatened more subtly by management activities including shifts in grazing regime (e.g., overgrazing or undergrazing), shifts in fire regimes or other disturbance regimes, application of pesticides or herbicides, and overharvesting. Invasive species also pose a large threat to rangeland biodiversity and can sometimes lead to broad-scale conversions from diverse ecosystems providing many services to low diversity systems providing few services (DiTomaso, 2000; Rice, 2005). Finally, climate change may threaten the persistence of rangeland plant and insect species (for example, due to decoupled phenology, higher aridity, or constrained range shifts).

Insect diversity and pollination

Insect diversity can support pollination, among other services. Pollination is the act of transferring pollen grains from the male anther of a flower to the female stigma of another flower of the same species, which leads to seed production. While wind takes care of this task for many plants, additional effort is required for others, with insects typically serving as the vector that moves pollen from one flower to another as they eat or collect pollen for its protein value or feed on a flower's nectar for energy. The loss of pollinators can lead to reduced seed and fruit production, and ultimately declines in plant populations.

Broadly speaking, there are native pollinators and there is the honey bee (*Apis mellifera*). Native pollinators in the U.S. include over 3,500 species of bees, butterflies, moths, wasps, flies, and beetles (and bats and birds). Native pollinators live, forage, and breed in the wild and have rarely been successfully domesticated. In addition to serving as protein and fuel sources, plants are often a source of nesting materials for these species. Some native pollinators depend on a single or a limited number of plant species for their dietary needs, which may be reflected in the distinct morphology of flowers and their specialist pollinators. As a result of these specializations, there is a relatively direct relationship between plant and native pollinator biodiversity.

In contrast, honey bees are an introduced, generalist species that have been domesticated for millennia. While they pollinate less efficiently than natives and can compete with native species, they have become a valuable livestock species managed by commercial beekeepers because they are easily transported to the variety of crops whose flowers they will visit and pollinate, including almonds, apples, blueberries, cherries, and cucumbers.

Grazing lands can benefit and be benefited by pollinators and this complementarity presents a challenge for distinguishing the benefits of plant and pollinator diversity. The presence of pollinators on the landscape is associated with the availability and diversity of floral resources (Otto et al., 2018). Plant diversity, which pollinators play a critical role in supporting, is associated with higher quality-adjusted ruminant forage yields (Shaub et al., 2020), with implications for returns to food and fiber production.

In addition to affecting food and fiber production on the parcel providing the forage and nesting habitat, pollinators also have the potential to generate off-site benefits. Roughly 35 % of the world's food crops—fruits, nuts, and vegetables—either require or benefit from insect pollination (NRCS, 2016). The estimated value of insect pollination services to crop production ranges widely, with $15 billion, 80% of which is attributable to commercial pollination by honey bees, being widely cited (Calderone, 2012). More recent work indicates the value of native pollinators to be at least as high as that of honey bees, with productivity being limited for five of seven major pollinator dependent crops by the dearth of adjacent refugia (Reilly et al., 2020).

However, off-site benefits may be difficult to fully realize when the forage habitat exists in a matrix of grazing land and there is no adjacent cropland to pollinate. Further, crops dependent on insect pollination, such as almonds or blueberries, may be relatively scarce where grazing lands predominate. More promising in terms of fully assessing the benefits of pollination services is the limited but growing evidence that the yields of otherwise self-pollinating commodity crops, such as soybean and canola, more likely to be in proximity to grazing lands may be favorably affected by the presence of pollinators (Garibaldi et al., 2021; Adamidis et al., 2019).

Honey bees have become a valuable livestock species managed by commercial beekeepers because they are easily transported to the variety of crops whose flowers they will visit and pollinate.

Effects of rangeland stewardship on the services

AVOID CONVERSION

Maintaining rangelands in an unconverted state is the first and most important step towards maintaining plant and insect biodiversity. Large areas of unconverted land provide a spatial buffer against temporally stochastic environmental and management events that frequently lead to temporary losses of diversity (e.g., due to fire, floods, heavy grazing, unseasonal frost, or harvesting). In the face of such losses, the presence of a "regional species pool" is key for retaining diversity and repopulating affected areas. In the era of climate change, connectivity among

patches of unconverted land is also critical to facilitate species range shifts (movements of individuals towards areas with more favorable conditions) and gene flow (movements of genes between populations) that will help plants and insects adapt and acclimate.

RESTORATION

After loss of diversity has occurred due to conversion or rangeland degradation, restoration typically involves planting diverse native plants and creating habitat (diverse and abundant floral resources and nesting sites) for pollinators and other insects. However, successful restoration of diverse native plant communities on degraded and converted rangelands remains extremely difficult. Currently in the western U.S., the federal government spends billions of dollars annually on post-fire restoration of invaded rangelands, but studies indicate that very few planted seeds actually establish (Svejcar et al., 2017) and projects rarely achieve their objectives (Arkle et al., 2014). Current research on this topic has begun to identify factors that control the probability of success, which include seed characteristics (Leger et al., 2021), seed provenance (Baughman et al., 2019), seeding rates, aridity/weather, soil and topographic conditions, and weed control (Shackleford et al., 2021). Some exciting new strategies for rangeland plant restoration are also emerging, including spatially strategic plantings (e.g., Hulvey et al., 2017), precision restoration that targets key establishment bottlenecks (James et al., 2011; Hulvey et al., 2014), and enhancing positive feedbacks among plants, biocrusts, and soil microbes. In areas experiencing only minor loss of plant species, diversity can often be restored or enhanced through targeted management strategies (see below).

ADAPTIVE+ MANAGEMENT

In many rangelands across the globe, some level of large herbivore grazing helps to maintain or enhance plant diversity (Milchunas et al., 1988). However, diversity tends to decline as grazing intensity and frequency increase above moderate levels (Herrero-Jaguerei & Oesterheld, 2018). If grazing reduces the cover of dominant species, this can enhance diversity by allowing space and resources for other plants to co-exist (e.g., Marty, 2005; Porensky et al., 2013; Koerner et al., 2018). If grazing tends to increase the abundance of the most dominant species, it can have the opposite effect on diversity (Koerner et al., 2018; Porensky et al., 2017).

Grazing management practices can also affect plant diversity by affecting plant invasion dynamics. Removal of grazing can suppress invasion by increasing the abundance of native plants (Al-Rowaily et al., 2015; Anderson & Inouye, 2001; Reisner et al., 2013; Veblen et al., 2015; Yeo, 2005) or biocrusts (Anderson et al., 1982; Root et al., 2020; Slate et al., 2019; Yeo, 2005) that are themselves able to resist invaders (e.g., via competitive exclusion). However, exclosures can also become more invaded than grazed sites (Augustine et al., 2017; Loeser et al., 2007; Milchunas et al., 1990; Porensky et al., 2017; Porensky et al., 2020), particularly if the native plants that compete most effectively with invaders are lost (Milchunas et al., 1992). In some cases, grazed sites support higher abundance or diversity of both native and non-native plants than ungrazed sites (Chaneton et al., 2002; Stahlheber & DAntonio, 2013). Moreover, recent work indicates that targeted grazing may be a useful tool for reducing invasion and enhancing native plant and animal diversity across multiple ecosystems (e.g., Bailey et al., 2019; Porensky et al., 2021).

This rich body of literature indicates that effects of grazing management on plant diversity are complex and likely context-specific. Moreover, results emphasize that grazing is almost never "always bad" or "always good" from the perspective of maintaining plant diversity. Similarly, fire may be necessary to maintain system-level heterogeneity and diversity (Fuhlendorf et al., 2009), or fire may lead to persistent losses of diversity (Olson, 1999; Davies et al., 2011). Overall, monitoring how plant and insect diversity are responding to different forms of management, and adapting management if trends indicate long-term declines in diversity, will be critical for maximizing these services in rangelands. Successful monitoring programs involve repeated data collection over time, which in turn requires active stewardship of these lands. People out on the land can track things like rare plants, invasive plants, and gradual shifts in plant composition. These observations and data can serve as critical early warning signals to help prevent the loss of biodiversity.

OPPORTUNITIES

There are a few opportunities for rangeland stakeholders to receive payments from society when taking actions to support biodiversity services, but these opportunities are currently limited. Although focused on conserving cropland, the conversion of highly erodible cropland to perennial species is the focus of the Conservation Reserve Program which provides incentives for producers who plant diverse native species mixtures, sometimes with the goal of creating habitat for pollinators. Payments for plant diversity can also be obtained through the collection and/or increase and sale of seed from species that are desired for use in native plant restoration or horticultural applications (Pedrini et al., 2020). Federal land management agencies like the Bureau of Land Management are increasingly interested in expanding their supply of high-quality native seeds for use in restoration efforts (see the National Seed Strategy).

Producers, particularly those located in areas near croplands, may be able to capitalize on floral resources present in existing rangelands by adding a honeybee business to their operation. Otto et al. (2018) found a strong association between where commercial beekeepers locate their colonies and the presence of prairie restored through Conservation Reserve Program participation. A considerable fraction of honey bee colonies in the U.S. are transported to the Northern Plains over the summer to forage on grassland flowers in preparation for overwintering and the pollination circuit, and to produce honey, valued at $321 million in 2021 (USDA NASS 2022). There are also emerging opportunities for producers to market products with a pollinator-friendly certification (e.g., https://www.beebettercertified.org/), though these opportunities still appear to be limited to crop-based operations. Ecosystem service market opportunities regarding biodiversity in rangeland systems are currently being explored by multiple entities, however an established protocol and or framework has yet to be realized.

Tatiana Gettelman, USGS

Improving critical habitat for sage grouse concomitantly improves the habitat for both game species and non-game species.

WILDLIFE HABITAT PROVISION

What are the services and benefits?

The ecological fabric of rangelands is the provision of food and fiber in the form of wildlife and livestock production (Brown & MacLeod, 2011). Rangelands provide biotic resources, such as vegetation heterogeneity for diverse wildlife habitats through inherently variable soils and resultant ecological sites. Heterogeneous rangelands support a greater number of plant and animal species because they contain additional structural complexity and/or diverse plant communities that provide added spatial and temporal niches (Tews et al., 2004). Rangelands adaptively managed for outcomes associated with wildlife habitat (e.g., vegetation height and structure) provide a diverse suite of habitats (Davis et al., 2020) and in return produce a suite of wildlife-related ecosystem service benefits.

41%

The 2016 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation showcased that 41% of the U.S. population participated in wildlife-related recreational activities.

$157B

Total amount spent of those participating in wildlife-related recreational activities.

Rangelands support wildlife species of importance that provide consumptive (hunting and fishing) and non-consumptive (viewing) values from recreational opportunities. The 2016 National Survey of Fishing, Hunting, and Wildlife-Associated Recreation showcased that 41% of the U.S. population participated in wildlife-related recreational activities. These recreationalists spent $157 billion with $76 billion on wildlife watching, $46 billion on fishing, and $26 billion on hunting. The status and condition of both consumptive and non-consumptive wildlife populations serves as an indicator of the overall environmental quality, health and condition of the rangeland. When wildlife populations thrive, the value of the rangeland, in terms of ecosystem services, typically thrives too as there are synergistic interactions between the two (Briske, 2017). However, some rangeland wildlife species and their related habitat are in peril and require additional attention. Purely identifying ecosystem services alone does not create or incentivize the production of these services (Huntsinger & Sayre, 2007). The additional step of addressing threatened & endangered species habitat requirements is needed to simultaneously support a multitude of other services (e.g., wildlife-associated recreation) while improving habitat for non-listed endemic wildlife. For example, improving critical habitat for sage grouse concomitantly improves the habitat for both game species (e.g., mule deer, pronghorn, mountain cottontail) and non-game species (e.g., Brewer's sparrow, horned lark) (e.g., Welch, 1999), and connects existing markets for both types of species.

OPPORTUNITIES

Producers and managers are currently applying management practices such as patch-burning (pyric herbivory, Fuhlendorf & Engle, 2001) and adaptive grazing management (Davis et al., 2020) with specific objectives for short- to tall-structured vegetation to emphasize wildlife habitat within their operations. Limited marketing opportunities are emerging to support these activities. For example, Audubon has developed a Conservation Ranching Initiative (Conservation Ranching | Audubon) that empowers customers to make a difference by purchasing their beef from grassland bird friendly lands. Other grassland bird-friendly beef efforts (e.g., Wisconsin Bird Friendly Beef, Beef | Bird Friendly Farming), as well as restoration efforts on grazing lands for bird-friendly beef (e.g. Restoring Grasslands for 'Bird-friendly Beef' – New Mexico Land Conservancy (nmlandconservancy.org), and business promotions (e.g., Hilton Hotels, Bird-friendly beef showcased by Hilton Hotels | BirdLife) showcase the emerging efforts. Moreover, producers and ranchers recognize the critical contributions of restored grasslands, including millions of acres enrolled in the CRP, for reducing fragmented landscapes in addition to other conservation benefits (see Biodiversity section). Other opportunities may arise from the application of USDA's CRP Grasslands, which was authorized in the 2018 Farm Bill to protect environmentally sensitive grasslands, including rangeland and pastureland while maintaining the areas as grazing lands.

Effects of rangeland stewardship on the service

AVOID CONVERSION

Conversion of rangeland to cropland or development has long been identified as the greatest and most persistent threat to native wildlife species (Wilcove et al., 1998; Green et al., 2005). Avoiding conversion has been shown to preserve species diversity and connectivity of habitat (Olimb & Robinson, 2019).

RESTORATION

Restoration of wildlife habitat should be synergistic with other ecosystem processes, including soil structure, infiltration, plant cover, and plant diversity (see other Topic Areas for more details on these). However, successful restoration of wildlife habitat can be extremely difficult, especially in dryland contexts (e.g., Arkle et al., 2014). In cases where rangelands have adequate plant cover, but wildlife populations are still in decline, restoration of rangelands for wildlife often needs to target increased heterogeneity, structural complexity, and plant diversity. Enhanced application of adaptive grazing management can restore wildlife habitat by creating spatially and temporally variable grazing intensities. Strategies such as fire-grazing (pyric herbivory) interactions, herding, rotating sequencing of use of pastures, and emerging technologies like virtual fence can provide beneficial variation in animal use of different areas over periods of a year or more, rather than "managing for the middle" (homogeneous structure) or for tall- and short-structured areas that remain static over time (Fuhlendorf & Engle, 2001; Toombs et al., 2010).

ADAPTIVE+ MANAGEMENT

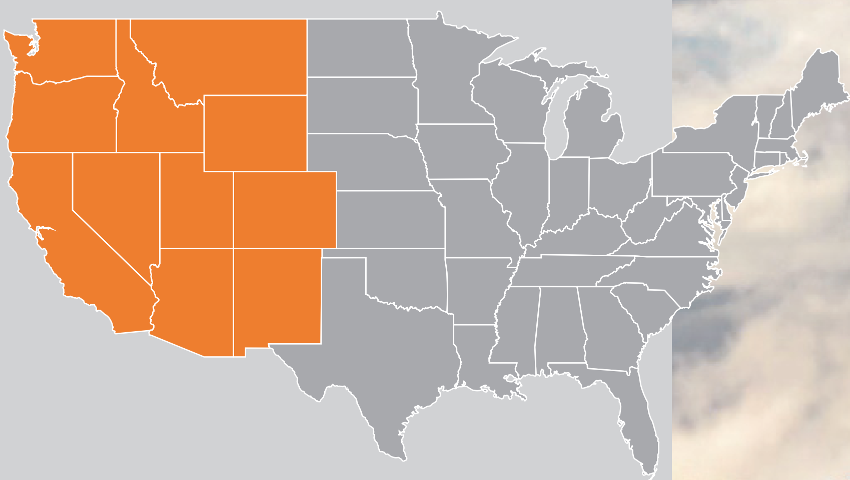
The use of livestock as "ecosystem engineers" to increase vegetation heterogeneity may increase habitat diversity for wildlife (Derner et al., 2009). To accomplish this, consideration for appropriate scales of heterogeneity (e.g., within pasture, among pasture, ranch-level, landscape) (Toombs et al., 2010) is needed for the wildlife species of interest. Strategies that are outcome-focused (Derner et al., 2022), increase variability in vegetation structure and/or composition, and embrace natural disturbance processes (fire, grazing, burrowing mammals, etc.) can provide opportunities for land managers to accomplish win–win results for wildlife and grazing livestock alike (Fuhlendorf & Engle, 2001; Augustine & Derner 2014; Augustine et al., 2014).

There are tradeoffs between traditional management for livestock production and provision of wildlife habitat (Augustine & Derner, 2012). Moreover, explicitly including wildlife habitat heterogeneity as an objective in adaptive grazing management can reduce livestock production compared to grazing strategies that emphasize livestock performance (Augustine et al., 2020). Grazing improves brood habitat for grassland birds as well as cover for nesting in the short-term. Livestock grazing can be harmful to endangered plant species and animals (Wilcove et al., 1998) if not properly timed and without clear habitat objectives. Priorities for adaptive management can be those that return the greatest gains per investment (Miller & Hobbs, 2007). These efforts are explicitly incorporating considerations of the appropriate scales of heterogeneity (e.g., within pasture, among pasture, ranch-level), (Toombs et al., 2010) with landscape applications projected to have the strongest effect through 1) spatially prioritizing locations of additional grassland restoration and reintroduction of fire and grazing, and 2) developing partnerships that can enhance cross-jurisdictional management (Augustine et al., 2021).

THREATS

Declines in wildlife species populations, particularly grassland birds, have been attributed to loss of spatial and temporal heterogeneity associated with intensive farming, advanced natural succession, fire exclusion, invasion and planting of non-native plants and urbanization (Askins et al., 2007; Briske, 2017). Since the 2000s, conversion of rangeland to cropland has reaccelerated with an associated loss of habitat for wildlife (Lark, 2020). Spencer et al. (2017) reported lesser prairie chicken range has declined by 84% since the beginning of the 20th century, and much of this decline is attributed to loss of habitat or fragmentation due to conversion. Efforts to limit grassland conversion were enacted in the 2008 Farm Bill ("Sodsaver") by Congress, but this provision only included six states that surround the prairie pothole region (Lark, 2020). Recent efforts to expand this provision to the entire country, including states with some of the greatest grassland losses (e.g., Kansas and Texas) failed to pass in the 2018 Farm bill (https://www.congress.gov/bill/115th-congress/house-bill/3939).

STATE AND FEDERAL CONSERVATION EFFORTS



As rangeland acreage shrinks, habitat fragmentation increases, along with the value placed on protecting or creating migratory wildlife corridors. Year-round access to critical resources is vital to maintaining big game populations (Stoellinger et al., 2020). As such, eleven western states (**AZ, CA, CO, ID, MT, NV, NM, OR, UT, WA, and WY**) and three federal agencies (**BLM, USFWS, NPS**) have designated plans to conserve elk, mule deer, and pronghorn migration corridors (U.S. D.O.I., 2018). But distribution of corridors, or other critical habitat is profoundly negatively affected when impermeable barriers, such as game-proof fencing or other barriers to migration become an obstacle (Stoellinger et al., 2020). For example, one study has shown pronghorn encounter fences 250 times per year, with 40% of those encounters ending in failed crossings (Xu et al., 2021). It is reasonable to expect that these "invisible" threats are not fully recognized by the public (Jakes et al., 2018), and until they are equally prioritized with other existing threats, their broad-scale effects (biological and economic) will continue.

National Parks Service

40% **A recent study (Xu et al., 2021) has shown pronghorn encounter fences 250 times per year, with 40% of those encounters ending in failed crossings.**

Rob Mattson, Noble Research Institute

HUMAN WELL-BEING AND HUMAN DIMENSIONS OF ECOSYSTEM SERVICES

The social and cultural aspects of ecosystem services relate to broad categories including "the nonmaterial benefits people obtain from ecosystems through spiritual enrichment, cognitive development, reflection, recreation, and aesthetic experiences" (Millenium Ecosystem Services, 2005). Here we aim to bring attention to the multiple social and cultural processes, outcomes, and benefits that result from rangeland social-ecological systems. Noting the diversity and importance of these social aspects of rangelands help us better understand how diverse peoples derive and steward social benefits, activities and relationships from rangelands, and to assess the quality of those benefits. Diaz et al. (2018) note that culture permeates all aspects of ecosystem services. For example, food is a material contribution of nature to people, but it is also full of cultural, social and political meaning, and these contributions are interlinked. Recognizing the value of social and cultural aspects of rangeland systems helps us see how people understand, value, interact with, and make meaning of rangelands around the world to maintain quality of life, wellbeing, and cultural and economic vitality. We recognize first that, for many people, these aspects of rangelands are sacred, invaluable "things of intrinsic worth", to quote cowboy poet Wallace McRae (1989).

"A major challenge today and into the future is to maintain or enhance beneficial contributions of nature to a good quality of life for all people."
Diaz et al, 2018.

When considering social aspects of rangeland systems, it is important to ask, “ecosystem services for whom?” --or to think about who is a winner and who is a loser when society places a value on a cultural aspect of rangelands. Socio-cultural values attached to (or lacking from) rangelands is a major driver for decision-making and management. Values affect the prioritization of objectives, and therefore, allocation of funds, labor, and research. Understanding the values humans associate with nature allows us to simultaneously understand why humans make the decisions they do. Socio-cultural valuation may provide a wealth of information regarding “how” and “why” people perceive certain ecosystem services so that effectively assessed values can be interpolated for decision-making (Scholte et al., 2015).

On the ground, valuation of these cultural dimensions is not a neutral activity. We see trade-offs between cultural services for different groups of people, which are often a source of decision-making conflict among stakeholders (Jacobs et al., 2016). For example, multiple use policies on public lands seek to balance the interests of multiple uses of rangeland and forest systems. However, changes in how society values different uses, such as wildlife conservation, recreation, energy development, or grazing access, result in various levels of access and benefit from different groups. Swete et al. (2021) studied land use transition on public lands from agriculture to alternative service provision (e.g., recreation), finding a 62% reduction in forage consumed by livestock since 1940 in their study area in the High Divide (central Idaho) of the Rocky Mountains. Other case studies of stakeholder valuation of ecosystem services have illustrated an emphasis on internal motivations and socio-cultural values, such as aesthetic and bequest values (Table 3), over economic values (Bartlett et al., 2002; Pike et al., 2015; Roberts et al., 2020; Winkler & Nicholas, 2016). For example, Bartlett et al. (2002) discovered that ranchers valued quality-of-life over the economic value of forage quality on public lands, exemplified by a willingness to pay for grazing permits, despite potentially low forage quality. The extent and social, economic, and political importance of rangelands globally means that power inequalities shape how some peoples’ use of rangelands is valued over others, and that cultural benefits for one group may negatively affect those of another group, resulting in escalating or protracting conflict or polarization among user groups.

SOCIAL DIMENSIONS OF RANGELANDS:

Here we provide some examples of social values (Table 3), and cultural and social processes and outcomes derived from human relationships to rangelands (Box A).

Table 3. Social values derived from rangelands (Sherrouse et al., 2011). For additional background and alternative framing of these concepts, see Bongaarts (2019), Diaz et al. (2015) and Pasqual et al. (2017).

Value	Description
Access to nature / recreation value	Outdoor recreation, both consumptive, such as hunting and fishing, and non-consumptive, such as walking along a nature trail to see grassland birds.
Aesthetic values	The value of the landscape or ecosystem to produce pleasure.
Bequest value	Wellbeing derived from knowledge rangelands will be available for descendants and future generations more generally to enjoy.
Cultural and spiritual values	The norms, beliefs, and practices that relate to rangelands and affect one’s stance on how they should be treated.

Box A. Cultural and social processes and outcomes derived from human relationships to rangelands

In rangelands, social and cultural benefits are often mediated by relationships with places, plants, animals, technologies, practices or materials that shape social, spiritual, cognitive, physical or aesthetic experiences. Here are some specific examples of processes and outcomes of social-ecological relationships that enhance social wellbeing. This list is not exhaustive but does provide general insight into some of the cultural aspects rangelands provide at local, community, and broader regional scales.

- Development and maintenance of social structures, norms, ethics, identity, quality of life, and interpersonal relationships
- Connection to place, landscapes, and other people and beyond-human beings (plants, animals, fungi)
- Knowledge development and advancement: The practice of Traditional Ecological Knowledge, language, symbols, community based natural resource management, local ecological knowledge, and conventional science and educational practices
- Customary and traditional ceremonial, vegetation management, livestock husbandry, hunting, gathering, cultural practices based in rangelands
- Food culture, including cultural practices for harvesting, preserving, processing, distributing, and consuming food produced or gathered on rangelands
- Fiber production and processing, including leather, rawhide, wood, wool and fiber products
- Development and use of tools, gear, clothing, technology, and other artifacts
- Traditional, folk and contemporary craft, artisan activities, art, literature, poetry, and music
- Spiritual and religious beliefs and practices
- Social, economic, and relational practices related to gender, romance, partnership, sex, marriage, family, death, and intergenerational connections.
- Recreational activities from a wide range of traditions
- Mental health benefits of nature
- Experiences of humor and levity
- Aesthetic experiences, art, and oral traditions
- Care and healing, including within human-nature relationships (psychological and social benefits derived from land management or restoration success)
- Historical preservation and remembrance, including sense of place and belonging

THREATS

Rangeland peoples need rangelands, and rangelands need rangeland peoples. The sustainability of these social aspects of rangelands are contingent upon ongoing social-ecological relationships, while rangeland ecosystem persistence and health are interdependent with social and cultural processes and stewardship (Brunson & Huntsinger, 2008). Among the more general ecological, social, political and environmental threats facing rangeland persistence and health, there are several that more strongly affect social and cultural processes in rangelands. These include: governance structures that lack transparency, accountability or are undemocratic, a lack of access to or tenure on rangelands, and reduced social capital in rural communities.

Outside of rangeland communities, a major threat stems from a lack of public awareness of and an appreciation for rangeland ecology and its uniqueness and contribution to one's sense of place. Cultural views of rangelands relative to other biomes that may get more "attention" (e.g., rainforests) can shape large scale, long term ecological, social, land use, management, and access conditions. Views that rangelands are "unpeopled", "wastelands" or "wildernesses" which have been pervasive throughout mainstream discourse and policy have political, social, and cultural implications, as they diminish the value of rangelands and rangeland peoples (Hoover et al., 2020). The mainstream public has limited understanding of the ecological and cultural values of rangeland systems, or of the consequences of rangeland conversion or degradation. Without opportunities to experience meaningful connections with rangeland systems, and to understand the ecological and social-ecological processes on rangelands that sustain human wellbeing, the general public is unlikely to see rangelands as more than lands that have not yet been converted to a more profitable use (Sayre et al., 2017).

EFFECTS OF RANGELAND STEWARDSHIP ON THE SERVICE

We address what rangeland users, managers, and organizations can do to foster solutions to these threats, in the section below.

The provisioning of cultural ecosystem services can be enhanced by changes to social, economic, and cultural structures (think: the rules people make for themselves). Avoiding conversion of rangelands into another land use prevents the loss of service, reduces how services shift over space and time, and helps maintain the quality of the service available to specific groups. Adaptive management or restoration activities may recreate or improve the quality and availability of a service for a particular group, dependent on the goal. Adaptive management can also include an element of collaborative learning or education, which can address lack of public awareness of rangeland ecosystems, and can serve to restore or rebuild local knowledge of rangeland systems. For example, Wilmer et al. (2019) documented how a group of ranchers, conservation groups, and researchers, and public agency employees created a new "nature-culture", or connections and knowledge of rangeland systems through the process of adaptively managing an experimental range in Colorado.

OPPORTUNITIES

Outside of the three opportunities discussed in other sections (avoid conversion, adaptive management, and restoration), opportunities exist to address political and economic dimensions of threats to cultural rangeland services. These include five key areas of opportunity outlined below.

EXPANDED EDUCATIONAL OPPORTUNITIES

for people of all backgrounds and ages to learn more about rangeland ecosystems and cultures, and to continue rangeland-related cultural practices. Education can include background in rangeland ecology, but also cultural aspects of rangelands, to promote positive relationships with nature, belonging, community, culture, and mutual respect.

ATTENTION TO ECONOMIC JUSTICE, INCOME DIVERSIFICATION, AND MARKET REORGANIZATION

Ranchers, communities, and decision makers have various opportunities to ensure financially viable and socially sustainable rangeland-based livestock production can promote the development and continuity of rangeland-based social benefits. This could include policy, programing, or private industry efforts to promote fair markets, specialty or value-added products, agrotourism, recreation, and marketing of other rural amenities and experiences, agricultural income diversification, and markets that rebuild food value chains directly with local processors and consumers (Jablonski et al., 2019; Lyson et al., 2008; Hendrickson et al., 2018; Carolan, 2020).

INVESTMENTS IN RURAL CULTURE, SOCIAL NETWORKS, INFRASTRUCTURE, AND ADAPTIVE CAPACITY

help bolster the interconnections between community wellbeing, rural prosperity, agricultural economies, and rangeland ecosystems. Investment in rural infrastructure, internet services, healthcare and educational services, small businesses, and other tangible and social aspects of rural communities have positive feedback loops for interconnected rangeland livelihoods, cultures and ecosystems.

TRUST BUILDING, LEARNING, AND CONFLICT RESOLUTION

collaborations or activities can help reduce power inequities and economic and political threats to rangeland related cultural benefits by working to restore, reinvigorate, or renew social and cultural connections to and benefits of rangelands. These may take the form of rancher-led, researcher-led, or other initiatives that promote listening, respect, trust building and learning, while recognizing (rather than ignoring) conflict as an expected part of rangeland management (see Porensky, 2021).

INCREASED INTEGRATION OF SOCIAL AND ECONOMIC SCIENCES

into rangeland ecology and management, public lands management contexts, and restoration sciences to better understand and improve social and cultural conditions across rangeland-related communities and value chains (Brunson et al., 2021). Social science and economic research can provide knowledge about social relationships, interventions (programs) and outcomes to empower communities, ranchers and range managers, and others to improve positive feedback loops between rangeland people and rangeland ecosystems.

Jeff Goodwin, Texas A&M Natural Resources Institute

CURRENT AND PROJECTED OPPORTUNITIES FOR PRODUCERS AND MANAGERS

Social and cultural processes are intertwined with the other biophysical and ecological aspects of systems. For example, Traditional Ecological Knowledge and local knowledge and management practices, passed down through rangelands cultures, can help future generations steward and sustain these systems. In another example, the Traditional Indigenous Use of spiritually, medicinal or culturally significant plant species involves particular practices of harvesting and use that have feedback loops through the ecosystem and the social system. This is well described by Robin Wall Kimmerer in her discussion of Native sweetgrass harvesting practices (2013). Additionally, social and cultural amenities derived from rangelands can create new opportunities for income for ranchers and landowners, who may sell or offer recreational or cultural experiences, products, and management knowledge to supplement their income, build stronger social or political networks, or for educational or service reasons. Recreation or tourism-based activities can help stabilize rangeland use and sustainability, and in turn have a positive effect on other outcomes for rangelands (connectivity, biodiversity).

PERSPECTIVES

INDIGENOUS PERSPECTIVE

In this report we explicitly include leadership from the Society for Range Management Native American Rangeland Advisory Committee (NARAC) in order to recognize that social and cultural aspects of rangelands have deep meaning for the many Indigenous Peoples in the U.S. and around the world that may be distinct from the experiences and frameworks used by other groups to understand these lands. Native Americans have been stewards of rangeland ecosystems in North America for thousands of years. As a Pueblo elder explains: Traditional knowledge passed down from generations and incorporation of Indigenous Traditional Ecological Knowledge (ITEK) for the stewardship of these landscapes into ways that benefit all that use these landscapes; "Our culture is not a written culture. It is passed on with stories but they're not just stories."

"What significance it has on the Native side is all the prayers, dances, and everything we sing about starts at the heart of the Pueblo, it works outward toward the river, down from the river into the rangeland, the prairie and into the mountains and back again, it's like a ripple effect it works both ways.

Rangelands are important because they are a part of our emergent story. All the songs that the Pueblos sing about, is for giving life and that's where life is generated, from small animals to predator animals, they all have a significant place in the pecking order and a big part of our culture." - Pueblo elder

From an Indigenous viewpoint, rangelands provide a balance of health and life. Rangelands serve as a buffer, as they hold soil and habitat for wildlife to prevent encroaching into the towns and causing issues with humans. It's important to keep a balance in the system. There are places people don't belong and in a native mindset you're not separate from the land, you are a part of it. Indigenous people learned from their surroundings to create a harmony to survive for long-lasting subsistence.


Frank S. Price

PRODUCER PERSPECTIVE

The venture to enhance the ecosystem services including sequestering carbon and the ability to do so, are based on the effectiveness of the rangeland manager to cause the many resources available to him, to create an environmental equilibrium of those resources.

West of the 100th meridian, limited rainfall is always of critical importance.

Being able to put that limited resource to the best use is, perhaps, the determining factor of the success of the manager to make positive or negative impact to the environment and the profitability of the ranching operation. Establishing, as close as practicable, continuous cover of the soil with healthy plant life should be the goal of the operator. When this is accomplished, evaporation is reduced to a minimum, runoff is limited to extreme rain events and the loss of moisture suddenly becomes only the issue of transpiration, which is an essential process of healthy growing plants. Perhaps the loss of available water for growth might be attributable to percolation into the aquifer, it is much better there than evaporated or lost from runoff, taking the valuable healthy soils to the rivers and lakes.

Healthy-growing plants create healthy soils which in turn create an excellent place to store that limited rainfall for future plant use. (My ranch headquarters has experienced a slight increase in rainfall average since 1983, not less.) From a historical standpoint I find little evidence that rainfall has become less over time, however the utilization of that moisture is greatly reduced. (Bare soils are a huge waste of the valuable water resource.) Those healthy soils and the humus they contain are the building blocks of virtually every ecological factor needed to maintain a biodiverse healthy ecosystem, storing valuable water, and sequestering large amounts of carbon needed to produce even more healthy plant life.

Profitability of the ranching operation is critical to the successful implementation and continuing improvement of the rangeland resource. Be it a profitable livestock operation, sale of viable ecosystem services or possible sale of carbon being stored within the soil. Short of government funding the successful carbon sequestering venture, that profit is the only viable reason for the effort required to move forward.

Recognizing that the limited rainfall, and the utilization of it, is the limiting factor in producing ecosystem services overall. Much research and time will be required to determine if carbon sequestering will have value in the west. Other services like water quality and volume may have a more predictable value to the rancher, as wildlife and social acceptance can be a large player in positive rangeland health. The ranchman is perhaps the best player in building improved rangeland as he controls the livestock and the potential rangeland benefits they have to offer. More simply said, grazing and rest of proper numbers of animals (Grazing management) is the one factor that can truly make a difference.

Not having experience with state and federal lands, I am naive in understanding the complexities of grazing those areas, however, careful thought is in order to find ways of implementing that rest from grazing that is key to overall rangeland improvement. Simply asking that stocking rate or density be adjusted is folly at best. That practice alone is proven within modern grazing operations to be relatively ineffective and at best only prolongs the poor rangeland health issue.

This is not a simple process to initiate and eventually accomplish, but numerous ranching operators are approaching-measuring great success in making the lofty goal of moving our depleted rangelands toward what they once were prior to European man's interference. Much has been lost that can never be recreated, but the success of those practitioners that have learned to utilize the tools available is providing some awesome evidence that it is worth the effort. The SRMs place in making this a practicable-successful process is providing the knowledge base of how to utilize those tools. Nothing more, nothing less. The problem may be in SRM membership and leadership understanding what tools are viable and what went wrong in the first place.

The recent article in Rangelands Vol 43, Issue 2 'Visions for large landscape drought resilience in rangelands' is an example of how SRM is failing in its approach to rangeland recovery and drought resistance. The article discusses in detail how to deal with the effects of drought and how to overcome the debilitating effect of the continuing drought cycle and its increasing recurrence west of the 100th meridian. It is disappointing the SRM is not actively discussing and providing detailed information as to how to improve the rangeland health by proper grazing management techniques that are proven to mitigate many of the debilitating effects of low rainfall periods. A short simple statement is all that is needed to begin this process. Healthy rangelands are not as severely affected by drought as those lands that are in degraded condition. A properly applied and managed grazing program utilizing rest and animal impact are the basis of that rangeland recovery.

The question has been raised by the SRM ecosystem services task force committee as to 'How can grazing management influence rangeland services?' The above statement is but a beginning of how to address this key issue. It must be a straightforward statement that does not try and cover past mistakes, but a statement that promotes true rangeland recovery and the benefits to those ecosystem services. Whatever they may be 'contrived' to be.

—Frank S. Price
Frank & Sims Price Ranch

RESOURCES TO LEARN MORE

American Prairie Conservation Act

An Assessment of Rangeland Activities on Wildlife Populations and Habitats

Audubon Conservation Ranching

Bee Better Certified

Conservation and Communities: A Study on Ecosystem Services — Earth Economics

Decline of the North American avifauna

Ecosystem Service Study | CA Ranching | Rangeland Trust

Ecosystem Services and Western U.S. Rangelands

Future Directions of Usable Science for Sustainable Rangelands: Water

Landscape characterization of floral resources for pollinators in the Prairie Pothole Region of the United States | SpringerLink

Managing Water to Create Sustainable Rangeland Systems

Rangelands Gateway- Payment for Ecosystem Services

Rangeland Ecosystem Goods & Services – Sustainable Rangelands Roundtable

Restoring Grasslands for Bird-friendly Beef

Sagebrush Rangelands Help Maintain Water Availability

USDA Conservation Reserve Program

USGS Rangeland Ecosystem Services

USDI National Seed Strategy

Wisconsin Bird-Friendly Beef

Xerces Pollinator Conservation Program

POTENTIAL ROLES AND OPPORTUNITIES FOR SRM

Our team has identified several potential roles for SRM in the conversation about Rangeland Ecosystem Services. This part of the document incorporates not only our own expertise, but also insights from a broad swath of SRM membership, gathered via an in-person and a virtual Campfire Conversation during the 2022 SRM Annual Meeting. Broadly, SRM roles include discovery, sharing, engagement, advocacy, and acting as a trusted liaison, which are not mutually exclusive categories.

DISCOVERY

SRM could play a role in the generation of new knowledge about ecosystem services, the benefits they provide, how to best support or enhance them via stewardship activities, and how to better link benefits with stewardship. Here, we include scientific, local, and other forms of knowledge generation. SRM is already well-positioned to support this role via, for example, nurturing the development of young rangeland scholars, supporting research and development on these topics, and creating opportunities for peer-to-peer networking that spark new knowledge generation activities. Specific opportunities in this area may include:

A. Creating a technical committee focused on this issue, which could identify knowledge gaps and enable networking among researchers, managers, and other knowledge generators.

B. Supporting the development of better measurement, reporting, and verification tools to quantify and value ecosystem services.

C. Focusing on this topic within SRM-sponsored student activities.

SHARING

SRM could play a role in sharing existing knowledge about rangeland ecosystem services and is already a central function of SRM. Here, we emphasize that learning and education within the SRM community should ideally be bidirectional and include opportunities for peer-to-peer engagement. Specific opportunities in this area may include:

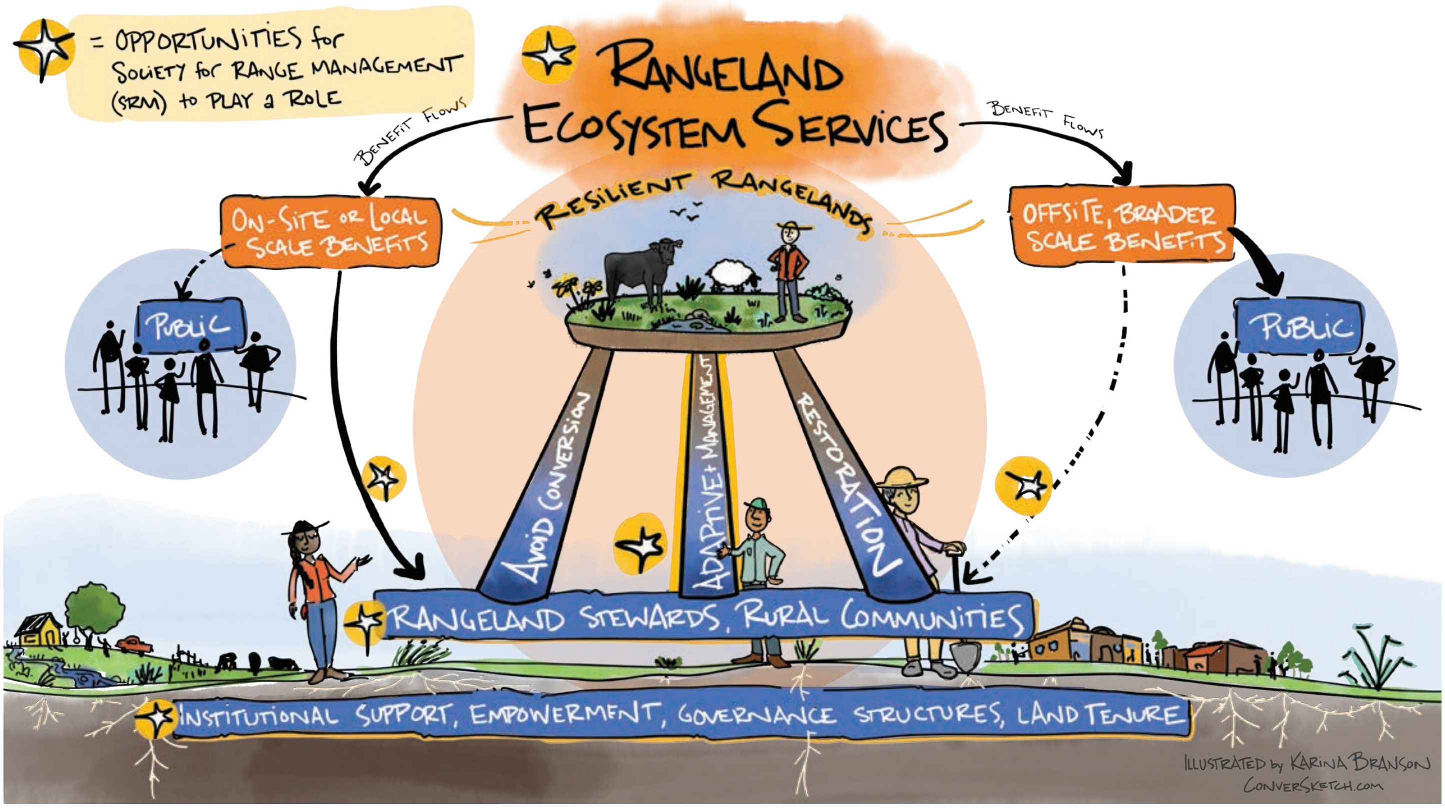
A. Creating a virtual hub for rangeland ecosystem service-related content and supporting said content through social media campaigns, webinars, and podcasts, to tell a more compelling story.

B. Supporting the sections to promote rangeland ecosystem services at the local level.

C. Creating space for SRM members to discuss this topic at the annual meetings.

D. Bringing in experts on this topic to present at SRM meetings (e.g., hosted symposia).

E. Sharing information about how to best support or enhance ecosystem services, and how to link public benefits with local stewardship activities.



Opportunities for SRM action exist in multiple locations within our conceptual framework.

ENGAGEMENT

SRM could play a role in engaging with people outside of SRM about issues related to rangeland ecosystem services. Key audiences for this type of engagement might include industry, policy-makers, and government institutions. Here, the emphasis would be on enhancing awareness of the importance of rangeland ecosystem services and rangeland stewardship, as well as current threats to both services and stewards. Specific opportunities in this area may include:

A. Sharing this report.

B. Engaging and learning from the stewards providing the services. They are safeguarding stewardship; we need to learn how to best support them.

C. Including ecosystem service briefings as part of national-scale SRM communications. Providing focused outreach to policy-makers in an effort to tell the story of rangeland ecosystem services.

D. Engaging industry and conservation groups regarding rangeland stewardship and production of rangeland ecosystem services.

E. Identifying and communicating about stewardship activities (Avoiding Conversion, Restoration, Adaptive Management) that are particularly important for sustaining or enhancing various services, or avoiding disservices.

ADVOCACY

Unlike many government agencies, SRM has the ability to advocate strongly and publicly for activities, policies and practices that benefit rangeland ecosystem services as well as rangeland stakeholders and communities, for example via Society-approved policy and position statements. Specific opportunities in this area may include:

A. Identifying and publicly encouraging rangeland stewardship activities that provide services and avoid disservices.

B. Advocating for better tools to quantify and value ecosystem services.

C. Recognizing producers and managers who are providing services via awards or other forms of positive encouragement.

D. Publicly supporting policies or market-based mechanisms that link public benefits with local stewardship activities (e.g., cost-sharing through large-scale collaborative stewardship projects).

ACTING AS A TRUSTED LIAISON

SRM may be able to play an active role in linking ecosystem service-related benefits with local rangeland stakeholders and stewardship activities. Specific opportunities in this area may include:

A. Supporting or facilitating public-private partnerships and large-scale collaborative projects that invest in the sustainability of rangeland ecosystem services.

B. Facilitating connections between the scientific community and land managers to strengthen the smooth transition between discovery and application of conservation for ecosystem service productivity.

C. Connecting rangeland stewards with marketing opportunities to strengthen the implementation of appropriate conservation activities that result in the production of ecosystem services.

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