Kane and Two Mile Ranches

Applied Research Plan

Grand Canyon Trust

Bureau of Land Management

U.S. Forest Service

Arizona Game and Fish Dept.

Northern Arizona University

University of Arizona

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Executive Summary

The Bureau of Land Management (BLM) and the U.S. Forest Service (USFS) manage more than 23-million acres of public lands in Arizona. Management of these federal lands requires balancing protection of natural and cultural resources with management for multiple uses. This document presents a research plan that was collaboratively developed by the BLM, USFS, Arizona Game and Fish Department (AZGFD), U.S. Geological Survey (USGS), Northern Arizona University (NAU), and the University of Arizona (U of A). The document outlines an integrated research agenda designed to inform land and resource management with sound science, enhancing the ability of management agencies to work with their partners and the public to integrate conservation objectives with the sustainable use of public lands on the Colorado Plateau. Six major research topics were identified that relate to primary management needs articulated by the land and wildlife management agencies and other interested parties. These topics include: 1) establishing reference conditions and refining baseline soils and ecological site information; 2) exploring livestock management strategies through designed experiments and rigorous observational studies; 3) examining effects of range management on wildlife species and wildlife habitat; 4) identifying environmental and management drivers of cheatgrass invasion; 5) developing and testing of effective methods for restoring arid and semi-arid rangelands; and 6) developing landscape-scale tools and applications for monitoring and adaptive management. Research needs, opportunities, approaches, and expected outcomes are identified for each of these topics.

Research approaches include:

1. Establishment of reference conditions and identification of ecological site descriptions through a mixed-methods approach involving soil surveys, the location of appropriate reference sites, existing datasets for mapping patterns of vegetation, and the compiling of historical and paleoecological information to understand the relationship of land use and climate patterns in driving ecological change.

2. Investigation of the effects of livestock grazing management on ecosystem attributes, such as plant productivity and diversity, biological soil crust development, soil properties, and soil and nutrient dynamics in arid landscapes, addressed via a multi-scaled approach incorporating small-scale grazing enclosures and exclosures, replicated across different elevations and soil types; and large, pasture-scale areas of livestock exclusion that are paired with comparable areas where continued grazing treatments will occur.

3. Investigation into the effects of range management on wildlife, including mule deer and pronghorn populations, through a combination of habitat use studies, vegetation measurements, remotely sensed information, and spatial data describing livestock management infrastructure and vegetation treatments. Pronghorn habitat use studies in House Rock Valley will be conducted in conjunction with the pasture-scale grazing and exclusion treatments described above, to identify effects of livestock presence and use on pronghorn habitat use and quality. In addition, mule deer condition, forage availability, and habitat use studies will be conducted on the west side of the Kaibab Plateau to identify factors affecting populations.

4. The identification of environmental conditions and management factors related to cheatgrass invasion, through spatial analyses and targeted experimentation that tests the effects of restoration treatments and

livestock grazing treatments on control, establishment, and spread of cheatgrass. Phenological studies that identify the patterns and predictability associated with cheatgrass life stages will also be incorporated.

5. The development and testing of restoration strategies (including alternative management treatments) intended to increase desirable vegetation and decrease invasive non-native species on arid and semi-arid rangelands through controlled, replicated experimentation.

6. The development of landscape-scale monitoring tools that can efficiently and accurately depict and predict on-the-ground changes in plant and animal communities in association with environmental and land use change. These tools will be developed using remote sensing techniques and statistical modeling frameworks, such as occupancy modeling, that leverage available ground data, often enhanced by carefully targeted field campaigns.

Research results can be integrated into management at a number of different levels of planning ranging from project -level to programmatic and regional planning processes. Coordination, communication, and discussion of planned projects and research results among the appropriate parties will be the critical first step toward achieving this objective. Approaches that can enhance opportunities to integrate research into management are described.

Introduction

The BLM and the U.S. Forest Service manage more than 23-million acres of public lands in Arizona. Management of these federal lands requires balancing protection of natural and cultural resources with management for multiple land uses. On the Colorado Plateau, additional research will be valuable in helping to guide land managers in decision-making related to integrating resource protection and use. Such research in support of the region's resources is an integral part of the research missions of Northern Arizona University, the University of Arizona, the Arizona Game and Fish Department, and the U.S. Geological Survey. The Kane and Two Mile Ranches provide a unique opportunity, whereby North Rim Ranches (owned by Grand Canyon Trust), as the holder of extensive grazing permits and leases for federal lands on the Colorado Plateau, is in a position to participate with the federal land management agencies and other partners in managing livestock for research purposes, while continuing commercial livestock production and range stewardship activities. This arrangement will generate knowledge and tools that can inform sustainable resource management practices on the Colorado Plateau and elsewhere during a period of rapid environmental change.

This document presents a research plan that has been collaboratively developed by the above-mentioned parties, who have contributed their expertise in land management, conservation, and applied forest, range and wildlife science. This research plan addresses specific management needs that have been articulated by cooperating land and wildlife management agencies and other interested parties. The approaches identified in this document are intended to formulate, test, and demonstrate practices that may contribute to the long-term sustainability of native plant and wildlife communities, while addressing livestock production and management objectives.

Management needs will be met by addressing the following collaboratively identified challenges through scientific inquiry:

1. Across the Kane and Two Mile Ranches and in particular in House Rock Valley and on the Paria Plateau, ***there is a need to identify reference conditions and ecological site potential at higher resolution and in a systematic and scientifically defensible manner so that desired plant community and other objectives can be identified, and appropriate management actions aimed toward achieving desired conditions can be implemented.***

2. Livestock grazing in arid and semi-arid lands such as House Rock Valley and the Paria Plateau has the potential to impact native plant communities and soil conditions. Thus, ***there is a need to better understand which livestock management strategies can most effectively lead to meeting desired ecological conditions across these landscapes.***

3. Habitat for wildlife species, including mule deer and pronghorn, can be influenced by range management, particularly where non-native invasive plants compete with native species. Specifically, the most significant management concerns include: 1) the influence of different levels of forage utilization by livestock, impacts of management on the distribution of water and fences, and other factors (e.g., vegetation management, etc.) on pronghorn population recruitment and survival in House Rock Valley; and 2) potential competition between livestock and mule deer for limited winter habitat on the west side of the Kaibab Plateau. Beyond this, ***there is a need to better understand how***

range management affects forage, cover, and other habitat attributes for a variety of key wildlife species (including House Rock Valley chisel-toothed kangaroo rat (Dipodomys microps leucoti), a BLM sensitive species) during critical time periods, and also how livestock management infrastructure influences wildlife habitat use and survival.

4. The Bridger Knoll Complex fire burned 53,000 acres of the west side of the Kaibab Plateau in 1996. Significant cheatgrass invasion ensued and the species has become dominant across large tracts of the landscape. The possibility of similar outcomes in more recent and future burn areas is a significant threat to the ecological integrity and productivity of the area. ***There is a need to better understand the influence of fire and other environmental and management factors influencing cheatgrass invasion, including how livestock can be managed and used as a tool to avoid further cheatgrass dominance and expansion.***

5. Restoring arid and semi-arid rangeland ecosystems is inherently difficult, due primarily to low and variable rates of precipitation. Despite this difficulty, managers recognize the need to inhibit cheatgrass invasion on the west side of the Kaibab Plateau and to enhance recovery of sensitive soils in House Rock Valley. There is also a need to increase or maintain shrub and perennial grass cover, stabilize soils, and improve watershed conditions in multiple locations across House Rock Valley in order to meet desired conditions. Overall, ***there is a need to better understand how factors such as species and site selection, seeding rates, soil chemistry, and seed bed preparation influence the efficacy of treatments intended to re-establish or otherwise benefit native and desirable plant species, especially in House Rock Valley and on the west side of the Kaibab Plateau.***

6. Monitoring is essential to inform and direct effective adaptive management approaches, yet the costs of monitoring on large landscapes often exceed available resources. In this context, there is a need to: 1) understand and predict patterns of nonnative species invasions, thereby supporting efforts to prioritize efforts and develop cost-effective control and mitigation actions; and 2) predict plant community productivity for the purpose of informing flexible livestock and wildlife management strategies. ***There is a need to develop landscape-scale monitoring tools that can efficiently and accurately depict and predict on-the-ground changes in plant communities, particularly invasive species, in a manner that supports timely management response.***

Establishing Reference Conditions and Refining Ecological Site Descriptions

Statement of need

NRCS Ecological Site Descriptions (ESDs) and the USFS equivalent, Terrestrial Ecosystem Units (TEUs), provide important tools for land managers, allowing them to stratify the landscape using physical and biological characteristics. ESDs form a fundamental unit for monitoring, assessment, interpretation of resource hazards and opportunities, prioritizing and selecting appropriate management actions, and for setting ecological objectives for management based on site potential (Bestelmeyer and Brown 2010). The utility of ESDs for these purposes is contingent upon having good and accurate information describing reference conditions. Across the Kane and Two Mile Ranches and in particular in House Rock Valley and on the Paria Plateau, there is a need to identify reference conditions and ecological site potential in a systematic and scientifically defensible manner and at higher resolutions than is currently the case so that desired plant community and other objectives can be identified, and so that appropriate management actions aimed toward achieving desired conditions can be implemented.

Background/Literature Review

Establishing Reference Conditions

Identification of reference conditions and the ecological potential of arid and semi-arid landscapes is paramount to establishing ecological targets and management activities aimed at achieving desired conditions (Herrick et al. 2006). Yet this information is typically difficult to come by, particularly in places like House Rock Valley and the Kaibab Plateau where few places were left unaffected by historical livestock grazing (prior to the Taylor Grazing Act). Approaches that integrate both historical and current information relating to land use and ecological condition provide some of the best opportunities to identify reference conditions and the processes leading to maintenance of and departure from those conditions (SER 2004, Courtois et al. 2004, Holecheck et al. 2006, Sprinkle et al., 2007, Davies et al. 2009). Paleoecological studies (e.g., Fisher et al. 2009) can provide valuable insights into the effects of historical land use and environmental change and context for establishing baseline conditions (Swetnam et al. 1999). Compiling historical accounts, agency documents, photographic evidence, and local knowledge are also important to deciphering management histories and historical conditions that influence current-day ecological conditions and trajectories (SER 2004). Perhaps the most practical approach to establishing reference conditions is to locate existing sites that have had minimal anthropogenic disturbance and represent present-day site potential. These may be found in parks, protected areas, road shoulders, and/or isolated plateaus. Four roughly 40-yr old livestock exclosures exist on the K2M (two on Paria Plateau and two in House Rock Valley) and provide some valuable information about ecological recovery and site potential, however the limited number and size of such exclosures limit the inference that can be drawn from these, given the wide range of soil and ecological site types that occur, particularly across House Rock Valley.

Ecological Site Descriptions as a Foundational Unit for Monitoring and Management

Stratification of the landscape into ecological sites, units that can support different kinds and amounts of vegetation due to soil, topographic, and climatic constraints, is a widely employed system that is used by the BLM to set ecological targets and management objectives based on the ecological potential of a site, as determined by reference conditions and our best understanding of how that site type responds to use or management (Herrick et al. 2006). An extensive body of work exists relating to the subject of ESDs and state and transition model development, with much of this research on methodologies being developed through the Jornada arid land research programs at New Mexico State University (http://jornada.nmsu.edu/(http://jornada.nmsu.edu/). Moseley et al. (2010) provides a primer for developing ecological sites through a multi-step process that involves researching reference conditions and land use histories, conducting field reconnaissance to identify reference sites, hypothesizing ecological site concepts, and testing them using field-collected validation data. A recent special issue of Rangelands (http://www.srmjournals.org/doi/full/10.2111/RANGELANDS-D-10-00083.1) provides an excellent overview of theoretical and methodological foundations for developing ESDs and state and transition models. Generalized conceptual state and transition models for dryland ecosystems on the Colorado Plateau are presented in Miller (2005). While this report was developed to assist National Park Service policymakers and researchers in the consideration and selection of vital signs for dryland ecosystems in Park Service units located in the Colorado Plateau, the document can also be useful for developing and/or improving hypotheses regarding monitoring of ecological sites in this region.

Status of Ecological Site Descriptions in House Rock Valley and Paria Plateau

The current ESDs for the Paria Plateau and House Rock Valley are based on Level 3 soil surveys conducted by the NRCS in the late 1970s and early 1980s. While the House Rock Valley soil surveys do a fairly good job of differentiating soil conditions, the Paria Plateau survey is rather coarse (S. Cassady, personal communication), and may not adequately distinguish variation in soils for the purposes of rangeland monitoring and management. Following completion of the soil surveys, the landscape was partitioned into Range Sites, the precursors to ESDs, which were based on soil types and differences in forage availability and palatability (S. Cassady, personal communication). The current ESDs are a reinterpretation of the range site descriptions, and while the plant lists may remain accurate, the estimation of what could appropriately be expected of these plants (due to varying soil conditions) are coarse and unproven. Thus, there is both a need and opportunity to develop, update and improve data related to ESDs, watershed function and condition, reference conditions, productivity, and ecological dynamics.

Research and Management Opportunities

To date, there has been no comprehensive effort to systematically and empirically document historical conditions in grassland ecosystems of House Rock Valley and/or the Paria Plateau, nor has there been this type of effort to document the range of reference conditions associated with ecological site types in these places. This information could prove invaluable, as it would provide a strong foundation for establishing realistic ecological targets for management and for designing research, monitoring, and assessment programs. While little information currently exists to provide a comprehensive view of historical conditions across House Rock Valley and the Paria Plateau prior to the introduction of domestic grazers, packrat midden studies, stratigraphic studies, and pollen dating have the potential to provide important information relating to the effects of environmental and anthropogenic changes to these ecosystems. In addition, locating existing protected and minimally disturbed areas that can represent reference conditions will greatly improve our understanding of appropriate management targets and ecological site potential. While ESDs currently exist for House Rock Valley and the Paria Plateau, there is a need to update and improve these due to 1) the coarse resolution of the soil survey for the Paria Plateau, and 2) and because the site descriptions are incomplete and dated. Moreover, there is a wealth of new information available that describes soil texture, stability, vegetation cover, vegetation species, and vegetation type in the GCT assessment plot dataset that could help to inform a refinement of ESDs. Coupling this information with comprehensive soil surveys and remotely sensed information would provide opportunity to efficiently improve the current ESDs.

Components of the Research Program

- Identify the level and intensity of soil survey that should be conducted on the Paria Plateau and House Rock Valley.
- Conduct soil survey on the Paria Plateau and remap ecological sites, leveraging existing vegetation and soils datasets (e.g., GCT data, BLM Key Area data, and remote sensing techniques).
- Conduct detailed soil surveys at BLM Key Areas and other monitoring sites to identify how representative these locations are of the ecological site types.
- Collect evidence to document and establish reference conditions for ecological sites identified by conducting site visits to possible reference sites (e.g., isolated plateaus, road shoulders, existing long-term exclosures)
- Collect evidence to elucidate historical conditions and trajectories associated with environmental change and land use history
    - Compile historical accounts, photography, maps, interviews, literature review, agency reports, ranch records, and scientific publications
    - Conduct paleoecological studies using local and regional tree-ring studies, pollen, stratigraphic studies, or packrat middens.
- Identify alternate states and potential drivers (accomplished through other research described in this plan) and develop ecological site-specific state and transition models.

Scale(s) of Implementation

Scale of implementation ranges from landscape (soil survey and ESD mapping) to site-specific (for discrete monitoring applications)

Expected Outcomes

- Reference conditions and ESDs will provide a solid foundation for research and monitoring activities as well as the development of realistic management objectives.

- State and transition models resulting from this and other components of the research plan will provide important information to help guide management activities aimed at achieving and maintaining desired conditions.

Datasets Available

- BLM Key Area datasets

- GCT Baseline Assessment datasets

- NRCS soils and ecological site GIS
- Ecological site keys developed by NRCS
- USFS Terrestrial Ecosystem Units and Soils datasets
- USFS frequency transects

Potential Partners

- NRCS

Potential Funding Sources

- Agriculture and Food Research Initiative
- NIFA Fellowships Program
- Rangeland Research Program
- Sustainable Agriculture Research and Education (SARE)
- National Landscape Conservation System

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Testing Livestock Management Strategies on Arid and Semi-Arid Public Lands

Statement of need:

Management of public lands requires integrating protection of natural and cultural resources with management for multiple land uses. On arid and semi-arid landscapes such as House Rock Valley and the Paria Plateau, livestock management has the potential to impact native plant communities and soil conditions. Thus, there is a need to better understand which livestock management strategies can most effectively lead to meeting desired ecological conditions across these landscapes.

Background/Literature Review:

<u>History of grazing and resource condition in the area of House Rock Valley and the Paria Plateau</u>
As with many areas across the Arizona Strip, domestic livestock were introduced to House Rock Valley and the Paria Plateau in the late 1800s. From the 1880s to the 1930s livestock use was excessive, peaking with tens of thousands of sheep, cattle, horses, bison, and goats (Seegmiller, 1999). Historical photos and accounts of House Rock Valley suggest that substantial ecological damage occurred during this time period, with many areas becoming denuded of vegetation, followed by significant soil loss. As late as 1968, sediment yield from erosion was estimated to be in the 0.27-0.70 acre-feet per square mile range for the House Rock Valley allotments, among the highest on the Arizona Strip (Vermillion Grazing EIS V1, 1979). Since the 1930s, livestock use has steadily declined and is now 60% lower in the Soap Creek and Badger Creek Allotments, with 7,038 AUMs (~ 1,000 head for 7 months) currently permitted (Soap Creek Standards for Rangeland Health Assessment, 2002). Grazing on the Paria Plateau followed a slightly different trajectory, as grazing was limited to just a few thousand goats due to rough terrain and lack of surface water until the 1950s, when several wells and a water distribution system was established. Since then, authorized use for cattle has remained in the range of 15,000- 18,000 AUMs (1,200 – 1,500 head year round; Trudeau, 2006). Although photographic evidence suggests that range conditions have improved dramatically over the past several decades with improved livestock management, livestock can still affect rangeland resources.

<u>Effects of livestock grazing management on Colorado Plateau arid and semi-arid ecosystems</u>

A substantial body of work addresses the effects of livestock grazing systems and management on arid and semi-arid landscapes. A brief overview of the effects of livestock grazing management on ecological structure and function in arid and semi-arid ecosystems on the Colorado Plateau, the intermountain west, and the southwestern U.S. is provided below. Note that livestock interactions with cheatgrass and wildlife are addressed in separate sections of this document.

Effects of Livestock Management on Plant Productivity

Forage plant productivity can be strongly influenced by stocking rate and associated grazing intensity (Holechek et al. 1999). Conservative stocking associated with utilization levels of 30-35% in arid and semi-arid rangelands can maintain or improve vegetation productivity, livestock productivity, and financial returns, as compared to moderate to heavy stocking (Holechek et al. 1999). A recent review (Holechek et al. 2006) found that long-term managed grazing at light to moderate levels (< 55%

utilization) can have variable effects and has the potential to decrease, maintain, or increase plant productivity, in semi-arid systems, but specific factors influencing these results were not described. Holechek (2006) also found that long-term grazing exclusion can result in vegetation stagnation. Based on these results, Holechek (2006) recommends maintaining average long-term utilization levels below 40% to maintain or increase plant productivity. Maintaining low stocking rates and use intensity is particularly important during instances of drought; high intensity grazing during drought resulted in reduced productivity, reduced diversity, and increased cover of non-native plants (Loeser et al. 2007) and can decrease germination, increase mortality, and increase population turnover of certain species (Chambers and Norton 1993). Holechek (2006) found that light to conservative grazing may actually benefit grasses during drought compared with no grazing. Season of use is also important, and plant productivity and reproduction are enhanced when grazing is deferred during the early stages of growth and reproduction (Chambers and Norton 1993, BLM 2001). However, in arid and semi-arid shrublands, timely adjustments to animal numbers and practices that disperse grazing activities at regional and landscape scales may be more effective in maintaining or improving rangeland health than fencing and rotational grazing systems (Bailey and Brown 2011).

Effects of Livestock Management on Plant Diversity and Community Structure

As reviewed in Jones 2000, the effects of livestock management on plant diversity and community structure are variable across the arid west. Based on a coarse-resolution global analysis of grazing effects on plant communities, plant communities on the Colorado Plateau, which evolved without abundant large herbivores and often have low annual net primary production, may be particularly sensitive to grazing relative to other arid ecosystems (Milchunas and Lauenroth 1993), as well as to other human uses (Schwinning et al. 2008) but the directional changes are difficult to predict. In part, this is due to a dearth of replicated experiments that relate ecological change to specific management factors such as grazing intensity (Jones 2000, Curtin 2002) and because changes are dependent upon interactions with fire, climate, soils, grazing history, and type of animal grazing (Milchunas 2006). For example, studies have shown increases (Harris et al. 2003), decreases (Floyd et al. 2003), and no change in woody vegetation (reviewed in Milchunas 2006) as a function of grazing and similar ranges of responses exist for measures of plant diversity (Jones 2000; Courtois et al. 2004, Holechek et al. 2006, Sprinkle et al., 2007, Davies et al. 2009). Impacts in riparian systems have been shown to be much more predictable and pronounced (e.g., Fleishner 1994, Belsky 1999) than in some upland systems in northern Arizona (Loeser et al. 2005, 2007).

Effects of Livestock Management on Biological Soil Crusts and Soil Processes

There is an extensive body of literature that addresses effects of ungulates on soil nutrient dynamics and microbial communities across the globe (e.g., Kieft 1994, McNaughton et al. 1997, Bardgett et al. 2001) with results ranging from positive to neutral to negative effects, depending on the balance of mechanisms that alter the quantity and quality of resources entering the soil (Bardgett and Wardle 2003). These effects may be mediated by the type of herbivore(s) grazing, overall productivity of the system, and by anti-herbivore defenses of plant communities, and there is a need for more research on these topics (Bardgett and Wardle 2003). On the Colorado Plateau, the effects of livestock management on biological soil crusts and soil processes have gained increasing attention. There is a widening body of research that suggests that grazing animals (i.e. livestock or wildlife) can affect cover and composition of biological soil crusts (Brotherson et al. 1983, Jones 2000, Floyd et al. 2003) and this has strong implications for increased soil erosion (Belnap and Gillette 1998, Neff et al. 2005) and altered nutrient dynamics (Gass and Binkley 2011, Neff et al. 2005, Fernandez et al. 2008). Implications for management are not specific, however, because these studies often lack a quantification of or explicit descriptions of stocking or utilization rates, season of use, or other parameters describing grazing management. Both the severity of impact (Herrick et al. 2010) and recovery rates (Belnap and Gillette 1998) are strongly dependent on soil texture. While no studies were found that explicitly address relationships between grazing intensity and soil crusts, one study investigated the impacts of seasonal grazing on cryptogamic soil crusts. This study concluded that controlled winter grazing has minimal impacts on the total cryptogamic plant cover that protects soil surfaces on cold desert range ecosystems – frozen soils in the winter, combine with some insulation of snow cover, mediated hoof impact on the cryptogamic cover (Memmott 1998).

Research and Management Opportunities:

Despite the extensive body of literature related to the impacts of grazing and livestock management strategies on arid and semi-arid rangelands, significant knowledge gaps remain. Based on a review of the literature, there is a clear need to bridge the gap between range management studies, which tend to focus on forage production and animal performance, and studies that attempt to address a broader array of biotic and abiotic responses and functions, at both community and ecosystem scales (e.g., plant diversity, biological soil crust development, soil properties, and soil and nutrient dynamics). This is particularly crucial given the management direction for managing the timing, duration, frequency, distribution, and intensity of livestock grazing in a manner that minimizes erosion and maintains biological soil crusts, plant and litter cover, and native vegetation communities on BLM lands (Arizona Strip RMP, 2008). Moreover, there is a need to conduct controlled, replicated, long term studies on the Colorado Plateau at multiple spatial scales to better understand what levels of grazing are compatible with the need to move ecosystem states toward desired conditions (or maintain existing conditions where objectives are already being met), and identifying where rest and or targeted grazing can be effective in restoring lands that do not meet desired conditions (Curtin 2002). These research needs could be addressed through a multi-scaled approach that incorporates both grazing enclosures and exclosures, replicated across elevational and soil gradients, complemented with observation studies where larger, pasture-scale areas of livestock exclusion that can be paired with areas of managed grazing.

<u>Components of the Research Program</u>

- Establish a network of small-scale grazing exclosures, experimental enclosures, and pasture-scale areas of livestock exclusion, with a focus on major soil and/or ecological site types found across the Southern Colorado Plateau.

- Conduct controlled small-scale experiments by varying timing, duration, and/or intensity of grazing and test effects on soil stability, vegetation composition and cover and/or biological soil crusts across different ecological site types.

- Conduct management experiments by varying timing, duration, and/or intensity of grazing at the pasture scale to test effects on soil stability, vegetation composition and cover, biological soil crusts, and/or wildlife habitat use across different soil and/or ecological site types.

Scale(s) of Implementation

Studies are best conducted at multiple scales to enable conclusions to be drawn from a spectrum of evidence types ranging from controlled, small-scale experiments, to larger scale studies that capture the inherent temporal and spatial vagaries of arid and semi-arid ecosystems at management-relevant scales and allow inference that can inform decisions related to maintaining economically sustainable herd numbers and best practices for herd management. Studies will require long time periods (e.g., multi-year to decadal) across a variety of ecological sites and scales for appropriate conclusions to be drawn regarding management effects on ecological trajectories.

Expected Outcomes

- Increased understanding of the relative effects of various livestock management practices (including rest) across ecological site types (e.g., intensity, frequency, season of use, and livestock distribution techniques) on soils, vegetation, wildlife habitat, and ecosystem processes
- Evaluation of the efficacy of various restoration, conservation, and livestock management options, singly and in combination, in reaching and sustaining desirable site conditions.

Datasets Available

- BLM Key Area datasets
- USFS frequency transects
- GCT assessment plot data
- Livestock utilization data
- Historical livestock actual use data
- Climate/Precipitation data
- Ecological Site Descriptions Terrestrial Ecosystem Units, soils, and vegetation GIS
- Results from previous, ongoing, and future field work and experiments

Potential Partners

- Canyonlands Research Center
- BLM Research Ranch Network

Potential Funding Sources

- Rangeland Research Program
- NIFA Fellowships Grant Program
- National Landscape Conservation System

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Effects of Range Management on Wildlife

Statement of need:

Wildlife species have habitat requirements that can be influenced by range management, particularly in areas where non-native invasive plants are displacing preferred native forage species or transforming native plant communities. On the Kane and Two Mile Ranches, the most significant management concerns include: 1) the influence of forage utilization by livestock, distribution of water and fences, and other factors (e.g., vegetation management, etc.) on pronghorn population recruitment and survival in House Rock Valley; and 2) factors affecting mule deer habitat and the population's habitat use. Beyond this, there is a need to better understand how forage use by livestock affects food, cover, and other habitat attributes for a variety of key wildlife species (including House Rock Valley kangaroo rat, *Dipodomys microps leucoti*, a BLM sensitive species) during critical time periods, and also how livestock management infrastructure influences wildlife habitat use and survival. The review and approaches described below relate primarily to two focal species: pronghorn and mule deer. Future documents may be developed in a similar format to address information gaps and research approaches for other species of interest.

Background/Literature Review:

Management History of Pronghorn in House Rock Valley

A brief natural history of pronghorn on the Arizona Strip is reviewed on the BLM website (http://www.blm.gov/az/st/en/prog/wildlife/pronghorn.print.html). Pronghorn historically occupied the Arizona Strip but were eliminated in the early 1900s. They were reintroduced in 1961 and management for hunting began in 1988. The House Rock Valley population size ranged from 90 to 156 animals over the past decade, and population size is strongly correlated with precipitation, as fawn survival and recruitment is lower during periods of drought (AZGFD 2009). According to the Pronghorn Management Plan (AZGFD 2009), the majority of suitable pronghorn habitat in House Rock Valley is of moderate quality, with very little high quality habitat. This plan also indicates that large monotypic stands of sage encroaching upon the grasslands. This results in loss of habitat, decrease in forage species richness, blocking of travel corridors, and an increase in predation. Besides the encroachment of shrubs, low species diversity was identified as one of the main limiting factors for pronghorn in House Rock Valley. Besides lack of nutrition, low species diversity also relates to lack of fawning cover. Low plant diversity was likely the result of prolonged (historic) overgrazing by livestock and fire suppression (AZGFD 2009).

Nutritional requirements for pronghorn and interactions with livestock grazing

Pronghorn rely heavily on forbs and shrubs for forage and nutrition (Harveson 2006). Of these two categories, forbs are the preferred diet for two main reasons 1) they have high protein and digestibility relative to shrubs and grasses, and 2) succulent forbs can provide water, reducing the need for pronghorn to find surface water sources (Autenrieth et al. 2006). Perennial forbs are preferable to annual forbs, given the reliability of this food source year-round (Richardson 2006). Shrubs are also an important component of the pronghorn diet, particularly when shorter stature vegetation is covered by snow, and during droughts, when forb production is low (Richardson 2006).

Given cattle preferences for grasses and pronghorn preferences for forbs and shrubs, diet overlap between cattle and pronghorn is not high, but can occur when grass or forb availability is limited and one or the other species is forced to shift to a common food source (e.g., during drought or heavy snow conditions, or due to overgrazing; Yoakum 2004). Livestock grazing history is likely to strongly influence community composition (Autenrieth 2006) and this can affect pronghorn positively or negatively, depending on whether or not the resultant vegetation community contains high proportions of palatable species and how it has influenced habitat structure. When rangelands are in healthy ecological conditions with an abundance of grasses, forbs, and shrubs, dual foraging by pronghorn and livestock can be compatible (Autenrieth 2006).

<u>Vegetation structure needs for pronghorn habitat and interactions with livestock grazing in arid and semi-arid shrub and grasslands.</u>

Pronghorn require habitats that afford high visibility and high mobility (Richardson 2006). This translates to places with low vegetation stature (e.g., 10-18”). Areas with high vegetation stature (e.g., > 25”) tend to be avoided (Goldsmith 1990), except when used for thermal cover (Richardson 2006). While low shrub densities can provide beneficial forage and some hiding cover, high shrub densities (e.g., when cover is > 40%) can impede movement and, thus, they provide less suitable habitat (Yoakum 2004).

Pronghorn are a “hider” species, and fawns spend up to 90% of their first few weeks in life hiding (Fichter 1974, Byers and Byers 1993). Climate and annual precipitation are the primary factors influencing hiding cover adequacy. Livestock grazing can also be influential by reducing standing biomass in the short term (Ockenfels 1994), and affecting productivity and/or community structure over the long term, with implications for forage availability and mobility (Richardson 2006). There is conflicting evidence regarding vegetation composition requirements for birth sites and fawn bedding sites, due to the wide variety of habitat types in which studies have been conducted. Low shrub cover was preferred in a Chihuahuan Desert study (Canon and Bryant 1997), while higher shrub cover sites were preferred in the sagebrush-steppe of Wyoming (Alldredge et al. 1991), and high grass cover was preferred in a South Dakota mixed-grass prairie (Jacques et al. 2007). Despite differences in cover type, data from these three studies indicate that vegetation height of bedding sites consistently falls in the range of 12-23”. Since no studies have examined fawn cover preferences in House Rock Valley, information gleaned from these studies may serve as a starting point for identifying fawn cover preferences for House Rock Valley pronghorn.

<u>Influence of livestock management infrastructure on pronghorn habitat use and survival</u>

Livestock management infrastructure, such as artificial waters and fences, can strongly influence pronghorn habitat. In the desert Southwest, pronghorn are most frequently found within two miles of water (Ockenfels et al. 1994). Pronghorn water needs vary considerably, depending on climate factors, life stage, availability of succulent vegetation, and physiological efficiencies and demands (Richardson 2006). Thus the importance of water distribution systems for livestock to pronghorn populations varies on a site-specific basis and is most critical during gestation and lactation times (Harveson 2006). Livestock tend to concentrate around water sources, so cover and forage requirements may not be met in places near to water; decreased vegetative cover can affect fawn survival by reducing their hiding cover (Autenrieth 2006).

Pronghorn require high mobility for survival and fences can restrict their movement, with implications for predator evasion and access to forage, habitat cover, and water. While removal of fences is the best way to facilitate pronghorn movement (Autenrieth 2006), herd management and/or strategic fencing provide opportunities to improve pronghorn movements. Fence adjustments to allow pronghorn passage can also help this situation, although the usefulness of these approaches varies among populations (Tom McCall, pers. comm.).

Management history of mule deer and livestock on the Kaibab winter range

The management history of the Kaibab mule deer herd is well-documented. Deer populations on the Colorado Plateau were reduced to very low levels during the late 1800s and early 1900s because of unregulated hunting (Watkins et al. 2007). Predator removal and other social and environmental factors led to a rapid increase in the mule deer population, which peaked at about 100,000 animals in the 1920s. This population boom, coupled with drought and excessive livestock grazing, led to degradation of the range and a rapid decline in the mule deer population size. Since then, mule deer numbers have fluctuated between 5,000 and 15,000 animals, in response to a number of possible causal factors, including changes in precipitation, fluctuating predator numbers, hunting management approaches, and competition with livestock (Shaw 1997).

Livestock and mule deer historically shared the same winter range on the west side of the Kaibab Plateau. Livestock numbers on the winter range have steadily declined since the early 1900s, going from 20,000 head in 1920 to 2,500 head in 1940 (Trudeau 2006), then from 2500 head to 1000 head between 1970 and 1986 (McCullough and Smith 1991). In 1996, the Bridger-Knoll Complex fire burned approximately 2/3 of the mule deer herd's winter range. Extensive cheatgrass invasion followed, and is continuing to expand. In a 2000 management decision, livestock grazing was limited to short-duration spring use for up to 800 head due to poor resource conditions and competition with mule deer, and two of the six pastures were closed to livestock grazing (Kane EA, 2000). Continued concerns about resource conditions and carrying capacity for mule deer have led to extensive habitat restoration efforts on the winter range.

Nutritional and habitat requirements for mule deer and interactions with livestock in winter

Watkins et al. 2007 provides a comprehensive review of the primary literature related to nutritional and habitat requirements of mule deer on the Colorado Plateau, including interactions with livestock. Mule deer are able to digest vegetation high in lignin. Shrubs are important components of winter diets but trees (e.g., juniper) are used only when other forage items are inaccessible due to deep snow and are considered "starvation foods". Grasses and forbs are major components of the diet when available at various times of the year. Overall, spring and summer forage is most important for meeting nutritional requirements for reproduction and summer/fall diet is important for accumulating fat stores and lean body mass. In the winter, body stores tend to be depleted and forage quality is an important control on the rate of depletion. On the Kaibab Plateau, four-wing salt bush, winterfat, big sagebrush, cliffrose, squirreltail, western wheatgrass, apache plume, and crested wheatgrass offer the highest digestible protein and metabolizable energy for wintering mule deer (Miller et al. 2009). Establishing species such as winterfat and four wing saltbush, which are actively selected by mule deer, through restoration treatments may improve nutritional quality of winter habitat on the west side of the Kaibab Plateau (Miller et al. 2009).

Numerous studies indicate that there is little significant dietary overlap between cattle and mule deer in general (Watkins et al. 2007) and there is little evidence for competition for forage on the Kaibab Plateau, specifically (Salas 1986). As reviewed in Watkins et al. 2007 (p 17) there is evidence suggesting that livestock and mule deer compete for space in arid and semi-arid regions, as cattle can displace mule deer from preferred foraging areas (e.g., Loft et al. 1991, Stewart et al. 2002, Coe et al. 2004, Kie et al. 1991, and others) and this may affect deer productivity (Watkins et al. 2007).

Research and Management Opportunities

There are many possible ways in which livestock management in House Rock Valley may be influencing pronghorn populations, given the presence of range fences and water distribution systems. It is unknown how much competition for forage occurs in this area, particularly during drought, and to what degree the infrastructure may affect pronghorn population dynamics. Coupling pronghorn habitat quality and use studies with grazing treatments described in the previous section will provide an opportunity for a better understanding of how livestock management influences pronghorn habitat quality, habitat use, and movement; in turn, providing insight into best management practices that ensure protection of pronghorn.

The Kaibab mule deer herd is of high social and economic importance nationwide and to local communities. Given current management objectives for the herd, there is a need to understand how deer have responded to extensive plant community changes on the winter range, particularly the loss of native forage plants and spread of invasive weeds. Similarly, there is a need to understand effects of management actions undertaken in response, including reseeding, development of new water sources, and modification of livestock grazing practices. Post-winter forage utilization and mule deer condition studies (both currently underway by AZGFD) can provide insights into the type and amount of forage used by mule deer, their nutritional status, and how this varies annually. Radio-collar studies examining mule deer habitat use and movements in relation to vegetation, topography, livestock management infrastructure, and areas used by livestock would be instrumental to gaining a better understanding of potential livestock – wildlife interactions. Mule deer habitat use studies could also be overlaid with remotely sensed information describing snow cover, snow depth, and/or plant cover to provide information on habitat constraints and use during this critical time period. Finally, near infrared spectroscopy of feces has been applied to study dietary quality and composition in a number of wild and domestic herbivores (Showers 2006, Greyling 2002, Keating 2005, Walker 2002) Additionally, animal performance and physiological characteristics can be non-invasively monitored using this technique (Foley 1998, Tolleson 2005). Fecal NIRS could be employed to augment vegetation, GPS collar and other wildlife/livestock interaction data collected to help determine the effects of habitat management on diet.

A variety of other wildlife species exist on the Kane and Two Mile ranches that are of high priority to managers, including a wide variety of bird species, small mammals such as the House Rock Valley chisel-toothed kangaroo rat, reptiles and amphibians, other game species (e.g., bighorn sheep, *Ovis canadensis*), and many others. Little is known about the habitat requirements of many of these species, and there is much opportunity to focus research efforts on these species as a part of this research program.

Components of the Research Program

Pronghorn in House Rock Valley

- Assess pronghorn fawn habitat cover suitability in House Rock Valley using literature-derived indicators and extensive monitoring and assessment data collected by BLM and GCT.

- Determine pronghorn fawn habitat cover preferences in House Rock Valley using radio collars in conjunction with vegetation measurements.

- Compare pronghorn habitat cover quality and forage availability among grazing treatments.

- Utilize near infrared spectroscopy of feces to monitor diet quality and animal performance as affected by such factors as grazing management, infrastructure, precipitation, and others.

- Use camera trapping techniques to compare pronghorn use of livestock waters among grazing treatments and/or in relation to surrounding forage and habitat quality.

- Leverage existing data and expert knowledge on the occurrence of pronghorn and their habitats to model and map patterns of space use, resource use, and connectivity in relation to vegetation, topography, and livestock management infrastructure and test these using radio collar studies.

Mule Deer on the Kaibab Winter Range

- Conduct forage utilization and mule deer condition studies.
- Utilize near infrared spectroscopy of feces to monitor diet quality and animal performance as affected by such factors as grazing management, invasive species, precipitation, and others.
- Estimate habitat availability and plant cover during winters of varying severity using retrospective time series analyses of remotely sensed information.
- Leverage existing data and expert knowledge on the occurrence of mule deer and their habitats to model and map patterns of space use, resource use, and connectivity in relation to vegetation, topography, and livestock management infrastructure and test these using radio collar studies.
- Equip mule deer with GPS collars to obtain fine-scale information on habitat use and movements and to test hypotheses related to habitat use (see above).

Other Wildlife Species

- Leverage existing data and expert knowledge on the occurrence of wildlife species and their habitats to model and map patterns of space use, resource use, and connectivity in relation to vegetation, topography, and livestock management infrastructure and test these by conducting animal habitat use studies.

<u>Scale(s) of Implementation</u>

Forage distribution and abundance as well as habitat use studies would be conducted at the landscape scale using existing ground measurements and remotely sensed data. Models of connectivity would be implemented at scales that encompass focal and adjacent habitat core areas using new or existing spatial data

Expected Outcomes

- Greater understanding of pronghorn forage and habitat needs and influence of livestock management on pronghorn population ecology.
- Greater understanding of mule deer forage and habitat needs and availability during critical winter time period and influence of livestock management on mule deer habitat use.
- Greater understanding of the habitat needs of a variety of wildlife species and the influence of livestock management on their ecology.

Key Datasets

- USFS long-term range monitoring data
- GCT Assessment plot data
- AZGFD mule deer condition survey data
- AZGFD mule deer browse data
- NDVI/other remotely sensed datasets

Potential Partners

- Arizona Antelope Foundation
- Mule Deer Foundation

Potential Funding Sources

- AZGFD Heritage Funds
- AZGFD Habitat Partnership Funds

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Environmental and Management Factors Influencing Cheatgrass Invasion

Statement of Need

Invasive species such as cheatgrass represent a significant threat to native ecosystems, watersheds, and communities. By displacing native perennial species and changing fire regimes in the Southwest, cheatgrass has reduced rangeland productivity of desirable species and has increased the vulnerability of the public lands to unwanted wildfires, soil erosion, climate change, and increasing demands for resources and recreation (Mack 1981, D'Antonio and Vitousek 1992, Knapp 1996, Bradley 2010).

Despite decades of research, substantial uncertainties still remain related to how management can prevent or promote continued expansion of this species across physiographic and climatic gradients with diverse disturbance histories. Moreover, there are few examples of successful restoration or reclamation efforts in areas that have been invaded by cheatgrass, thus, it is important to continue efforts to develop efficient methods for promoting resistance and resilience to invasion in vulnerable ecosystems prior to significant invasion occurring (Davies and Sheley 2011).

Cheatgrass invasion is of particular concern on the Kaibab Plateau, where thousands of acres on the "West Side" – a critical wildlife area – have already been invaded and tens of thousands acres more remain vulnerable. Given climatic drivers, soil conditions, fire history, propagule pressure, and the scale and extent of the ongoing invasion, there is a need to prioritize where and how limited management resources can be allocated in the most efficient and effective ways. Moreover, there is a need to better understand how management of livestock grazing, recreation, wildlife habitat, and vegetation affect cheatgrass abundance and spread, and also how they influence the resistance and resilience of native vegetation communities to cheatgrass invasion as well as invasion by other non-native species (e.g, Russian thistle, red brome, bull thistle, and others).

Background/Literature Review

Influence of Climate and Physiography on Cheatgrass Invasion

A large body of research exists that describes the influence of landscape-scale controls such as climate and soils on cheatgrass distribution. Cheatgrass is primarily limited by water availability at low elevations and by low temperatures at high elevations in the Great Basin (Chambers et. al. 2007) and similar patterns have been observed in the Southwest where susceptibility to cheatgrass invasion tends to be highest in climate zones located at mid elevations (e.g., 5000 – 7500 ft) (Dickson et.al., in prep). Landscape-scale differences in cheatgrass invasion have been observed among soil types in several studies (Bradford and Lauenroth 2007, Floyd et al. 2007, Dickson et.al in prep). These differences may be attributable to soil texture, as cheatgrass exhibits a preference for soils with higher clay and silt to sand ratios, which in turn leads to higher water holding capacity, and higher nutrient concentrations (Miller et.al. 2006). While soils and climate are foundational determinants of cheatgrass invasion susceptibility, variation in topographic features such as slope, aspect, and topographic position have also proven influential to invasion (Bradley and Mustard 2006, Dickson et.al., in prep).

Influence of Fire on Cheatgrass Invasion

The connection between cheatgrass invasion and fire is well established. Post-fire cheatgrass dominance is influenced by many factors, including fire severity (Crawford et.al. 2001, Hunter et.al. 2006, Kuenzi et.al. 2008) pre-fire seedbank (e.g., abundance of cheatgrass vs. perennial grass seed), soil moisture, fire intensity, soil nitrogen and sunlight availability (Keeley and McGinnis 2007). The primary mechanism by which post-fire environments provide enhanced opportunities for cheatgrass invasion is by releasing available soil nitrogen (Johnson et.al. 2011), which cheatgrass can take advantage of compared to native perennial species due to life history adaptations such as fall germination. This adaptation gives cheatgrass a head start on resource consumption in early spring when water availability is high. Because cheatgrass dies and dries out in late spring/early summer, it provides fine, flammable fuels that carry fire more readily than perennial vegetation, in turn causing further degradation of the native plant community in which it is embedded. A positive feedback mechanism, called the cheatgrass-fire cycle (D'Antonio and Vitousek 1992), results as cheatgrass increases its abundance in post-fire environments, in turn increasing fire risk (Link et.al. 2006) and fire frequency (Whisenant 1990).

Influence of Livestock Management on Cheatgrass Invasion

There are many possible ways in which livestock management can directly and indirectly advance or attenuate cheatgrass invasion. By means of consuming vegetation, livestock can modify fuel loads and continuity, which in turn influences patterns of fire that can promote or suppress cheatgrass invasion and alter plant composition (See Strand et.al. 2008 for a review on both of these topics). Land use history (Courtois et al. 2004Davies), and interactions with other disturbances such as fire and/or vegetation treatments (McGlone et.al. 2009, Davies et.al. 2009) also influence the effects of livestock management on cheatgrass invasion. Beyond this, livestock movement can facilitate the spread of seeds (Davies and Sheley 2007) and may also facilitate establishment by damaging biological soil crusts that resist cheatgrass germination (Belnap et.al. 2001).

The influence of livestock on the above-mentioned processes can depend on the timing and duration of grazing, as well as intensity (Loeser et.al. 2007). There is substantial evidence that early spring "targeted" grazing can reduce standing cheatgrass biomass, density, and seed production (Finnerty and Klingman 1971, Tausch et.al. 1994, Hempy-Mayer and Pyke 2008, Diamond et.al. 2009); however, grazing must be applied prior to the purple stage to be effective (Mosley 1996) and livestock must be removed from the area prior to seed set to avoid dispersal (Davies and Sheley 2007). The effectiveness of this approach is also highly dependent on the plant community, as overall effects on plant communities can be negative when the timing of grazing coincides with periods of active early growth of comingling perennial grasses (Laycock 1967, Young et. al. 1987, Miller and Eddleman 2001, Loeser et al. 2007).

Influence of Vegetation Management Treatments on Cheatgrass Invasion

The effect of vegetation management treatments on cheatgrass invasion can vary in relation to the type of treatment and the severity of disturbance it causes, and on site characteristics and history. Vegetation treatments on the Kane and Two Mile ranches that are intended to affect cheatgrass invasion directly include seeding with native grasses and treating cheatgrass populations with herbicide (e.g., Plateau). Other vegetation management treatments that occur on the ranches that may indirectly influence cheatgrass invasion include forest and woodland thinning treatments, drill seeding shrubs, and prescribed fire.

Treatments intended to reduce cheatgrass invasion such as broadcast seeding grasses have had variable success, particularly in post-fire environments (Peppin et.al. 2010). Post-fire seeding has been documented to help prevent cheatgrass invasion (Floyd et al. 2007, Jessop and Anderson 2007), but has also been identified as the primary cause in instances where low-quality seed supplies contaminated with cheatgrass seed were applied in post-fire environments (Hunter et.al. 2006 Getz and Baker 2007). Drill seeding grasses is a more costly but potentially more effective (Monsen et.al. 2004) approach to establishing native grasses, provided that precipitation is sufficient to allow for both germination and establishment of species. There is some evidence to suggest that disturbances caused by drill seeding can promote non-native species invasions (Bernstein et.al. in prep), thus land managers must weigh the costs and benefits of such an approach. Herbicide treatments are also a frequently used method for suppressing cheatgrass. The herbicide Imazapic has been shown to reduce exotic annuals over the short-term; however, there are effects on non-target grasses and forbs (Shinn and Thill 2004, Sheley et.al. 2007, Baker et.al. 2009, Owen et.al. 2010, Davies and Sheley 2011) that must also be considered, especially when coupling herbicide and seeding treatments. Likewise, the fungal pathogen *Pyrenophora semeniperda*,(AKA Black Fingers of Death) has also been shown to effectively reduce cheatgrass by attacking the seedbank, however this pathogen is not specific to cheatgrass and can effect seeds of non-target native species (Beckstead et al. 2010).

Cheatgrass invasion may be indirectly influenced by vegetation management treatments that are completed for other objectives. In the case of forest or woodland thinning and prescribed fire, the degree to which understory plant communities are maintained and the manner in which woody debris is treated has important influences on post-treatment cheatgrass invasion potential, soil stability, and native plant biodiversity (McGlone et. al. 2009, Owen et. al. 2009).

<u>Mechanisms of Cheatgrass Spread</u>

There are many potential mechanisms for cheatgrass dispersal, including wind and water, vehicles, and animals (including humans and wildlife). Cheatgrass exhibits significant short-distance dispersal (Kanarek and Kao 2011) but the relative importance of short-vs. long-distance dispersal in affecting spread is unknown. Mean dispersal distance is a strong driver of spread (Coutts 2011), thus an understanding of the mechanisms for long-distance dispersal and establishment is important. There is strong evidence to suggest that vehicles significantly influence cheatgrass spread (Fowler et.al., 2008, Gelbard and Belnap 2003, Bradley 2010, Getz and Baker 2007) as they are able to disperse seeds long distance to roadsides, where soil disturbances have occurred. Perhaps the most significant and least understood dispersal mechanism, however, is animals. The hooked barbs on cheatgrass seeds suggest they are adapted for dispersal by attaching to animal fur or feathers (Davies and Sheley 2007) and thus, dispersal is strongly dependent on animal behavior (Russo 2006). Cheatgrass seeds can also be ingested by animals. Whether cheatgrass can survive the digestion process and successfully germinate is unclear. One study suggests that seeds do not survive in the guts of cattle (Blackshaw et.al. 1991), however another study in Oregon that tested several other *Bromus* species (but *tectorum* was not tested) indicated successful germination, post-digestion (Bartuszevige and Endress 2008). Limited survival of cheatgrass seeds in the guts of lagomorphs has also been reported (Cosyns 2004). There are few studies that actually test the relative influence of animal dispersal to other vectors. Davies and Sheley (2007) provide a good conceptual model for framing management to minimize invasive species dispersal based on classification of seed adaptations. They stress several critical research needs, including identifying major vectors and developing strategies to reduce dispersal effectiveness of those vectors, quantifying the viability of dispersed seeds, and testing how different management strategies affect those quantities.

Factors Influencing Resistance and Resilience to Cheatgrass Invasion

Maintaining ecosystem resistance is the best approach for hindering cheatgrass invasion, given the difficulties associated with trying to reverse cheatgrass invasion, once it has invaded. Multiple studies have suggested that sites with high perennial herbaceous species cover provide greatest resistance to cheatgrass invasion (Beckstead and Augspurger 2004, Chambers et.al. 2007, McGlone 2010). Multiple studies have also demonstrated that moderate grazing in areas with low levels invasive annual grasses reduces the probability of widespread landscape transformations caused by extensive cheatgrass (Curtois et al. 2004, Davies et al. 2009) and red brome invasions (Germano et al. 2001, Sprinkle et al. 2007), compared to areas that have been excluded from livestock grazing for extended time periods. Low plant-available nitrogen and phosphorous may be the mechanism by which these communities maintain resistance (Beckstead and Augspurger 2004, McGlone 2010), as annual species such as cheatgrass rely on high-nutrient environments to successfully establish (Marschner 1995). Many species of perennial grass seedlings are poor competitors with cheatgrass (Lowe et al. 2003, Humphrey and Schupp 2004), but are good competitors once mature (McGlone 2010, Mazzola 2011), thus careful management of established perennial grass communities, when possible, offers less expensive and less risky advantages over seeding.

Once disturbance has occurred, resilience to cheatgrass invasion varies along natural gradients such as available water and nutrients and net primary productivity (Chambers et al. 2007, Wisdom and Chambers, 2009) but may also be dependent upon historical disturbances that can influence disturbance intensity and select for plant community traits that are pre-adapted to disturbance, thus transitioning into an undesirable state (Davies et.al. 2009). Pre-disturbance seed bank composition (Keeley et.al. 2006) and resulting propagule pressure is also an important determinant of resilience, as are the functional traits of pre-disturbance plant communities that determines their response to the disturbance (Floyd et.al. 2007, Davies et al., 2009).

Research and Management Opportunities

Based on review of the literature and work completed to date, several research opportunities are apparent. First, it is clear that restoring cheatgrass-dominated rangelands is a formidable and costly task. Despite the difficulty, however, active control coupled with restoration of native grasses will likely be needed in source areas and high-value landscapes. Far more efficient are efforts that slow or prevent the spread and establishment of cheatgrass. Understanding where and how to best allocate limited management resources can improve the effectiveness of management efforts. These efforts could be aided through use of existing models of cheatgrass invasion created specifically for the Kaibab Plateau, coupled with on-the-ground experimentation. In addition, management would benefit from stronger empirical evidence regarding the relative influences of different dispersal agents on cheatgrass spread. As cheatgrass invasion continues to advance across western rangelands, knowing the relative importance of cheatgrass dispersal mechanisms, and using tools to attenuate its advance, are important steps in understanding how management can manage its spread. Beyond this, the practicalities associated with implementation of pasture-scale livestock rotations that are timed to avoid dispersal and establishment of cheatgrass, or to reduce cheatgrass seedbanks, are dependent on the predictability of cheatgrass phenology. Opportunities to better understand the predictability of annual phenological changes to Kaibab Plateau cheatgrass populations using remote sensing techniques could inform the viability of livestock management strategies at large (pasture-level) scales. Finally, while there is a substantial body of work describing effects of vegetation treatments, fire, and livestock management on cheatgrass invasion, there are few studies that link interactions between them. Incorporating interactive effects into one or more of the above-mentioned opportunities would provide additional clarity to highly relevant management questions surrounding cheatgrass invasion.

Components of the Research Program:

- Test accuracy of the predictive cheatgrass abundance model (Dickson et.al.) using ground or remotely sensed data.
- Use predictive models to identify areas particularly susceptible to invasion, but not yet invaded.
- Use remotely sensed information to track multi-year patterns in cheatgrass phenology.
- Conduct targeted experiments to examine the relative importance of cheatgrass spread vectors such as vehicles, wildlife, livestock, wind, water, and/or purchased seed intended for restoration treatments.
- Conduct controlled livestock grazing experiments (e.g., using enclosures and exclosures) to test how timing, intensity, and/or duration of livestock grazing influence cheatgrass biomass, reproduction, and seed dispersal.
- Conduct targeted seeding and/or cheatgrass eradication experiments across gradients of cheatgrass invasion to identify thresholds for successful establishment of perennial grasses that can create resistance and resilience by competing with cheatgrass.

Scale of Implementation

While predictive modeling is best implemented at the landscape scale, controlled experimental work exploring effectiveness of restoration techniques, dispersal mechanisms of cheatgrass, and effects of livestock management will be best accomplished a smaller scales, given the costs and risks associated with large-scale manipulations and the need to control extraneous environmental factors. Moreover, smaller-scale experiments provide opportunity for replication that cannot be achieved at large scales. While some results (e.g., dispersal experiments, predictive modeling) may be easily attained in the short term, it will likely take several years to realize results of experiments meant to assess the effectiveness of reseeding and livestock management effects.

Expected Outcomes

Results from the approaches listed above can contribute to a greater understanding of how management can be directed toward mitigating dispersal and establishment of cheatgrass. The above-mentioned body of work will help to: 1) predict the distribution of cheatgrass across the Kane and Two Mile Ranch landscape under current and future scenarios, 2) demonstrate methods for predicting cheatgrass distribution on other landscapes, 3) identify areas most susceptible to cheatgrass invasion as well as locations where restoration techniques might be most successfully applied, 4) develop an understanding of the multi-year phenological patterns of the Kaibab Plateau cheatgrass population 5) develop an understanding of the relative influence of dispersal mechanisms to cheatgrass spread, and 6) develop an understanding of how proper livestock management can be used to attenuate cheatgrass establishment and spread.

Key Datasets

- USFS long-term range monitoring data
- GCT Assessment plot data
- GCT mule deer habitat enhancement monitoring data
- NDVI/other remotely sensed information
- GIS soils , topography, climate data

Potential Partners

- Natural Resource Conservation Service

Potential Funding Sources

- Joint Fire Science Program
- Rangeland Research Program

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Methods for Restoring Arid and Semi-Arid Rangelands

Statement of need

Restoring arid and semi-arid rangeland systems is inherently difficult due to low and variable rates of precipitation and the presence of highly competitive invasive plants, such as cheatgrass. Despite this difficulty, there is a need for action to stop or reverse cheatgrass expansion on the Kaibab Plateau and to enhance recovery of sensitive soils in House Rock Valley. There is also a need to increase perennial plant cover, rejuvenate decadent shrublands, stabilize soils, and improve watershed conditions on various locations adversely affected by wildfire and historical management practices. Overall, there is a need to better understand how factors such as species selection, seeding rates, soil chemistry, and site selection influence the efficacy of treatments intended to re-establish or otherwise benefit native and desirable plant species, especially in House Rock Valley and on the west side of the Kaibab Plateau.

Background/Literature Review

Sensitive Soils in House Rock Valley

Most of House Rock Valley consists of sandstone and limestone alluvium originating on the Kaibab Plateau to the west. House Rock Valley covers the Moenkopi redbeds and Kaibab limestone which are exposed in portions of the allotment. Eolian and alluvial sands emanating from off the Paria Plateau are found in the northern portion. There are areas of House Rock Valley, mostly in drainage bottoms, that are dominated by Russian thistle. These areas generally follow the clayey bottom range site. Two soil types have been identified in these areas: the Jocity (a clay soil found in the floodplain of the bottoms) and the Monue (a sandy soil found upland from the Jocity). There is little evidence of surface erosion on the Monue soil and slight erosion on the Jocity. There are very few rills or gullies forming, no pedestaling of plants, and little evidence of litter movement by surface water runoff on the sandy fans. The low precipitation in the area and the moderate to high infiltration rates of the sandier upland soils may explain the small amounts of runoff and surface litter movement. However, there is evidence of soil movement from flood events on the Jocity soil. There is also evidence of a soil layer at or near the soil surface that is indicative of a loss of soil porosity and may be reducing the rate of water infiltration as well as hindering the establishment of seedlings. Studies have shown that soil surfaces must be conducive to seedling establishment (for example, no surface crusting or downcutting of stream channels in adjacent areas) if the vegetation is to recover (Monsen 2004). Evidence of surface layer thickening up-slope (on the Monue soil), indicates that the compacted layer was possibly once the original surface. It appears that the healing of the sandy fans is related to the normal alluvial deposition of the fan soils, by wind and water, down towards the toe-slope, over the compacted layer, creating a more suitable seed-bed. Evidence of healing of the Jocity floodplain soils is harder to determine, but it appears that young plants are establishing along the edges.

Methods and conditions for actively reseeding degraded rangelands

Plummer et.al. 1968 outlines several principles of restoration that should be considered when implementing restoration seeding treatments. These principles relate to a myriad of independent and interactive factors such as soil (e.g., depth, texture, and chemistry), site productivity potential, precipitation, controlling competition, species selection, seed mix, seeding rate, season of planting, seed bed preparation, and post-treatment management. Restoring Western Rangelands and Wildlands (Monsen et.al. 2004) is a comprehensive guide that can serve as a starting point for addressing these principles. It is based on a wide body of research conducted over the past several decades in the Great Basin.

Arid conditions and irregular moisture patterns may not be conducive to seedling establishment. Sites in regions receiving less than 8 to 10 inches of annual precipitation are the most difficult to treat. However, recent studies have identified and developed promising species for semi-arid sites (Monsen 2004). Aridland restoration techniques such as imprinting (Bainbridge 2007) may facilitate seedling establishment in more arid climates but tends to be costly. Many semi-arid ranges need improvement, but changes can often be more easily attained through proper long-term management than through revegetation (Monsen 2004).

Soil conditions that allow effective seed bed preparation and have nutrient balances appropriate for the species being planted are essential to restoration success and soils that are coarse, rocky, shallow, alkaline, or saline are unlikely to result in seedling establishment (Stevens 2004). Seeding method and selection of species are important considerations but the influence of various choices on overall success is very site specific and requires a deep knowledge of soil physical and chemical properties and climate at the site as well as knowledge of the biology and range of tolerances of specific species and ecotypes available for seeding (Monsen and Stevens 2004, Godefroid 2011).

Seeding rate is also very site and situation specific, and is based on factors such as viability, purity, size, seed mix, and potential for competition (Monsen and Stevens 2004). Recent research related to reseeding cheatgrass infested areas suggests that propagule pressure is important (Mazzola 2011, Godefroid 2011) and that reintroduction of mature plants (e.g., grass plugs) that can more readily compete with cheatgrass may ultimately be more successful than seeding due to the poor competitive ability of most native species in the seedling stage (McGlone et. al. 2010, Godefroid et. al. 2011). Based on a global analysis of the results of plant reintroductions, Godefroid et al. (2011) concluded that conservation benefits of plant reintroductions could be improved by increasing focus on species biology, using more transplants (as opposed to seeding), and incorporating long-term monitoring to take better account of establishment, seed production and recruitment.

Methods for increasing vigor and regeneration of native shrubs

Several methods exist for increasing vigor and regeneration of shrubs, including both fire and mechanical treatments. Cliffrose regeneration on the North Kaibab has been shown to respond more positively to fire than to mechanical treatments (Steinhard 2006). Mechanical methods (e.g., chaining, roller chopper) have been shown to increase leader length (Fairchild 2005) and seed stalk height (Summers 2005) in big sagebrush and Wyoming sagebrush.

Approaches for breaking continuity of fine fuels and reducing wildfire spread

Fire can ruin even the most promising revegetation efforts, and increased fire frequency and spread is often facilitated by cheatgrass invasion. Creation of fuel breaks is an approach that may help to prevent the spread of cheatgrass invasion into new areas by limiting the extent of fires. A number of methods exist for creating fuel breaks, including mechanical or chemical removal of vegetation, prescribed burning, or greenstripping. While complete removal of vegetation is unlikely to have lasting effects, the greenstripping method has been used for long-term protection of native plant communities adjacent to cheatgrass-infested areas across the intermountain west (Pellant 2004). This method involves seeding or disking non-flammable species across wide swaths of land strategically located between cheatgrass infested areas and the area where protection is desired. Species are typically chosen based on fire resistance, drought tolerance, competitiveness with annual weeds, likelihood of establishment and persistence, and palatability to livestock and wildlife (Monsen 1994). Crested wheatgrass and forage kochia are commonly used. Greenstripping can be effective at reducing flame length and spread of fire (Pellant 1994, Harrison et al. 2002) but there is a lack of replicated experiments that are needed to indicate what factors lead to successes and failures of this approach, as well as the broader ecological consequences of such approaches.

Research and Management Opportunities

While there is a wealth of information available to help guide restoration projects in the western U.S., there is no one-size-fits-all approach to successfully restoring degraded rangelands. Restoration of the Kaibab winter range and sensitive soils in House Rock Valley will be challenging due to the prevalence of shallow, highly alkaline soils, limited precipitation, and extensive cheatgrass and Russian thistle invasion in some pastures. As suggested in Monsen 2004, these conditions have a high probability of reducing restoration success, however; the relative importance of these factors and the thresholds at which they control restoration success is unknown. These thresholds could be identified through a multi-scaled approach that includes controlled, small scale experiments, as well as carefully designed management experiments that explore interactions between site factors and species or ecotype selection, seeding rates, and seeding methods. In addition, there is a need to more rigorously quantify the effects of treatments intended to enhance vigor and regeneration of perennial grass and shrub species, as these methods are much more likely to be successful and will produce more rapid results and increasing shrub forage for wildlife by growing it from seed. Finally, based on a previous seeding study conducted in House Rock Valley, there is potential for limited success of seeding, but low and unpredictable precipitation is highly constraining (Bernstein 2008). There are many opportunities to build from this study, including attempts to seed in different soil types and/or using different species in seeding treatments. Knowledge of the relative costs and benefits of long-term rest from disturbance and active restoration techniques would be highly informative.

<u>Research program components</u>

- Conduct small-scale seeding experiments, varying soil type, vegetation condition (e.g., invaded vs. not invaded or burned vs. unburned), species selection, seeding rate, and/or seeding method to determine the relative importance of these factors to successful establishment of seeded species.
- Conduct management-scale experiments to test practical reseeding strategies identified through plot-based studies. Conduct these in a manner that enables isolation of factors mentioned above.
- Conduct small-scale experiments to study interactions between management activities such as livestock grazing, herbicide treatments, and/or soil nutrient treatments and seeding techniques.

- Conduct small- and/or management-scale experiments comparing the effects of passive (i.e. rest from grazing) vs. active restoration approaches, and a combination of these approaches, to increasing vegetation cover of desired species in sensitive soils in House Rock Valley.

- Conduct small scale experiments of mechanical or other treatments designed to benefit native shrubs.

Scale(s) of Implementation

Scales of implementation would vary from small test plots to management scale (hundreds of hectares). Small-scale, highly controlled experiments would allow for replication and strong inference. Implementation of management scale experiments will require close coordination and a commitment to conducting treatments in a manner that will facilitate identification of causal factors. These studies will likely require 5+ years of post-treatment monitoring before results can be appropriately interpreted.

Expected Outcomes

- Understanding of seeding techniques and site types that result in successful restoration of native and desirable plants.

- Identification of treatment options that rejuvenate native shrubs, reduce spread of invasive weeds, stabilize soils, and increase available forage for wildlife and livestock

Datasets Available

- GCT monitoring datasets for House Rock Valley grassland experiment and Kaibab west side restoration monitoring

- BLM and USFS Key Area datasets

Potential Partners

- NRCS

Potential Funding Sources

- NRCS

- Joint Fire Science Program

- Rangeland Research Program

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Development of Landscape Scale Tools for Monitoring Vegetation Conditions and Change

Statement of need

Monitoring is essential to inform and direct effective adaptive management approaches, yet the costs of monitoring on large landscapes often exceed available resources. There is a need to develop landscape-scale monitoring tools that can efficiently and accurately depict and predict on-the-ground changes in plant communities, particularly invasive species in response to dynamic processes (e.g., climate or fire) and in a manner that supports timely management responses. Specifically, the most significant management needs identified on the Kane and Two Mile Ranches include: 1) understanding and predicting patterns of non-native plant invasions and identifying where cost-effective mitigation actions might be taken, and 2) predicting plant community productivity and change for the purpose of informing flexible fire, livestock and wildlife management strategies under changing land management and climate scenarios.

Background/Literature Review

Remote Sensing Tools and Applications

Remotely sensed information, such as freely available Landsat TM and MODIS data products and color infrared digital orthophotos, provide powerful information for estimating landscape condition and change at high temporal, spatial, and spectral resolutions. These tools have been used effectively to relate environmental drivers to patterns of non-native species invasions such as cheatgrass (Bradley and Mustard 2005, 2006, Bradley et al. 2007, Clinton et al. 2010), above-ground plant productivity (Paruelo et al. 1997) and fire susceptibility (Chen et al. 2011), among numerous other applications. In addition, integration of ground- and remotely-derived spatial information with forage production models and real-time climate data can enable dynamic forecasts of forage production (Stuth et al. 2005) allowing livestock and wildlife managers opportunities for management response. Image synchronization techniques offer additional opportunity to conduct efficient assessments of range condition by coupling georeferenced digital photographs (Louhaichi et al. 2010) or spectral images (e.g., obtained using spectroscopy techniques; Huete et al. 2002) and other ground data with remotely sensed information from satellite platforms. Once strong relationships between remotely sensed imagery and ground measurements are developed, this approach provides opportunities to efficiently and remotely monitor landscape condition and change at extensive spatial scales.

Modeling Techniques and Applications

Contemporary statistical modeling and analysis methods can maximize information gleaned from existing data and provide opportunity for increased efficiencies associated with assessment and monitoring (e.g., hierarchical approaches; Royle and Dorazio 2008). These approaches also can be applied to predict change and elucidate processes at multiple spatial and temporal scales. The applicability of these methods is enhanced when coupled with information on geographic location or spatial structuring, permitting spatially explicit predictions over large areas (Dickson et al. in press). Occupancy modeling techniques offer additional opportunities to make efficient use of data (Mackenzie et al. 2006, Royle and Dorazio 2008). Occupancy modeling provides a robust framework for predicting species distribution, colonization and extinction dynamics, and habitat use by livestock and wildlife. These models are based on the presence/absence of a given species, reducing or eliminating the need for detailed abundance data, or other information that can be challenging or expensive to collect. By developing a comprehensive and large-scale sampling design within an occupancy modeling framework, managers can mitigate against the recurring need for costly and time-consuming field efforts.

Research and Management Opportunities

Coupling GCT-collected data, ESD soils and vegetation inventory data, and data from other research efforts on the Kane and Two-Mile ranches with remotely sensed information provides an opportunity to employ spectral information in powerful analytical frameworks that will allow inference to on-the-ground conditions and landscape-scale processes. This effort will allow managers to predict landscape-scale change in non-native plant invasions, forest and range conditions, and wildlife responses to these changes within an adaptive management framework.

<u>Components of the Research Program</u>

- Use ground- and remote-sensing based measurements to develop predictive models of non-native plant species invasions (i.e., occurrence, abundance, and spread) at landscape scales
- Pair ground-based measurements of vegetation biomass and/or cover with environmental predictors (e.g., climate, soils) to develop predictive models of vegetation community productivity and composition.
- Overlay models of wildlife or livestock space use information on vegetation maps to gain a better understanding of habitat selection.

<u>Scale(s) of Implementation</u>

Predictive modeling could occur at multiple spatial (e.g., from thousands to hundreds of thousands of acres) and/or temporal (seasonal to decadal) scales.

Expected Outcomes

- Efficient and effective methods for monitoring, predicting, and managing non-native plant species invasions.
- Efficient and effective methods for monitoring, predicting, and managing vegetation community productivity
- New data and models for monitoring changes in forest structure, fuels, and fire attributes
- Efficient methods and robust tools for monitoring and managing key wildlife populations and their habitats

Datasets and Tools Available

- BLM Key Area datasets

- GCT Baseline Assessment datasets
- GIS datasets describing vegetation, terrain, and other biotic or abiotic landscape features, as well as related processes, such as fire behavior and hazard
- Remotely sensed datasets (e.g., multidate Landsat TM (30-m resolution) and MODIS (250 m) scenes, and color infrared digital orthophotos (2006, 2010; 1 m)
- Backpack field spectrometers and spectroscopy lab facilities at NAU and/or U of A
- ESD inventory data
- USFS range cluster/frequency data
- Existing models of cheatgrass and wildlife occupancy, forest conditions, and habitat connectivity

Potential Partners

- Livestock Early Warning System (LEWS) Team at Texas A&M.

Potential Funding Sources

- [TBD]

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Mechanisms for Integrating Research into Management

The research agenda identified and proposed in this document is intended to illuminate important management issues relevant to the federal lands associated with the Kane and Two Mile Ranches, and also to provide information relevant to management of similar landscapes on the Colorado Plateau. Beyond the science, the benefits of this work will ultimately be realized through opportunities to integrate results into planning processes and inform project-level adaptive management. Research results can be integrated at a number of different levels of planning ranging from project -level to programmatic and regional planning processes

At the project planning level, results from the research efforts described herein will generate foundational information that is highly relevant to standards and guidelines and rangeland health assessments. Assessment information, coupled with results from experimental- and management-scale research should be used to prescribe livestock management practices contained in allotment management plans and annual operating instructions, and will likely inform other types of projects, such as range developments, or restoration projects focused on establishing native vegetation and combatting non-native species invasions. After the formal planning phase, there is opportunity for research results to continue to contribute toward refinement of approaches through informal planning and adaptive management. There is also opportunity to incorporate results at the programmatic level (e.g., Forest Plan or BLM Resource Management Plan), as these plans provide general guidelines for management activities and best management practices that can be informed by the research described in this plan. Finally, results from this research plan may either leverage or feed into regional planning , research, or assessment efforts, such as the BLM Research Ranch network, the Southern Rockies and/or Desert Landscape Conservation Cooperatives, the BLM Rapid Ecoregional Assessment, and/or the Southwest Climate Science Center.

Coordination, communication, and discussion of planned projects and research results among the appropriate parties will be the critical first step toward achieving this objective. The following approaches can enhance opportunities to integrate research into management:

- Identify and discuss among relevant project partners opportunities for management integration during the planning phase of research projects, and revisit these opportunities during final phases of the project.
- Seek formal commitment from public and private entities to utilize research results in planning and management.
- Identify and discuss among relevant partners opportunities for research integration during early phases of management plans.
- Incorporate results from research into reports and peer-reviewed literature and ensure that it is distributed within the agencies, partner institutions, and elsewhere.
- Ensure that the discussion of research results, planned projects, and how the two may be integrated remains a standing agenda item in annual or biannual coordination meetings among project partners.
- Identify delegates to participate and provide representation for the Kane and Two Mile Ranches research program in selected, high priority regional planning and assessment activities (e.g., Southern Rockies and/or Desert LCC, Climate Science Center, BLM Ecoregional Assessment, etc.).
- Review the use of research results in the management of K2M landscapes on an annual basis as part of the partnership's central workplan.

Appendix I – Full List of Preliminary Research Questions Identified by the Collaborative Group

Research questions/topics contributed by Arizona Game and Fish Department (AZGFD), Bureau of Land Management (BLM), U.S. Forest Service (USFS), and Grand Canyon Trust (GCT) were ranked according to priority (high, moderate, low) by one representative from NAU, BLM, USFS, GCT, and U of AZ. Each representative also identified their "Top 5" research priorities. The enumerated lists below represent the relative rankings of research topics within each category. Six topics were identified as a "top 5" priority by two or more individuals. These were also ranked "high" priority by several other individuals, indicating that there was a good level of agreement on the priority of these topics. These six topics, highlighted in bold red text below, may represent a good initial list of group priorities; however, given the intuitive and non-systematic nature of the ranking process, should not be considered a definitive list without further discussion regarding whether this fully captures the priorities of entities involved. Research topics marked with an asterisk represent other topics ranked as a "top 5" priority by individuals in the group.

PRIORITIZED RANKING OF RESEARCH QUESTIONS

Livestock Management and Soils/Vegetation

1. **Establish reference conditions, update ecological site descriptions, and develop State and Transition Models**
2. **Influence of grazing strategies (including rest) on short and long-term trajectories of aridland soils and plant communities in relation to desired future conditions.**
3. Effects of post-fire livestock management on recovery of soils and native plant communities, including high severity burn areas (e.g., Bridger Knoll, Slide, and Warm Fire areas).*
4. Short- and long-term interactive effects of livestock grazing and drought/climate on soils and plant communities, including below- and above- ground processes. (e.g., below-ground biomass, woodland expansion into shrub-grassland, species composition and productivity, soil erosion/stability, etc.).
5. Influence of livestock management on the effectiveness of native species restoration efforts.
6. Effects of livestock management on trajectories of physical and organic soil crust formation.
7. Identify levels of plant cover and litter required to protect soils from wind and water erosion and effects of livestock management on these attributes.

Livestock Management and Wildlife

1. **Nutritional and habitat needs of wildlife, including special-status species, e.g., bighorn sheep, mule deer, chisel-toothed kangaroo rat, California condor, and pronghorn and influence of livestock management on population recruitment and forage and habitat availability for wildlife.**
2. Behavioral interactions and space use of livestock, mule deer, bison, and desert bighorn sheep.*
3. Additive effects of livestock management on wildlife in concert with other factors (e.g., climate change, prescribed and/or wildfire, etc.).

4. Potential for and impacts of disease transmission between wildlife and livestock , e.g., among cattle, bison, pronghorn, mule deer, and bighorn sheep surrounding Vermilion Cliffs and House Rock Valley.

Revegetation and Restoration Techniques

1. **Efficacy of treatments intended to re-establish or otherwise benefit native/ desirable plant species. (e.g., effects of seeding rate and soils on seeded species establishment, plant community responses to tree mastication in pinyon-juniper woodland, identification of plant species that can compete with highly aggressive non-natives (e.g., cheatgrass)).**
2. Options for revegetating high-severity burned areas (e.g., Bridger Knoll and Slide fires).*
3. Development of predictive models for strategic placement of restoration/mitigation treatments.
4. Influence of pinyon-juniper treatment design on wildfire severity and spread.

Invasive Plants

1. **Physiographic, climatic, and other factors (e.g., management practices) affecting plant community susceptibility and establishment/spread of invasive plants. (Particularly on the west side of the Kaibab Plateau).**
2. Influence of grazing practices and forest/woodland treatments on invasives. (Can the west side of the Kaibab Plateau or other heavily invaded areas be grazed in a way that does not spread cheatgrass (or even reduces cheatgrass) and continues to maintain or improve our native grassland vegetation?).*
3. Efficacy of approaches for preventing spread of invasive plants, e.g., enhancing resilience of native communities by seeding native species, protection of soils from disturbance, seeding with non-native species, herbicidal control of invasives.*
4. Influence of fuels treatments and fire management on invasives.

Wildlife Ecology

1. Identification of species most sensitive to changes in land use and climate.*
2. Response of Kaibab mule deer to wildfire and management-related habitat changes on the west-side winter range.*
3. How to design and implement project activities (e.g. forest restoration, prescribed fire) and special uses (e.g., grazing) to avoid impacts to wildlife populations or sensitive habitats.*
4. Influence of environmental and anthropogenic factors on habitat connectivity.
5. Identification of movement pathways for species of high conservation value.
6. Effects of broom snakeweed on selenium levels in wildlife.

Monitoring

1. **New tools to design and monitor at landscape level (e.g., remote sensing techniques for monitoring invasive species, plant productivity, etc.).**
2. Development of range monitoring metrics that incorporate watershed condition and affected wildlife communities (e.g., stubble height, forb and shrub diversity in relation to pronghorn fawning and habitat).*

Climate Change

1. Thresholds for sustainable livestock use under current and future climatic conditions.*
2. Predicted trajectories in soil conditions and plant communities under various climate change scenarios.

Forest Restoration/Management

1. What spatial arrangements, types, and extent of treatments maximize objectives related to fire management, desired future conditions for forest structure and special-status wildlife species identified in agency management plans.*
2. Post-fire mitigation techniques for achieving plant community and soils desired future conditions identified in management plans.
3. Long-term effects of post-fire seeding with non-native species (e.g., Lolium, Agropyron) on plant community composition and dynamics.

Springs and Seeps Restoration/Management

1. Identifying best practices for maintaining ecosystem function/water availability at springs and seeps while also providing water for livestock and wildlife.*
2. Ecological effects of spring diversion for livestock and wildlife water developments
3. Options for restoring springs and seeps.
4. Historical reference conditions of springs and seeps.

Biodiversity

1. Environmental and habitat contributors to plant and animal population 'hotspots' (i.e., areas with relatively high abundance or numbers of species) or 'coldspots' (i.e., relatively low abundance or numbers of species on the landscape.
2. Effects of pinyon-juniper treatments on plant and animal diversity.

Riparian Restoration

1. Effects of biocontrol on tamarisk reproduction and spread.
2. Efficacy of methods for removing invasive woody species (e.g., biological control of tamarisk).
3. Effects of invasive woody species removal on native plants, animals, and ecosystem functions.
4. Influence of flow regime, and site conditions on reestablishment of native woody species.

Appendix II. Creating the Infrastructure to Support an Applied Research Partnership: Research Design for the Kane and Two Mile Ranches

(updated 3 July 2012)

Introduction

In order to efficiently and effectively address the many objectives of the Research Plan, members of the Kane and Two Mile Research and Stewardship Partnership developed this draft Research Design. The document articulates both the conceptual underpinnings and the infrastructural developments that will facilitate the rapid build-out of a coordinated research effort involving multiple investigators, agencies, and organizations. It serves as an appendix to the Research Plan, as well as a practical guide to the development of scientific capacity.

The Research Design comprises multiple "elements" – the structural features that will be created, including experimental plots, exclosures, and control areas – which will be distributed across the extensive Kane and Two Mile Ranches landscape according to robust sampling designs which are, themselves, the products of analysis and deliberation by the Partnership. Below, this design is presented in several sections, reflecting the multi-scale approach that the Research Plan presupposes and that the Partnership's Design Team addressed explicitly when creating this Research Design.

The infrastructure of the Design includes three primary infrastructural elements that allow for multiple experimental designs aimed at addressing the key elements of the Applied Research Plan. First, pasture-scale controls are included to allow experimentation at scales consistent with the management processes of interest, primarily livestock grazing. For example, evaluation of the ability of various livestock management strategies to achieve desired ecological conditions (Plan Element 2), and study of the effects of livestock management on wildlife species (Plan Element 3) will rely heavily on these design elements to ensure that "treatments" (namely differing livestock management strategies) are being applied at that scale at which actual management typically occurs. Second, enclosure/exclosure pairs are included to allow for more intensive experimentation, particularly in cases where experimentation requires more intensive management, involves more ecological risk, or requires greater replication for strong inference. These elements will be especially critical to our ability to understand, for example, the factors influencing cheatgrass invasion and their relationship to management approaches (Plan Element 4). Lastly, the infrastructure includes a series of factorial design elements to test various rangeland restoration approaches (Plan Element 5), and to allow evaluation of the interaction of management activities and climate change on a variety of ecosystem attributes. This multi-scale design allows evaluation of "fine-scale" conclusions at management-relevant scales, while also providing valuable information for developing tools for monitoring landscape change (Plan Element 6).

In addition to guiding the build-out of the research infrastructure, the Research Design is intended to inform the development of management plans and related activities carried out by state and federal agencies, and the Grand Canyon Trust and its affiliate, North Rim Ranches, Inc., who hold the grazing permits across the Kane and Two Mile Ranches. This pairing of appropriate infrastructure with land management plans that recognize and facilitate the applied research mission of the Partnership are the foundations for the development of the applied research program previously endorsed. While all members of the Partnership are committed to cooperating on the implementation of this design and the conduct and/or support of relevant research studies, full implementation will depend on the Partnership's ability to attract and engage independent researchers who are interested in working on the questions articulated in the Research Plan. By providing a clear, agreed-upon Research Design, the Partnership signals to potential researchers from federal and state agencies, universities, and other organizations that there is agreement on the value of research, a recognition of its relevance for public lands stewardship, and a commitment from the land management agencies, grazing permitees, and landowners to facilitate ambitious, long term, and spatially extensive research efforts.

When considered in light of the Grand Canyon Trust's Restoration Plan (2008), the Memorandum of Understanding formalizing the Kane and Two Mile Research and Stewardship Partnership (2012), and the Research Plan (2012), this Research Design represents a formal commitment to working with researchers to develop the on-the-ground capacity for major research initiatives that are directly tied to the information needs of public lands managers. To the degree that this capacity is realized and the linkage of research to management is strengthened, this Research Design will have served its purpose: providing a practical blueprint for scientific development at management-relevant scales, ensuring that the production of knowledge becomes one of the most valuable long-term benefits derived from this magnificent landscape and the partnership formed to guide its management.

Design Element 1: Pasture-scale Experimental and Control Areas

For robust applied research to truly inform land management decision-making, it must occur at scales relevant to land-managers. Historically, this has proven challenging, not only because experimental manipulation at large scales is difficult, but also because comparable controls (in terms of size and ecological condition) rarely exist. Creation of pasture-scale controls is critical to our ability to rigorously test relationships and results generated at smaller scales (i.e., through the enclosure/exclosure pairs or experimental plot elements, identified below) to scales relevant to land managers. Further, this design element enhances our ability to evaluate the effects of different management approaches on large-scale processes, such as wildlife habitat selection and movements (e.g., House Rock Valley chisel-toothed kangaroo rat, American pronghorn), ecosystem function (e.g., nutrient cycling, carbon sequestration), and disturbances (e.g., wind erosion, fire). Lastly, pasture-scale controls allow rigorous assessment of questions related to the effects of timing, duration, and intensity of grazing within a "real world" context.

The design team identified controls within four of the Key Management Areas of the Ranches. These include: the west side of the Kaibab Plateau, ("West Side"), the top of the Kaibab Plateau ("Kaibab Plateau Top"), House Rock Valley, and the Paria Plateau. Pastures were selected to capture elevational and vegetational gradients, as well as soil differences, within each Key Management Area, while accounting for operational and land-use history considerations. Those pastures not identified as controls will support experimental or operational grazing. These pastures are identified now to facilitate land management agency planning efforts; however, in some instances (re)development of infrastructure or ongoing experimentation may delay implementation.

Pasture Designation by Region (Appendix III):

1) West Side (USFS Central Winter Allotment)

a) Control Pastures: Jump-up, Sowats

b) Experimental/Rotational Pastures: Slide, Ranger Pass

c) Rotational Pastures: Little Mountain

2) Kaibab Plateau Top (USFS Central Summer Allotment)

a) Control Pastures: SE Corner of South Summer

b) Experimental/Rotational Pastures: North Summer, potentially Burnt Corral (if created)

3) House Rock Valley (BLM Soap Creek and Badger Allotments, USFS Burro, House Rock Wildlife Area (AGFD) and Kane Allotments)

a) Control Pastures: Vermilion Cliffs, Badger, South Soap, Upper Jacob's Pools, northernmost pasture on House Rock Wildlife Area

b) Experimental/Rotational Pastures: Kane, North Canyon/Buffalo, Rider Point, Sand, Lower Jacob's Pools

c) Rotational/Transitional Pastures: North and South Kane, North and South Burro

4) Paria Plateau (BLM Sand Hills Allotment)

a) Control Pastures: Pine (Moquitch), Jarvis, North

b) Rotational/Experimental Pastures: All remaining "non-holding" pastures

c) Rotational/Transitional Pastures: All holding pastures

Design Element 2: A Network of Replicated Enclosure/Exclosure Pairings

In addition to, and in concert with, the pasture-scale grazing and non-grazing treatments, a network of smaller-scale enclosure and exclosure pairs offers additional flexibility for addressing questions within the Research Plan, as well as providing a key link in our nested, multi-scale design. This is particularly true in cases where experimentation requires more intensive management (e.g.. prescribed timing or amount of grazing), involves more ecological risk (e.g., > moderate utilization), or requires more replication for inference. Examination of questions related to factors influencing cheatgrass invasion and strategies for combatting that invasion will benefit greatly from these design elements. We recommend the following as guidance for the number, size, and arrangement of paired exclosures and enclosures across the Ranches (A description of the process used to identify potential locations appears in Appendix IV).

Structural Elements

- Enclosures sized to provide ~ 10 AUMs each, within a given Management Area
    - Target 4-week grazing period with ~3-week minimum duration
    - Assumes ≤ 50% utilization (actual grazing efficiency will be a function of standing crop and paddock size)
    - Likely ranges from 20–40 ac in size
- Built with 4-strand barbed wire
    - Wood corners
    - Smooth bottom wire
    - Appropriate number and location of gates
- Paired with ungrazed exclosure
    - Same size as enclosure
    - Sub-exclosures provide additional options for experimentation
    - May require different fencing to achieve increasing levels of exclusion from herbivory by other species (i.e. deer, rodents, etc…)

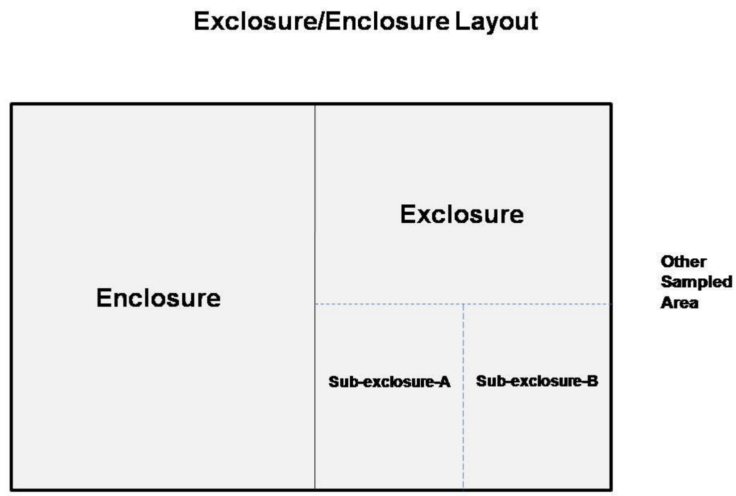


Figure 1. Schematic of enclosure/exclosure pair with subexclosures.

General Placement Considerations

- Minimum of 7 pairs placed within each management zone
- Located within 0.25 to 0.5 mi of existing livestock water (or 0.25 mi of existing pipeline) to allow temporary access to water during the experimental grazing period
- Located according to a stratified random design, based ecological gradients relevant to the ecosystem in question
    - West Side: Fire severity, time since fire, topographic position
    - Kaibab Top: Elevation and vegetation community
    - House Rock Valley: Soil and vegetation type
    - Paria Plateau: Elevation, soil, and vegetation

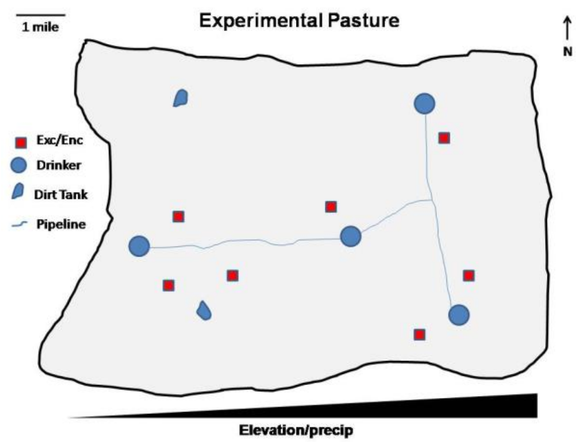


Figure 2. Schematic of placement of enclosure/exclosure pairs with respect to existing water infrastructure.

Design Element 3: Experimental Plot Arrays

To address the fine-scaled processes that govern the dynamics of ecological systems, experimentation is often an essential aspect of an integrated, landscape-level research program. For example, the spread of invasive plant species may be governed by broad environmental conditions, such as soil type and climate, but they are also influenced by competition, herbivory, and a multitude of factors that unfold at finer, local scales.

In addition, the establishment of common gardens, where plants from multiple sites are established in experimental plots in selected sites, offers powerful experimental possibilities for examining the adaptive capacity of species to major changes in environmental conditions, including climate. Thus, the establishment of several arrays of experimental plots, in different Key Management Areas, comprises the finest-scale element of our multi-tiered Research Design.

These approaches to experimentation at the plot level, with appropriate replication of experimental treatments, can address local factors and complement the broad-scale studies that unfold at pasture scales. For these reasons, we include in this Research Design an element that will enable intensive experimentation in small plots, employing multiple treatments with appropriate levels of replication. Because such experimentation typically involves manipulation of conditions and disturbances within multiple plots, as well as control of access to experimental plots by herbivores and humans alike, these research elements will be initially confined to private lands owned by the Grand Canyon Trust, including the Kane and Two Mile Ranch headquarters, Cram Ranch, and other isolated tracts of private lands. Following completion of the aforementioned enclosure/exclosure pairs, additional arrays of experimental plots will be incorporated within various sub-exclosures.

The specific footprint of Experimental Plots and Common Gardens will be formalized with researchers at the time that specific research projects are proposed. However, these research elements will have a number of common characteristics:

- Placement on private land, initially, to simplify planning and permitting
- A fenced perimeter to control access to experimental plots
- A large number (N > 100) of small (< 50 m^2) plots, allowing adequate replication of multiple experimental treatments
- A capacity for manipulating moisture regimes through irrigation and/or rain-out shelters
- Proximity to existing roads, allowing easy access for instruments and other equipment

While specifics will be determined with researches at the time of project proposal, one previous effort provides an example of how experimental plots might be developed on the Kane and Two Mile Ranches. In 2006, Eli Bernstein and researchers from Northern Arizona University and the Grand Canyon Trust established a factorial, manipulative experiment to examine factors underlying the reestablishment of native bunchgrasses. An array of 100 plots, each 3 m^2 in size was constructed on the Cram Ranch, near the center of House Rock Valley. Figure 1 illustrates the range of treatment types and the extent of replication (N=10) for each treatment. The particular number and dimensions of these plots was arrived at for the specific purposes of the research project, as will undoubtedly be true for other arrays of experimental plots and common gardens.

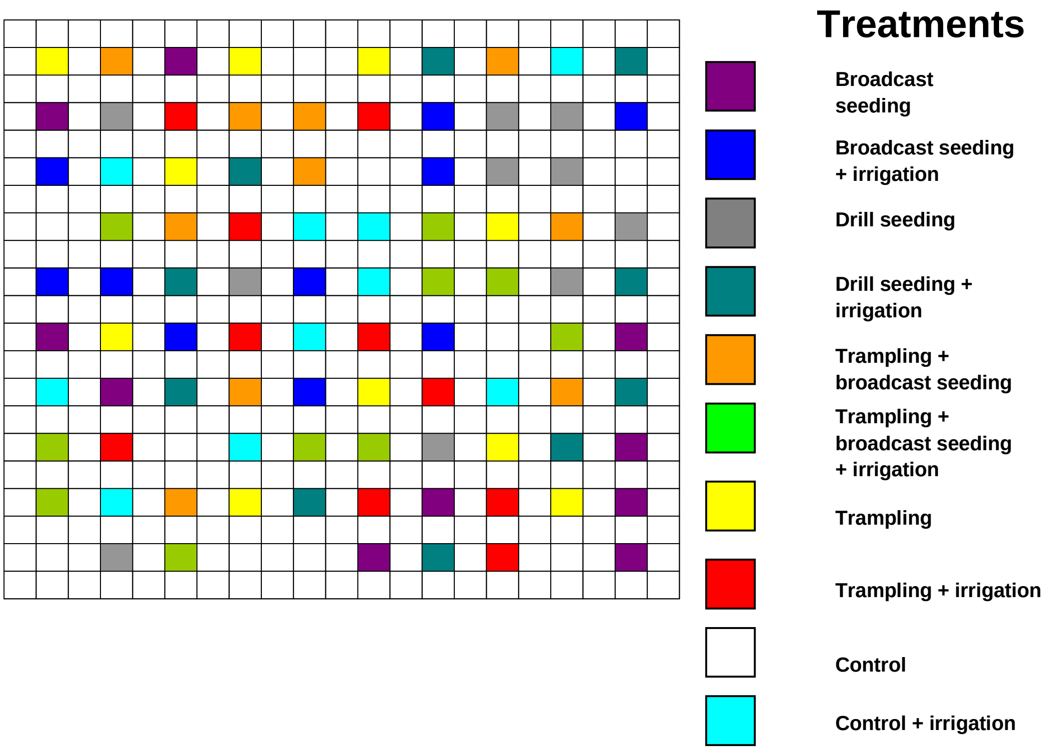


Figure 3. One example of a randomized block design, comprised of 100, 3-m2 study plots representing 10 restoration treatments comparing the effects of 1) seeding technique, 2) cattle trampling, and 3) irrigation (to simulate an exceptionally wet year) on bunch grass germination and recruitment (Bernstein et al., in prep).

Because of the effort and expense associated with the establishment of experimental plots and common gardens, these elements will be few, with complementary efforts in the major bioclimatic zones of the ranches. In addition to the existing facility at Cram Ranch, priorities include a similar capacity for factorial experimentation on the West Side of the Kaibab Plateau, on the Paria Plateau, and in riparian habitats in the lower Paria or Kanab Creek Canyons. As discussed above, exact locations and specific design elements for these efforts will conform to the needs of proposed research efforts. However, as these plot arrays are developed, the Partnership will ensure that they have permanence and the capacity to address multiple research questions over a long time period, beyond the immediate objectives that motivate initial construction.

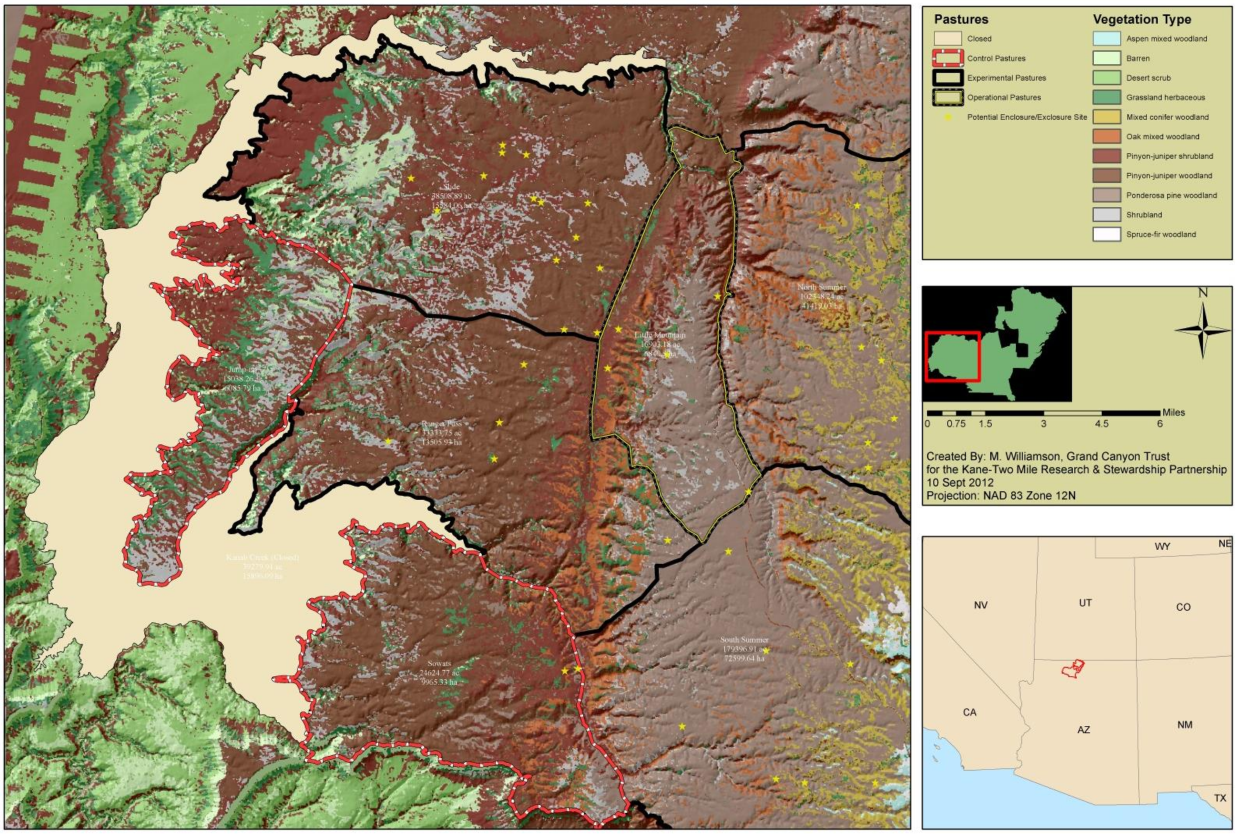
Conclusion

This Research Design anticipates the need for a multi-scaled scientific facility capable of supporting the applied research that is needed to help address emerging management challenges on the public lands. It articulates the value of and technical specifications for three design elements: Pasture-scale Experimental and Control Areas, Replicated Exclosure/Enclosure Pairings, and Experimental Plot Arrays for fine-scaled, manipulative studies. Articulation of these infrastructural elements should be complemented by land and resource management plans that recognize the priority of research when establishing guidelines for livestock use, wildlife management, recreation, and other management practices.

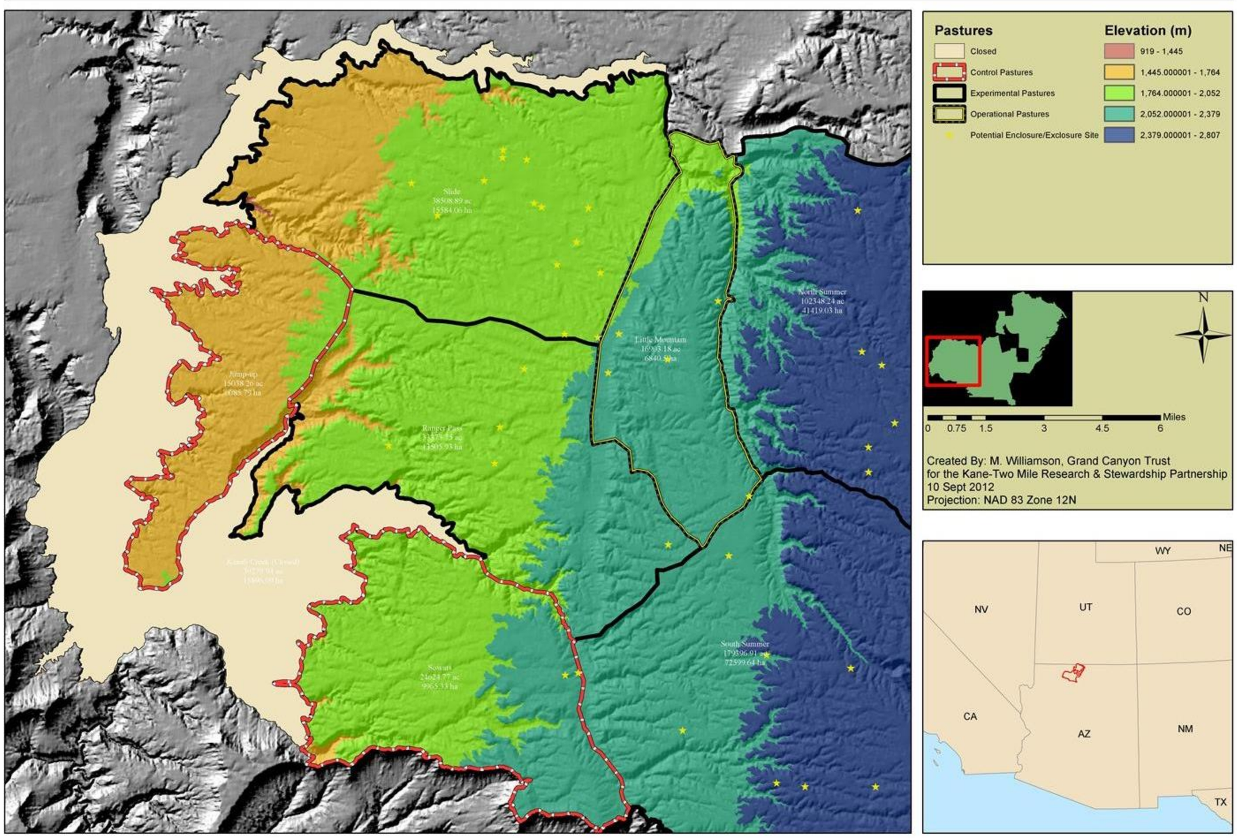
Other important aspects of managing the research program require further consideration and development. These include an explicit plan for data management and information sharing; a streamlined and transparent process for obtaining the necessary research permits; a clear process for proposing new research activities; and a research funding strategy that will provide matching funds or other incentives to help attract researchers who will address the most relevant issues facing land managers, as articulated in the Research Plan. After adoption by the Partnership, this Research Plan will serve as a blueprint for build-out of the research capacity and development of related management plans, and it will be formalized as an appendix to the Kane and Two Mile Applied Research Plan.

Appendix III: Location of Experimental Infrastructure on the Kane and Two Mile Ranches, Coconino County, Arizona, USA.

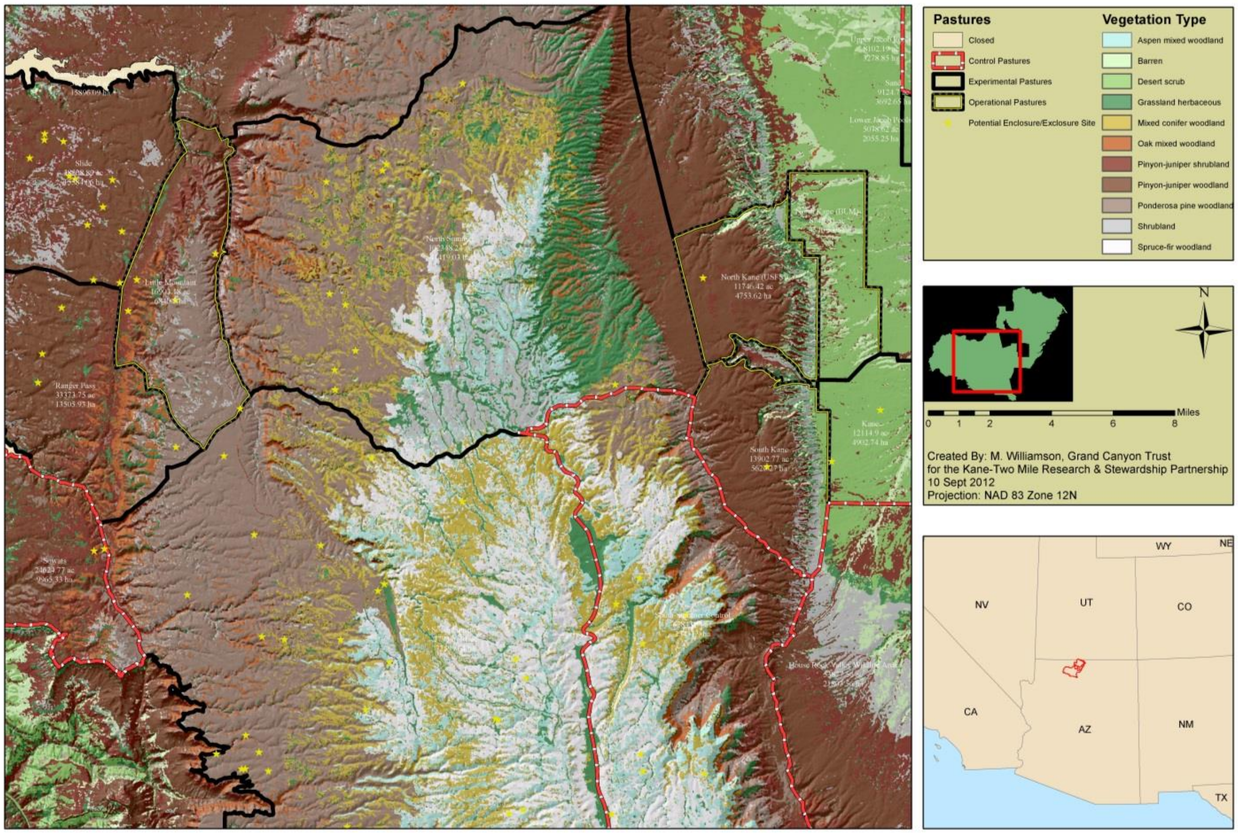
Research Infrastructure & Vegetation: West Side



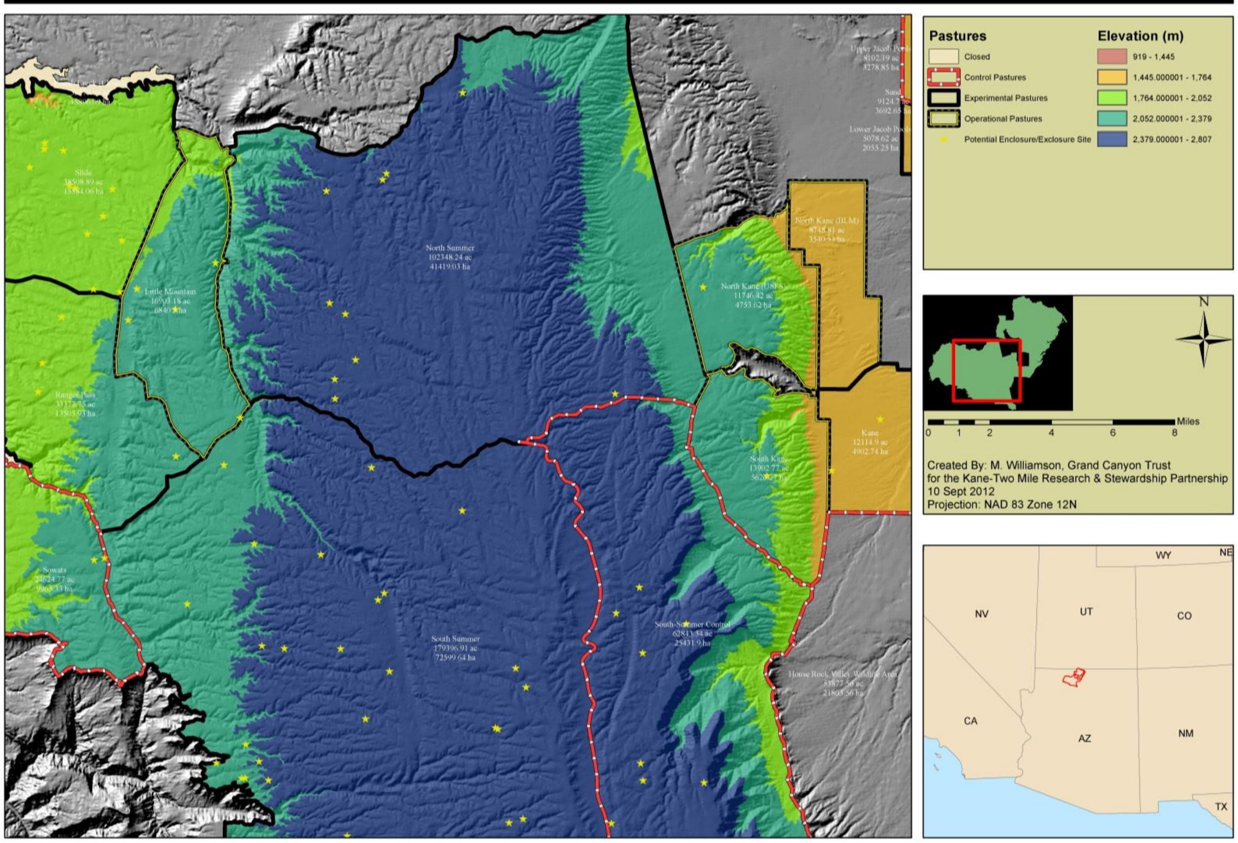
Research Infrastructure & Elevation: West Side



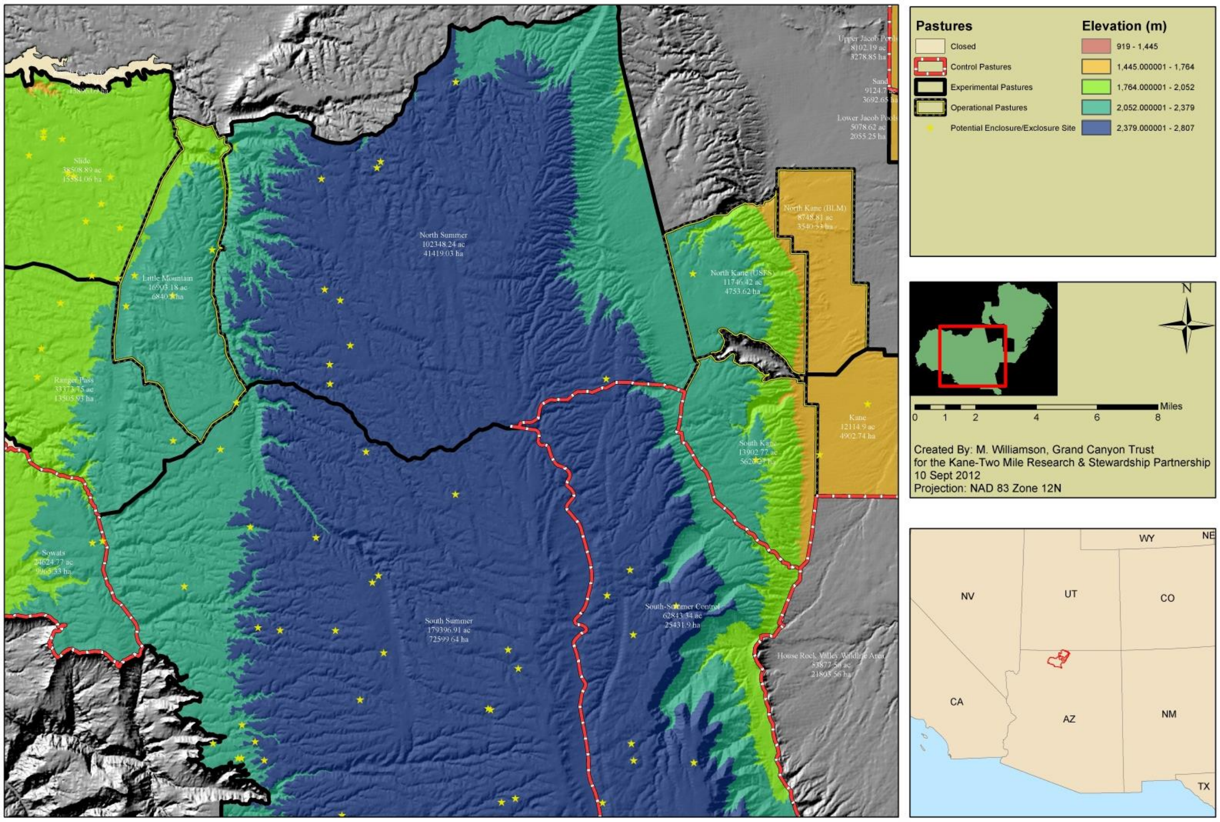
Research Infrastructure & Vegetation: Kaibab Plateau Top



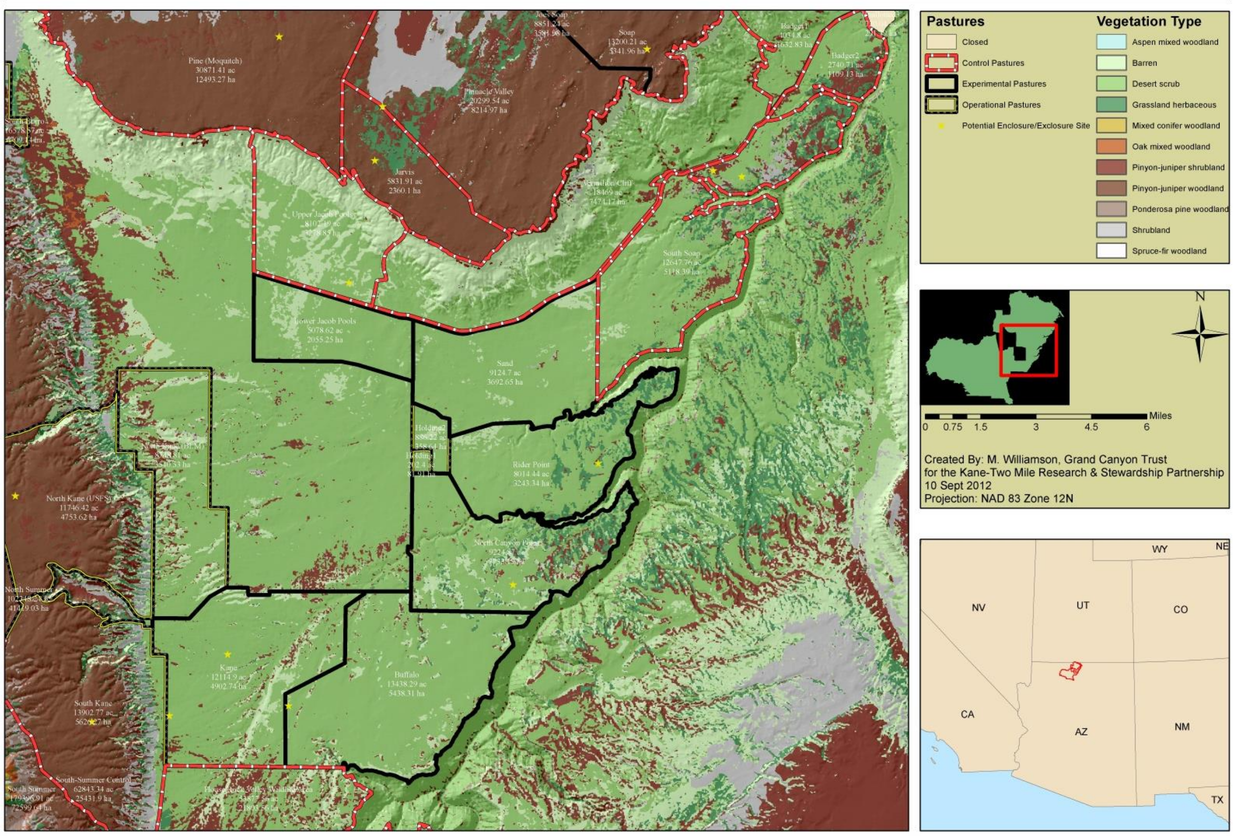
Research Infrastructure & Elevation: Kaibab Plateau Top



Research Infrastructure & Elevation: Kaibab Plateau Top



Research Infrastructure & Vegetation: House Rock Valley



Appendix IV. Identifying Potential Locations for Design Elements 2 & 3

Metadata for Kane and2-Mile Ranches – Paired enclosure/exclosure sampling design

The area of the Kane and Two Mile ranches is located on the north rim of the Grand Canyon National Park in the Kaibab National Forest in Arizona. Provision for research infrastructure is underway, including locating paired enclosure/exclosure permanent research plots. Locations for these pairs were based on nine criteria outlined in a research plan described in the "Design Element 2: A Network of Replicated Enclosure/Exclosure Pairings" from the development of research Partnership Design for the Kane and Two Mile Ranches. This analysis produced the spatial extent of all areas meeting these criteria with placement of stratified random points selecting twenty sites from each of the four vegetation types.

Location selection was limited to USFS lands within the Kane and Two Mile Ranch boundary minus the Burro Allotment in the four dominant vegetation types of mixed conifer, desert shrubland, ponderosa pine and mixed pinyon-juniper woodland. Efforts to provide access to enclosure/exclosure plots within reach of water (greater than quarter mile and less than half mile) and the common criteria of slope of less than ten degrees in areas that had not experienced disturbance in the form of wildfire in the last ten years (2002-2012). Low slope areas located in canyon bottoms were removed from consideration.

Analysis was conducted in the ESRI platform, ArcGIS 10.0 (ESRI.com) and Geospatial Modeling Environment (spatialecology.com) by the Lab of Landscape Ecology and Conservation Biology.

Contact person: Tom Sisk
Analyses contact: Jill Rundall
Metadata contact: Jill Rundall

Table 1. Specific criteria for site selection, spatial data layer source and the processing completed for this analysis. Spatial data layers whose action is 'removed' are areas defined as unavailable for enclosure/exclosure placement based on their selection criteria outlined in the table. Those whose action is 'retained' are defined as areas available for enclosure/exclusure placement based on their selection criteria outlined in the table.

Name	Layer source	Selection criteria	Action
Kane 2 Mile boundary	Lab of Landscape Ecology and Conservation Biology		Analysis extent
Allotments	Kaibab National Forest	Burro allotment	Removed
Slope	Derived from LANDFIRE DEM	less than 10 degrees	Removed
Wildfire	Lab of Landscape Ecology and Conservation Biology (Monitoring Trends in Burn Severity Project; Kaibab National Forest)	2002-12	Removed
Land ownership	Arizona Geographic Information Council	State, private lands within K2M and within quarter mile buffer	Removed
Wilderness	Kaibab National Forest	Wilderness	Removed
Topographic position index	Lab of Landscape Ecology and Conservation Biology	Canyon bottoms	Removed

Improvements	Grand Canyon Trust	Greater than quarter mile and less than half mile from: developed springs, unfenced reservoirs, water storage, water storage tank, wells, dirt tanks, pipeline	Retained
Vegetation	Landfire existing vegetation type/GCT reclass/ LLECB reclass - for exclosure effort	Mix conifer, desert shrubland, ponderosa pine, mixed pinyon-juniper woodland	Retained
Stratified random points	ArcGIS 10.0 / GME	20 sites per vegetation type	

Literature referenced

Sisk, Tom, Matt Williamson, and Doug Tolleson. 2012. Kane and Two Mile Research Partnership. Appendix I to Kane and Two Mile Research and Stewardship Partnership (Draft, 29 June 2012).