Oral and Poster Abstracts

Abstracts are ordered alphabetically by presenting author.

Abiotic surrogates can prioritize sites for species representation when you don't know where species are

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Abstract: If a planner has species inventory data for all sites in a planning area, she can prioritize sites for their ability to represent species. But without wall-to-wall inventories, a planner has been unable to prioritize sites for species representation – until now. Here we show that environmental diversity (ED) can prioritize sites without ANY species inventories, and that predicted rarity-weighted richness (PRWR) can prioritize sites with inventories for <20% of sites. ED (invented by Faith & Walker in 1996, but untested and forgotten) selects sites that best span multivariate space defined by freely-available abiotic data (e.g., elevation, insolation). Across 8 study areas, sites prioritized by ED (using no species data) represented species with 40% efficiency – i.e., ED was 40% as effective as having species inventories for 100% of sites in its ability to improve on random selection of sites. PRWR (invented by us, and described here for the first time) does require species inventories for a subset of sites in the planning area, and performance improves as the percent of sites inventoried increases. But with species inventories for a mere 20% of sites, PRWR can prioritize 100% of sites based on their abiotic conditions. PRWR's efficiency was a whopping 66% across 6 test datasets. We hypothesize that ED and PRWR are effective surrogates because diverse abiotic conditions are important drivers of biodiversity. If so, these surrogates should be useful for prioritizing conservation sites in a changing climate.

Genetic and genomic applications to investigating the impacts of climate change and exotic species invasion in riparian ecosystems

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Abstract: The application of genetic and genomic tools to ecological and environmental questions has revolutionized the study of ecology and evolutionary biology. Such methods are also proving important for direct application to the conservation management of native plants and animals on wildlands. In this overview, I will present information on how genetic and genomic tools are developed and applied to ecological and environmental questions. Using examples from riparian ecosystems, I will emphasize the utility these methods have for addressing critical management issues, including climate change and the amplified effect of exotic species invasion. In particular, I will use examples from genetic and genomic studies of cottonwoods to demonstrate how they can be used as a model system for developing a "genes to ecosystems" approach and one that can be applied to predict, manage, and conserve biodiversity on wildlands. My discussion will also incorporate examples of how genetics and genomics can be combined with common garden experiments to further understand the role that genes play in determining species' responses to environmental change and how this, in turn, may allow characterization of the "interactome" of key foundation species that drive community structure and associated ecosystem processes. Finally, I will briefly discuss how genetic and genomic information can be incorporated into species distribution modeling and how this information can be used to better predict future species' distributions in the context of climate change and exotic species invasion.

A synthesis of contrasting evidence and perspectives on global vulnerability to tree mortality and forest die-off from hotter drought in the Anthropocene

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Abstract: Drought accompanied by warmer temperatures - "hotter drought" - is an emerging characteristic of the Anthropocene. Tree mortality and forest die-off due to hotter drought are the focus of rapidly expanding scientific literature. Despite recent observational, experimental, and modeling studies suggesting increased tree vulnerability to hotter drought and associated pests and pathogens, substantial debate remains regarding future mortality risks. We summarize mortality-relevant findings, differentiating between those implying lesser versus greater levels of vulnerability. Evidence suggesting lesser vulnerability includes forest ben-

efits of elevated [CO2] and increased water-use efficiency; observed and modeled increases in forest growth and canopy greening; widespread increases in woody-plant biomass, density, and extent; compensatory physiological, morphological, and genetic mechanisms; dampening ecological feedbacks; and potential mitigation by forest management. In contrast, recent studies document more rapid mortality under hotter drought due to negative tree physiological responses and accelerated biotic attacks. Additional evidence suggesting greater vulnerability includes rising background mortality rates; projected increases in drought frequency, intensity, and duration; biases in vegetation models such as non-mechanistic mortality functions; and wildfire synergies. Grouping these findings, we identify ten contrasting perspectives that shape the vulnerability debate but have not been discussed collectively. We present a critical set of global vulnerability drivers that are known with high confidence: 1) droughts eventually occur everywhere, 2) warming produces hotter droughts, 3) atmospheric moisture demand increases nonlinearly with temperature during drought, 4) mortality can occur faster in hotter drought, consistent with fundamental physiology, 5) shorter droughts occur more frequently than longer droughts and can become lethal under warming, increasing lethal drought frequency nonlinearly, and 6) mortality happens rapidly relative to growth intervals needed for forest recovery. These high-confidence drivers, in concert with research backing greater vulnerability perspectives, support an overall viewpoint of greater forest vulnerability globally. We highlight urgent challenges for research, management, and policy-making communities.

Quagga mussel containment at Glen Canyon National Recreation Area

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Abstract: As the quagga mussel infestation expands in Lake Powell and the Colorado River below the dam, Glen Canyon National Recreation Area (GLCA) continues to operate a comprehensive containment program to prevent the spread of quagga mussels to other waters. Containment includes education, decontamination, and administrative controls. The NPS has launched a highly visible public education and outreach program to increase awareness of and compliance with state aquatic invasive species laws and regulations. A targeted education campaign is aimed at come-and-go boaters to reinforce watercraft operator responsibility to "clean, drain and dry" their vessels and to "pull the plug". The collaborative public messaging effort with the states of Utah and Arizona includes roving technicians on launch ramps and in marinas. Technicians also assist with protocols, if necessary, and answer questions about quagga mussels and applicable state requirements.

Recent developments at three western CESUs: an update from the Colorado Plateau, Desert Southwest, and Rocky Mountain CESU directors

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Abstract: We will present brief introductions to the history, management, partners, and level of activity of the Colorado Plateau, Desert Southwest, and Rocky Mountain Cooperative Ecosystem Studies Units (CESU). We will describe recent developments such as new partners; new areas of research, education and technical assistance activity; and collaborations among our three CESUs. We will also discuss some best practices for managing our CESUs and challenges (e.g., ensuring adequate participation and reporting by all partners and the difficulties in ensuring that some of our smaller partners are selected to implement projects). We will conclude by highlighting some opportunities to make our CESUs more effective in achieving their mission.

Quagga mussels in Lake Powell

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Abstract: Quagga mussel (*Dreissena bugensis*) veligers were detected in Lake Powell late in 2012. Adult quagga mussels were located on structures and boats in marinas and then on submerged canyon walls in 2013. The established population of mussels is currently spreading across the immense reservoir and downstream through the Glen Canyon Dam (GCD) into Grand Canyon. Lake Powell veliger densities initially detected in 2012 near the dam were estimated at one veliger per 40,000 L of lake water; by the end of 2014, these concentrations exceeded one veliger per L. The area of veliger detection has expanded each year and extends beyond Dangling Rope Marina (~ 40 miles upstream of GCD) in 2015. In early 2015, veligers were also detected for the first time near Bullfrog Marina (~100 miles upstream from GCD), likely indicating a second reproductive population in the lake. Veliger detection is accomplished through analyzing plankton samples using polymerase chain reaction (PCR) and cross-polarized light microscopy.

Weathering patterns of rock art panels at Horseshoe Mesa, Wupatki National Monument, Arizona

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Abstract: Horseshoe Mesa, located in the northernmost part of Wupatki National Monument, is one of a series of "flatirons" on the eastward dipping limb of the Black Point Monocline. Regional faulting, folding, and jointing further define the shape and condition of Horseshoe Mesa, which is actively disintegrating into rectangular boulders. Weathering is increased along the joints by the concentration of water. Although it is a semi-arid environment, the interaction of water with various salts is a dominant weathering process. The weathering patterns on the sedimentary strata are nearly as mesmerizing and provocative as the rock art panels themselves. Delicate arches, tiny windows, precarious overhanging ledges, and labyrinthine honeycomb shapes are evidence of tafoni and alveolar weathering, created by chemical and physical interactions between the substrate and the surrounding environment. Pressures are created by volume changes resulting from the dissolution and recrystallization of soluble minerals like halite, gypsum, and other salts. Sandblasting, freezing and thawing, and running water are physical processes that help to weather the bedrock. Disaggregated material is then removed by wind, water, and gravity. The location of weathered strata at Horseshoe Mesa varies. Of the six defined strata, all exhibit some degree of weathering at some location around the mesa. While most of the panels are located in the lower two strata, very few rock art panels exhibit significant weathering. Several artists utilized the weathering patterns to orient their work, indicating that much of the weathering took place prior to the creation of the panels. Therefore, although weathering is severe in places, the petroglyph panels themselves are in excellent shape and not in immediate danger of being adversely affected by the ongoing weathering processes.

Restoring the living skin of the earth: progress in biocrust restoration in the Great Basin and Chihuahuan Desert

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Abstract: Drylands make up approximately 40% of Earth's terrestrial surface, and are host to a suite of land use practices that have severely degraded 10-20% of the landscape. Biocrusts are a ubiquitous consortium of bacteria, cyanobacteria, lichens, and mosses providing essential ecosystem functions, including soil stability, biogeochemical cycling, and water capture in these systems. Land degradation has led to a decline or loss of biocrusts in some systems. While it is widely accepted that biocrust restoration is necessary for dryland ecosystem health, research in this area is in its infancy. We present results of multiple projects aimed at developing a biocrust restoration technology. In particular, we have developed a system for cultivating biocrusts in the greenhouse for experimentation and for production of field inoculum. Experiments demonstrate that 1) mature biocrusts develop from moss or lichen fragments in months, 2) cultivated biocrusts are fixing ecosystem-relevant levels of nitrogen, and 3) biocrust organisms have unique "recipes' for maximum growth. We also initiated field trials to determine if greenhouse-cultivated biocrusts will survive in the field. We tested several hardening methods, and after 6-months in the field, preliminary data suggests cultivated biocrusts are able to withstand field conditions, with or without prior hardening. Finally, we have been working to determine the best methods for re-establishing crusts in two desert ecosystems. Experiments were implemented to determine 1) how much inoculum, 2) which habitat modifications, and 3) which soil stabilization practices will maximize biocrust establishment and development. Results after one year show small amounts of inoculum are as good as large amounts of inoculum. Adding shade benefits biocrust development, likely by reducing damaging UV and reducing evaporation. Of multiple stabilizing techniques tested, vertical straw borders were among the most effective. Together, these projects are helping to inform the best practices in developing a biocrust restoration technology.

Snow cover estimates using Landsat satellite images

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Abstract: Snowmelt in the semi-arid southwest is crucial in supplying water for the ecosystem as well as metropolitan populations. It is known that spring snowmelt contributes to increased groundwater recharge, providing up to 85 percent of annual water supply to Arizona, but due to large tree canopies, snow is intercepted and evaporated before it can replenish the soil. However, the United States Forest Service is conducting what is known as the Four Forest Restoration Initiative (4FRI), the nation's largest forest restoration effort that includes prescribed fires and mechanical thinning techniques to nearly 2.5 million acres of ponderosa pine forests in efforts to decrease the threat of large-scale catastrophic fires. The purpose of our study is to use remote sensing satellite data to estimate snow accumulation, snow water equivalence (SWE), and snow retention as a result of forest restoration treatments. A total of 66 Landsat TM/ETM+ images, spanning 26

years (1988-2014), were used to estimate snow accumulation at five local study sites near Flagstaff, Arizona. Each of the five sites is approximately 10 hectares in size and contains three treatment types: a control, thinned, and thinned-and-burned. Field measurements were also taken to ground truth the Landsat data using time-domain reflectometer (TDR) probes and a MoisturePoint meter that measure snow retention as well as soil moisture. The Landsat images were analyzed using the normalized difference snow index (NDSI) algorithm, which estimated snow accumulation at each site. The NDSI analysis and ground-truth data showed that the thinned and thinned-and-burned sites had greater snow accumulation than the control sites. The sites with greater snow accumulation prolonged into the spring season, possibly contributing to groundwater recharge. Understanding snow cover, especially in the desert southwest, is vital to the region because it is projected that temperatures will increase and snow seasons decrease due to global climate change.

Sustainability and the archaeological example: water conservation strategies of prehistoric groups in the Southwest

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Abstract: The management and study of cultural and archaeological resources can go beyond the academic study of the past and provide information and solutions directly relevant to solving the problems of the present. The Inter-governmental Panel on Climate Change predicts that the southwestern United States will experience elevated temperatures, higher evaporation rates, and lower precipitation, requiring creative solutions to what will likely become increasingly pressing needs for conservation and adaptation. Faced with an uncertain precipitation and temperature regime as the result of climate change, resource managers should diversify reclamation and conservation strategies to mitigate risk and uncertainty. Archaeology provides resource managers with low-tech and locally-adapted examples of resource exploitation systems that mitigate the uncertainty of a changing climate. Prehistoric and ethnographic cultures in the southwest developed highly resilient water exploitation and agricultural systems that have allowed people to persist and survive the semi-arid climate of the Colorado Plateau and the Sonoran Desert for more than 2,000 years. Archaeological records of the southwestern United States, including the ancestral Puebloan groups in northern Arizona and the Hohokam of southern Arizona, affirm that resource managers could work to reduce risk by adopting aspects of these adaptive strategies. Based on the archaeological and ethnographic record, many of the southwest's prehistoric cultures that practiced agriculture diversified their water collection and food planting strategies to encourage positive outcomes in both wet and dry years. Studying resilient systems developed by the prehistoric agricultural groups in the southwest provides resource managers with concepts that allowed people to survive the variable and uncertain climate.

Tracking patterns of climate change: impacts to archaeological sites at Flagstaff Area National Monuments

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Abstract: Although the study of climate change impacts to archaeological sites is relatively recent, archaeologists have been collecting data, monitoring site condition, and tracking impacts and threats to archaeological sites for decades. At Flagstaff Area National Monuments (FLAG) archaeologists have entered data on site condition and impacts into the national Archeological Sites Management and Information System (ASMIS) database since the 1980s. These data are also stored in the local archaeological database, FLAGARCH, along with additional information on site type, location, setting, and other data of local interest to FLAG archaeologists. While having to deal with potential issues related to legacy data (lack of consistency, differing opinions and definitions, different degrees of optimism/pessimism, etc.), the data contained within FLAGARCH can provide over three decades of information on site condition and impacts (including level of impact), allowing FLAG archaeologists to track condition over time, particularly for sites at Wupatki and Walnut Canyon National Monuments. This large data set, used together with spatial information, facilitates the analysis of a number of topics of interest in the study of climate change impacts, including changes in the levels of certain types of impacts over time, the types of impacts associated with certain areas and site types, and even in evaluating the efficacy of potential treatments. The results of the analysis of FLAG's long-term data set can help managers at the monuments better understand what impacts related to climate change have been identified and how they have changed, identify sites that are at greater risk from these impacts, and even to help develop responses.

Novel ecosystems are structured by novel interactions: the role of non-native species in pollination

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Abstract: As species shift their distributions in response to environmental change, species interactions are also affected. Novel interactions are those that occur between species that have not previously interacted. Unless interaction partners are highly redundant in the services they provide, a shift to a novel partner could alter an organism's growth rate, fitness, or even evolutionary trajectory. I used flower visitation observations and pollination treatments to study novel pollination interactions in an island ecosystem that contains a limited suite of interactors and thus serves as a macrocosm within which to examine the effects of such a shift. Introduced, non-native bees (*Apis mellifera*) and birds (*Zosterops japonicus*) visited fewer native plant species than did native pollinators, but were able to provide effective pollination services to those species. Fitness correlates declined for plant species lacking pollinators, but were unaffected by a switch from native to non-native pollinators. The lack of visitation by non-native pollinators to certain native plants may place those plants at risk of future population decline. My current work expands these concepts to the Colorado Plateau region, where rapid climate change and shifting fire regimes are likely to produce novel pollinator assemblages. Non-native plants in this region are visited by both native and non-native pollinators, and non-native bees appear particularly abundant in sites recovering from severe fire. Novel pollination relationships in this region could influence plant community composition and dynamics going forward, with potential ramifications for a wide diversity of taxonomic groups and disturbance recovery processes.

Optimizing ponderosa pine forest management regimes to maximize the production of multiple ecosystem services

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Abstract: Forest managers are faced with the difficult task of managing for the production of multiple ecosystem services (ES) with an incomplete understanding of the complex ways these ES interact. Managers can evaluate ES responses to forest management thorough use of simulation models, but these models are not designed to identify the optimal ES management plan when hundreds to thousands of stands are considered. We developed a quantitative model to help managers better understand the effect of 13 different management options on eight ES over a 45-year time horizon. The eight ES analyzed were 1) Mexican spotted owl (*Strix occidentalis lucida*) habitat, 2) merchantable timber harvested, 3) woody biomass removed for potential energy generation, 4) northern goshawk (*Accipiter gentilis*) habitat, 5) scenic beauty, 6) fire-hazard risk reduction, 7) carbon storage, and 8) restoration of pre-European settlement forest structure represented through larger stand quadratic-mean diameters. We integrated eight ES production functions with a forest growth-and-yield model to simulate the effects of three management actions over a 45-year period. The results from the growth-and-yield model were input into a goal-programming model to identify the optimal management regimes given a corresponding set of five different management objectives. We designed management objectives to reflect the likely goals a forest manager may choose for each ES in this region. ES goals were distinguished at the forest- and stand-level spatial extents. Results demonstrate the flexibility of the ES optimization model to plan for a variety of situations and preferences. For instance, two ES management goals viewed as conflicting are the protection of Mexican spotted owl habitat and the reduction of fire hazard risk. One ES optimization model (Model 5) produces a plan that reduces fire hazard risk from 56% to 7% of the study area in 2015 without any reduction in owl habitat quality throughout the time-horizon.

The energy-water nexus: How will hydro-power be effected by climate change and potential water shortages?

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Abstract: In our modern lives, energy and water are dependent on each other. Water is used to generate electricity directly with hydropower and also to cool thermal plants, like coal and nuclear, and ensure safe operation of those plants. Energy is used to pump water to different places as well as clean it to provide safe drinking water. With climate change, a new layer of complexity is added to this interaction. Many types of electricity production produce carbon dioxide emissions, which drive climate change. Climate change is contributing to higher temperatures and lower rainfall in the Southwest United States. Hydropower does not produce carbon dioxide emissions while generating electricity and thus does not contribute to climate change. However, climate change may be decreasing our ability to produce electricity with hydropower. The two largest dams in the Southwest United States, Hoover Dam and Glen Canyon Dam, and their respective reservoirs, Lake Mead and Lake Powell, have seen less water in recent history. There is concern that Lake Mead will hit a new low this year. In addition to hydropower producing electricity, it is also a useful resource when it comes to balancing variable sources of renewable generation like wind and solar. Wind and solar vary with the weather and can change quickly. Hydropower has the ability to ramp quickly to help balance those changes. As we think about how our electricity system is going to change in the coming years, it is important to analyze the changes in water and predict how that will affect electricity. This is being investigated currently with the NREL II study, which is focusing on Navajo Generating Station and its possible closure, as well as potential replacement generation.

Fulfilling our mission: documentation, public interpretation, and preservation of petroglyphs at Horseshoe Mesa (WS834), Wupatki National Monument, Arizona

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Abstract: A cooperative agreement between Flagstaff Area National Monuments (FLAG) and the Museum of Northern Arizona (MNA) resulted in complete baseline documentation of more than 1,100 petroglyphs at Horseshoe Mesa (WS834) in Wupatki National Monument. This spectacular site comprises one component of the well-known prehistoric Crack-in-Rock community. Photographs, scaled drawings, and descriptions of each panel and individual element provide a detailed record of petroglyphs that represent several thousand years of human activity. A geomorphic assessment of the site and the native stone that hosts the panels offers insight into the current condition and potential threats to these irreplaceable cultural resources. In-field consultation with tribal representative revealed information that enhances the human story of the petroglyphs. Information gained from the cooperative study will increase our ability to interpret and protect the site for the long-term enjoyment of visitors. Options for public dissemination of the project results include visual displays at contact stations and on park websites that will allow more visitors to experience and learn about the access-restricted backcountry site.

Changes in mycorrhizal propagule densities and soil properties across varying forest restoration treatments in warm dry mixed conifer, southwest Colorado

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Abstract: Thinning and prescribed fire treatments in warm/dry mixed conifer forests affect mycorrhizal propagule densities and soil properties in a variety of different ways. Most studies have examined the effects of fire on mycorrhizal propagule densities and soil properties shortly after fire treatments. The majority of these studies found that immediately following prescribed fire, mycorrhizal propagule densities are greatly reduced. It is possible that these decreased propagule densities are transient in nature. However, long-term post-fire effects have not been frequently studied. The objective of this study was to quantify the long term (7 years post-fire) effects of three different forest restoration treatments (thin/burn, burn only, and control) on mycorrhizal propagule densities and soil properties. Sixty bioassays of both ponderosa pine (*Pinus ponderosa*) and corn (*Zea maize*) will be grown, using soil from 10 random points for all 12 treatment plots (4 blocks x 3 treatments). We hypothesized that the greatest amount of percent root colonization will be in the thin/burn plots, followed by the burn only and controls and that pH and phosphorous levels will be higher in the thin/burn and burn only plots. Decreased tree competition from the thinning and burning will allow trees to experience a growth spurt, which should increase ectomycorrhizal propagule densities. More sunlight in decreased forest stands in the thinned and burned plots should increase understory herbaceous abundance and arbuscular mycorrhizae. If thinning and burning is indeed found to have a positive, long term effect on mycorrhizal propagation, it could be a viable management tool for warm/dry mixed conifer forests in the Southwest. As the climate is projected to become warmer and drier, plants in the Southwest will experience severe water and nutrient stress, and healthy populations of ecto and arbuscular mycorrhizae will facilitate increased water and nutrient uptake making ecosystems more resilient to climate change.

Pulaskis to plowshares: creating our future leaders through your conservation projects

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Abstract: The Civilian Conservation Corps (CCC) was created to meet two specific goals: combat rampant poverty and unemployment and help implement a conservation program for the country. Much like the CCC, today's Conservation Corps programs still place a large emphasis on social goals and employment while implementing projects with the best and latest knowledge and practice. Our tactics have evolved to better assist today's youth, but our goals are much the same. From preparing our members for jobs in public lands management to helping them find their path in whatever endeavor they choose for themselves, Conservation Corps strive to stay on the cutting edge while we "get the job done". Come learn what the 21st Century Conservation Corps are up to and how 10 corps programs engaged in three years of survey through the Public Lands Service Coalition and Texas A&M University to quantify the cultural impacts of outdoor conservation programming as related to a non- corps comparison group. Impacts cover items such as recreation, stewardship, environmental interest, grit, and more.

Adaptive silviculture: how do we respond to a changing climate?

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Abstract: The uncertainty of forest ecosystem response to a changing climate requires forest managers to attempt various adaptation strategies for managing forests. Adaptation strategies can be based on multiple lines of evidence such as past observations of forest responses including long-term research and dendrochronological studies or new research. For example, the Adaptive Silviculture for Climate Change study, a network of experimental long-term silvicultural trials in distinct forest types across the United States, is being established to evaluate management options designed to enable forests to respond to a changing climate. In 2014, a workshop in partnership with the San Juan National Forest was convened to implement a planning framework to develop climate change adaptive management strategies designed by local natural resource managers and regional scientists specific to the warm-dry mixed conifer forest type. Three adaptation treatments were developed to demonstrate a gradient of accommodating change: resistance, resilience, and transition. This replicated study will contribute to the broad understanding of adaptive management strategies designed to address the uncertainty of climate change across the network of sites, while testing site-specific effects on forest resiliency to increased wildfire potential, drought, disease, insects, and other disturbance factors relevant to the San Juan National Forest and other dry mixed conifer forests in the region.

Conserving nature's stage

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Abstract: I advocate using geodiversity or enduring features (landform, bedrock, soil, topography, and other abiotic features) in a coarse filter strategy for conservation planning in the face of climate change. The approach is attractive because it focuses conservation on the physical factors that create diversity, allowing species and communities to rearrange in response to a changing climate. It provides a logical structure for designing conservation networks that assume nature is dynamic and resilient, and challenges us to create arenas for evolution not museums of the past. This presentation: (1) describes ecological theory, and biogeographic and paleo-ecological evidence supporting the idea geodiversity is a major driver of species distributions and ecological processes in terrestrial systems; (2) presents a global map of 670 geodiversity types (land facets) and how much of each type is protected in each of 8 biogeographic realms; (3) summarizes evidence that geodiversity is a good surrogate for biodiversity of terrestrial plants, mammals, birds, amphibians, and reptiles, and 11 marine phyla; (4) describes cases studies in which geodiversity targets have been incorporated into traditional conservation plans without increasing the total area prioritized or decreasing the achievement of other targets; and (5) explains how geodiversity can be incorporated into the work of agencies that are mandated to focus on conservation of particular species. To extend the metaphor of the ecological theater and the evolutionary play, I conclude that we should now focus on conserving nature's stage for the evolving cast of players in the coming era of climate change.

Definition, examples, and global extent of novel ecosystems

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Abstract: Human activities have led to emergence of novel ecosystems, defined as ecosystems without historical precedence that are self-sustaining and that cannot (due to ecological, financial, or social barriers) be restored to a predominantly natural ecological state or trajectory. I provide 4 examples related to 4 human activities. (1) Land conversion: After wholesale abandonment of farming on Puerto Rico, about 75% of Puerto Rico reverted to novel forests dominated by non-native species with altered soils that cannot support native forests. (2) Exotic species: The non-native *Cinchona* tree has invaded formerly treeless shrublands of Santa Cruz Island, providing increased substrate for epiphytes, altering understory composition, and transforming ecosystem function. (3) Extinction: The extinctions of two endemic giant tortoises, the dominant keystone herbivores on Rodrigues Island, have led to profound changes in vegetation structure and composition. (4) Air pollution: Industrial activities increased nitrogen deposition on serpentine grasslands in California by 10- to 30-fold, facilitating invasion by non-native grasses to the detriment of endemic plants. Recent studies have estimated that novel ecosystems cover 28-36% of Earth's ice free land-surface, but these studies classified an 85-km^2 cell as novel if any part of the cell was used by humans. Managers are intervening in each of these novel ecosystems to conserve endemic species and provide important ecosystem services. The other papers in this symposium provide additional examples of conservation interventions in novel ecosystems.

Geochemistry of springs in Snake Gulch, AZ compared with the geochemistry of the reclaimed Pigeon Mine

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Abstract: Changes in chemistry that occur as water flows from source areas through breccia-pipe uranium deposits in the Grand Canyon region are not well understood. Snake Gulch, a tributary to Kanab Creek, which flows into the Colorado River, was chosen for a geochemical study because there is a reclaimed breccia-pipe uranium mine (Pigeon Mine), unmined collapse features, and several perched groundwater springs in the drainage. Several springs in Snake Gulch were sampled for general water chemistry and uranium in 1982, just before the Pigeon Mine began operations, and were re-sampled again between 2009 and 2014. Pigeon Spring had the highest uranium concentration (44 µg/L) of the spring samples collected during 1982 and had the highest again (average 80 µg/L) in the recent 2009 through 2014 samples. The uranium concentration of other spring samples collected in Snake Gulch ranged from 2.7 to 18 µg/L in the 2009 to 2014 samples. Multivariate statistical analysis of major and trace elements in background sediment and mining impacted sediments gives an indication of the geochemical composition of Pigeon Mine material. Leachates from the Pigeon Mine waste and spring trace element chemistry were also analyzed by multivariate statistical methods. Stable ($\delta^{18}O$ and $\delta^{2}H$) and radioisotope (carbon-14, uranium, radium, strontium, and tritium) data from spring samples provided information about groundwater recharge elevations, likely water-rock interactions, and water residence time. The geochemical analysis of the water, sediment, and rock samples collected from Snake Gulch provided a better understanding of potential sources of uranium to perched groundwater resources near breccia pipe deposits.

Cultural adaptations to climate change: Navajo practices of animal grazing and animal husbandry on the Navajo Nation

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Abstract: For centuries, indigenous tribes throughout the Southwest have lived and survived by following oral tradition to guide land management practices. Today, many tribal communities, including the Navajo Nation, continue to utilize and incorporate oral traditions as they interface with Western science to carry out management activities. But as climate change continues to impact the southwestern United States, with increasing temperatures and extended drought expected over large areas for decades to come, the Navajo Nation is left with ever larger challenges in efforts to protect and sustainably manage their land and cultural resources. Sheep grazing and the rise of modern cattle ranching have both been critical to Navajo wellbeing. With climate change becoming a leading concern on the Navajo Nation, it is important to examine the evolution of Navajo grazing knowledge and practice to develop suitable practices or methods that will support resiliency on grazed lands, in the face of ongoing climate change. This research analyzed grazing practices on the Navajo Nation and provides insight on the interface of traditional ecological knowledge (TEK) with western sciences as it affects grazing practices during this period of rapid climate change. Using in-depth interviews, I documented grazing TEK and climate and range indicators that inform management decisions, particularly during extended drought periods. This knowledge is compared to chapter rangeland management plans and scientific literature on these grazing systems. Recommendations suggest strategies to help sustain appropriate grazing practices and integrate TEK under climate changes.

Reproduction, abundance, and recruitment dynamics of young Colorado pikeminnow in the Green River Basin, Utah and Colorado, 1979-2012

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Abstract: We assessed long-term patterns of Colorado pikeminnow (*Ptychocheilus lucius*) reproduction and age-0 recruiment in the Green and Yampa rivers of the upper Colorado River basin to better understand reasons for declining abundance of adults. Timing of reproduction in summer was positively related to date of peak spring runoff flow as well as water temperatures. Abundance of larvae produced from spawning areas was positively correlated with both spring peak and summer base flows (mean July-August flow) in the lower Yampa River and the lower Green River. In low flow years, few larvae were produced from spawning areas and transported to nursery habitat reaches in summer (e.g., 1994, 2002, 2007) so few age-0 pikeminnow were evident, especially in middle Green River backwaters in autumn. In most other years, production of larvae was thought sufficient to produce more age-0 fish but other factors controlled their survival and recruitment to autumn. Densities of age-0 Colorado pikeminnow in middle and lower Green River backwaters declined over the study period. Exact mechanisms controlling abundance of age-0 Colorado pikeminnow were

not known, but moderate base flow levels were consistent with higher abundance in most years and lower abundance was noted in lower and higher base flow years. Growth of age-0 Colorado pikeminnow was positively related to length of the summer growing season and summer water temperature. Higher base flow levels were also associated with reduced autumn abundance of red shiner (*Cyprinella lutrensis*), a potential competitor and predator on early life stages of native fishes. Although data patterns were messy, a result of high variability in pikeminnow abundance and environmental factors, a clear signal was that Green River base flows in summer and autumn need to be increased to favor survival of larger numbers of age-0 Colorado pikeminnow and bolster populations of adult life stages.

River regulation affects reproduction, early growth, and suppression strategies for invasive smallmouth bass in the upper Colorado River basin

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Abstract: Understanding the reproductive ecology of organisms enables predicting effects of environmental factors to control population growth. Otolith microstructure was used to estimate hatching dates and growth of invasive smallmouth bass Micropterus dolomieu collected in regulated or partially regulated reaches of the Green River, and the free-flowing Yampa River, Colorado and Utah, 2003-2011. Smallmouth bass hatching in the unregulated Yampa River was initiated in June through mid-July consistent with a 16°C water temperature threshold over a range of flow levels. In dam-regulated and partially regulated Green River reaches, spawning occurred only after habitat was available and was several to many days after the 16°C threshold, so bass reproduction was controlled by water temperatures and flow level. In all reaches, bass hatched later in cooler and higher flow years and earlier in warmer and lower flow years. Total length of Age-0 smallmouth bass in mid-September was positively influenced by length of growing season as well as water temperature and indicated flow reductions from water storage or climate change would increase bass growth and negative effects on native fishes. Management actions such as abrupt flow increases (managed floods), reduced water temperatures, or physical disturbances directed at disrupting spawning smallmouth bass may reduce reproductive success but need to consider effects on other native and nonnative fishes as well as water availability tradeoffs. Increased use of flow and water temperature regimes from dams to reduce negative effects of nonnative fishes, and to increase growth and survival of native kinds, is advocated as a viable use of reservoir water storage and may offer management agencies another tool to achieve a more naturally functioning river ecosystem and enhance recovery of native biota.

Modern approaches to rock art documentation

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Abstract: Rapid advancement in the profession of rock art site documentation has occurred parallel with advances in technology that include digital cameras and their accessories such as Gigapans, programmable GPS units with sub-meter accuracy, sophisticated image enhancement software, portable tablets with powerful applications, faster and cheaper computers with cost effective storage, and accessible photogrammetry and 3-D applications. Drone photography has also helped transform the way archaeological and rock art sites are documented in the 21st century. This presentation will highlight examples using some of the above techniques at public and private rock art sites on the Colorado Plateau and at three other Southwest Region National Parks that have partnered with the Museum of Northern Arizona researchers through the Cooperative Ecosystem Studies Unit program. We will offer observations about the benefits, drawbacks, and conditions under which best results are achieved, plus provide insight into the importance of having various types of baseline documentation that is easily accessible to land managers.

Monitoring and evaluation of the effects of natural, legacy, and current uranium mining water resources in the Grand Canyon Region of Northern Arizona

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Abstract: The Grand Canyon Region contains high-grade uranium ore hosted in geologic features called breccia pipes. The exploration and extraction of uranium ore from breccia pipes that are mineralized can pose potential risks to humans and biota of the region. From 2009 to 2013, the USGS has conducted regional water-chemistry studies to develop better baseline water-chemistry characterizations of the regional aquifers and other water-bearing zones in the region. This information is needed to better characterize regional water chemistry and changes in water chemistry of water resources exposed to unmined, mined and reclaimed, and actively mined orebodies. Currently, dissolved uranium in groundwater is about 5.0 µg/L or less regionally, except in proximity to uranium ore

bodies where concentrations can be higher than 100 µg/L. Most of the higher uranium concentrations occur within a mile or two of naturally exposed ore bodies or ore bodies that have been mined and reclaimed, or left exposed since the 1970s and 1980s. USGS scientists are actively collecting the data needed to determine whether mining increases or changes uranium concentrations relative to natural levels. There is no evidence currently to link present-day mining activity to changes in local or regional water chemistry. The current discharge of total uranium in the Colorado River from the Grand Canyon Region have concentrations of 4.0 µg/L or less resulting in a total annual load of uranium delivered to Lake Mead of about 30 to 40 tons. This results in little if any impact to drinking water supplies to the Lower Colorado River States. Ongoing activities include additional data collection and monitoring to expand base-line water-chemistry characterization, monitoring to better understand temporal trends, and evaluation of the geochemistry of springs and nearby reclaimed mines. This study and ongoing activities also support ongoing biological assessments in the region.

Precipitation interpolation in the Sonoran Desert: a multiagency effort to inform time sensitive land management decisions

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Abstract: Precipitation is the driving factor behind the natural systems of the Sonoran Desert. Precipitation is highly variable across the region, especially during the summer monsoon. Knowing amounts and the spatial distribution of rainfall is of great value to a large number of time sensitive resource management questions that land managers are faced with in the region. This includes responding to stressors on threatened and endangered species (for example, understanding when and where emergency feed and water stations are needed), better targeting the timing and location of control measures on invasive plants, and identifying cultural and other resources that may have been subjected to extreme erosional events. This poster highlights an ongoing effort between multiple agencies in Southwest Arizona - to better understand precipitation distribution. Multiple times per year, climate monitoring data are being combined from over 110 precipitation recording sites across these jurisdictions and from surrounding lands. Many of these recording sites are manual download and their data are not available to larger scale modeling efforts - like PRISM. These data are then used to interpolate rainfall surfaces and those surfaces are compared with long term climate normals. These surfaces serve to inform many land management decisions.

Vegetation monitoring using LiDAR and high-resolution imagery on the Barry M. Goldwater Range, Arizona

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Abstract: The Barry M. Goldwater Range East comprises 1.05 million acres of the lower Sonoran Desert in Southwest Arizona. We are acquiring high-resolution (10 cm and 24 cm) 4-band imagery of the range on a multiyear interval. We have also recently acquired Quality Level 1 (QL1) LiDAR (8 points per square meter point spacing) for the bulk of the range. We are exploring several techniques to use this information to assess vegetation metrics across the range. A number of plots have been extensively ground surveyed to provide data to compare with these models. The goals include inference about the impacts on vegetation by military training exercises, border patrol activities, recreational use (including the formation of novel illegal roads), erosion, and wildfire.

Reducing the risk of climate change mitigation strategies with genetics-based species distribution models

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Abstract: Mitigating species responses to global change is one of the greatest challenges of this century. Predictive species distribution models (SDM) can reduce risk and uncertainty associated with management decisions; however, most current models operate under the simplifying assumptions that there are no barriers to gene flow and all populations share the same climate niche. Yet we know that most species are genetically differentiated throughout their ranges, and local adaptation in response to climate-related selection pressures is common. Here we present an evolutionary modeling strategy to improve predictions of future climate change

impacts on species distributions, using the broadly distributed foundation riparian tree *Populus angustifolia* (narrowleaf cottonwood). We collected leaf samples from 696 trees at 34 sites and assessed geographic patterns of genetic diversity and structure using 12 microsatellite loci. Genetic analyses revealed that *P. angustifolia* is differentiated into seven genetic clusters across its range. We also found strong support for niche separation by climate among the genetic clusters (perMANOVA: $R^2 = 0.78$, $p = 0.001$). Based on both genetic and ecological distinctness, we designated seven evolutionarily significant units (ESUs) for use in subsequent modeling. Comparing the full species model (FM) with six regional SDM (rSDM) based on ESUs, we found FM predicted 40% less current suitable habitat than the seven regional models combined. Projecting forward to climate scenarios in 2099, FM predicted 75% gain, whereas rSDM predicted 20% loss in suitable habitat. We further identified temporal corridors where climate is predicted to be continuously suitable through 2099, indicating regions of high conservation priority. Our findings illustrate how FM and rSDM can produce drastically different predictions. We suggest evolutionary-based rSDM can provide more accurate predictions to help land managers prepare for the impacts of climate change.

Rapid cultivation of N-fixing lichens and biocrusts for rehabilitation of drylands

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Abstract: Degradation of drylands present major challenges to restoration ecology due to resource limitations, biological invasions, and persistent erosion. Rehabilitation of biological soil crusts (biocrusts) in degraded drylands may benefit ecosystem recovery by capturing resources, discouraging invasive plants, and curbing erosion. In order to do so, culture methods for biocrust organisms, including lichens, mosses, and cyanobacteria, must be optimized. We cultured six different biocrust lichens or mosses, alone or in various combinations, in a full-factorial experiment which also manipulated water quality and hydration schedule. All cultures resulted in a multi-species biocrust, often dominated by cyanobacteria. The lichen *Collema* was the best performer, increasing cover by up to 238% over the 5 month experiment, and also promoting the greatest cyanobacterial cover. This taxon is highly desirable as a restoration material because of its N-fixation activity and large role in ecosystem N-cycling. The mosses *Syntrichia caninervis* and *S. ruralis* also attained positive growth, whereas three other target lichen species initially grew but eventually lost cover. Species combinations featuring *Collema* and both mosses exhibited greater growth rates for all species, compared to each species growing alone. This finding suggests that the initial species composition of a culture will likely affect the success of the various species, and that there may be facilitative species interactions to exploit in order to produce inoculum faster. All species either were unaffected by water quality, or performed better when irrigated with de-ionized water as opposed to tap water. Several species responded favorably to shorter dry periods, although shortening dry periods may favor undesired green algae in open cultures. If these culture techniques are refined and up-scaled, we may have a means to culture the restoration-relevant amounts of biocrust materials necessary to combat land degradation, trigger favorable ecosystem state transitions, and reduce problematic dust emissions.

Climate change, drought, and tree mortality in the southwestern US

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Abstract: Severe droughts cause widespread tree mortality and decreased growth in forests across the globe. Forest managers are seeking strategies to increase forest resistance (minimizing negative impacts during the drought) and resilience (maximizing recovery rates following drought). Limited experimental evidence in managed forests suggests that forests with particular structural characteristics have greater capacity to resist change and or recover ecosystem function in the face of drought. Here, we examined tree mortality in conifer forests across the southwestern U.S. from USDA Forest Inventory and Analysis data and quantified the relative importance of stand structure (notably density) and weather fluctuations on mortality patterns. We examined mortality patterns in tree species in subalpine (Engelmann spruce, subalpine fir, and lodgepole pine), montane (Douglas-fir and ponderosa pine), and woodland (two-needle pinyon pine and Utah juniper) forests. We related these observed patterns to climate and weather conditions and contrasted the relationships with anticipated trajectories of climate over the 21st century (10 GCMs simulating RCP8.5). Results indicate that both weather conditions and stand structure influence mortality, and the relative importance of these two drivers changes from mesic to xeric forest types. Stand structure was the dominant influence for species in cool, wet, high elevation locations and weather dominated responses of species in hot, dry, low elevation areas. Placing these relationships in the context of climate change indicated that climate is shifting toward conditions that will likely increase mortality rates in many, but not all, tree species. Additionally, these results illustrate several important interactions between weather variables and stand structure, which indicate that the effectiveness of management strategies for maximizing drought resistance will vary geographically. This work highlights the consistent and important control that stand structure exerts over drought impacts on tree mortality and suggests a framework for assessing the consequences of climate change on managed and unmanaged forests.

Enhancing the resilience of riparian/wetland ecosystems in light of climate change

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Abstract: The Gunnison Climate Working Group works to design and implement an on-the-ground climate adaptation project to retain water and enhance the resilience of riparian/wetland in light of climate change. The GCWG comprises public agencies, academic institutions, and private organizations working to: 1) increase understanding of threats posed by climate change in the Gunnison Basin, 2) prioritize strategies and techniques for helping people and nature cope with climate change, and 3) promote collaboration and effective implementation of strategies. The GCWG includes BLM, CNHP, CPW, Gunnison County, Gunnison County Stock Growers, LFVC, NCAR, NPS, TNC, NRCS, TU, UGRWCD, USFS, USFWS, WSCU, WWA, and RMBL. Between 2012 and 2014, we focused on increasing the resilience of wet meadow/riparian systems to help them cope with projected impacts of increased intensity and frequency of droughts and flooding associated with climate change. So far, GCWG has restored 15 stream miles on USFS and BLM lands and on three private properties. Within these areas, 40 acres of wetland/meadow acres were restored. We have used techniques developed by Bill Zeedyk in *Let the Water Do the Work*, including constructing plug and spread structures and installing drift fences and rock structures. The following are achieved goals: 1) Dispersed flows more widely across floodplain surfaces to maximize infiltration and increase bank storage during flood events; 2) stabilized eroded wet meadow soils to control head cutting and reduce gully expansion thereby retaining bank storage and extending base flows; 3) expanded the size, extent, and distribution of riparian/wetland sites in response to objectives #1 and #2; and increased health, vigor, and density of riparian/wetland vegetation, such as native sedges, rushes, wet-loving grasses and forbs. In addition, we have used several communication methods, including video, fact sheets, website, presentations at conferences and meetings, field trips, media and press releases, trainings, and reports to disseminate information and to educate.

Recent insights on tree die-off from hotter drought

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Abstract: Numerous recent studies reinforce the risk forests face due to tree mortality associated with hotter droughts. A sampling of some these studies will be highlighted and includes: mortality occurs faster and faster and temperatures rise; a new experimentally determined bioclimatic envelop specific to climate extremes and mortality underscores high vulnerability to die-off under warmer climate; the best tested vegetation models converge on predictions of massive die-off of needleleaf evergreen conifers in coming decades; and a potential amplifying effect of forest-die-off, if it occurs at a large enough scale, is that ecoclimatic teleconnections can occur within and among continents, whereby changes in post-die-off microclimate feedback to the climate, influence climate elsewhere, and, in turn, can modify and in some cases exacerbate water stress of vegetation elsewhere. These examples collectively highlight greater levels of vulnerability for forests to hotter drought and present key challenges for land managers.

Enhancing ecosystem services through collaborative restoration: processes and outcomes

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Abstract: The concept of ecosystem services has gained widespread acceptance over the past two decades. Ecological restoration is often characterized as a means for enhancing flows of ecosystem services. Typically when such a claim is made, the focus is on two types of services: supporting services such as soil formation and nutrient cycling necessary for the production of other ecosystem service, or regulating services such as pollination or climate modulation. A third category of ecosystem services, provisions such as food or fiber that can be extracted from ecosystems, are often downplayed or discouraged because extractive activities often cause the conditions that make restoration necessary. Less recognized is the role restoration can play in providing the fourth type of ecosystem service: cultural services such as recreation, education, sense of place, or spiritual renewal. Volunteers in restoration hope to achieve certain outcomes, some of which are benefits to the ecosystem and some of which are benefits to themselves. Whether or not they are materially compensated for engaging in restoration, participants gain cultural benefits through the end product – a

restored natural setting that improves as habitat as well as a place to engage in contemplative types of recreation – and also through the process of participation. Restoration participants necessarily gain new awareness of the functions of, and relationships between, components of a restored ecosystem. Often there are social benefits as well. Partly, this is because restoration almost always requires people to work cooperatively towards a goal. Collaborations among multiple groups – often ones that might otherwise tend to maintain adversarial relationships – are important not only because they allow land stewards to achieve restoration goals that might otherwise be unaffordable, but also because they build relationships that make it easier to pursue additional restoration efforts in the future.

A Forest Service senior leader's perspective: how Southern Paiute traditional ecological knowledge has been a foundation for land management decisions

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Abstract: Southern Paiute traditional lands range from central Utah, southern Nevada, and northern Arizona. Much of these lands are managed by the federal government as a national park or public and forested lands managed by the National Park Service, Bureau of Land Management, or Forest Service. These lands include Southern Paiute landmarks, waters, topography, and vegetation, and are steeped in tribal tradition that provide continuity of cultural delivery to the next generations. As a senior federal land manager responsible for forested lands, the core foundation of Southern Paiute values associated with land management, enable a much broader perspective on natural resources. Long-term tribal implications of state and federal management decisions contribute to a loss of tribal traditions and ways of life. Tribal knowledge that was previously put aside should now be contemplated as an alternative for consideration. From a tribal perspective an example in case, many generations of Southern Paiute people burned areas to propagate plants for basket making, food and medicines, reduced fuel loads for deer herds, and used fire to frighten the lightning during the monsoon season. Modern science states that the manipulation of vegetation with the use of fire enhances the ecological process. Watersheds, springs, rivers, and creeks were important to families and were often owned and managed in the high desert of the Colorado Plateau. Today, we are moving to managing watersheds for the protection of clean water for urban areas. The holistic view of tribes in managing an entire ecosystem, with the philosophy of "everything is related" is now the trend when federal managers are making decisions when restoring resources on the land.

Approaches to integrating Hualapai TEK in cultural resources monitoring along the Colorado River in Grand Canyon

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Abstract: The Hualapai Tribe Department of Cultural Resources has been conducting annual monitoring river trips for nearly 25 years, mainly to support information needs of the Glen Canyon Dam Adaptive Management Program (GCDAMP). Over the course of this time, monitoring activities have been modified in some respects, largely in response to changes in conditions along the river, implementation of certain actions in the broader GCDAMP (e.g., the High Flow Experiment protocols), and the more explicit incorporation of traditional ecological knowledge (TEK). The use of historical imagery and more recent photo-matching at the local landscape level have also gained more prominence in evaluating ecological changes since construction of the dam, particularly in identifying culturally significant plants. These approaches have the further potential to convey to youth, who participate in monitoring trips, and elders, who may not be able to, the historic changes that have occurred along the river and the effects on natural and cultural resources. From elders and other knowledgeable tribal members, we then seek to elicit TEK about the significance of past and present conditions. This paper discusses how adapting to changes in the overall GCDAMP has led to increasingly holistic approaches to addressing resource conditions and providing relevant input for management decisions, while also further meeting the needs of the Hualapai Tribe.

The ecological footprint of drought legacies across plant communities on the northern Colorado Plateau using remote sensing

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Abstract: Natural resource managers face tremendous challenges in the future as climate change impacts the abundance and distribution of plant species. These challenges will be especially daunting in the southwestern U.S., which is projected to experience large increases in temperature and changes in precipitation regime. Plant communities in the southwestern U.S. may be particularly vulnerable to changes in climate as the productivity of many plant species is strongly water-limited. Our study examines the relation-

ship between drought indices and vegetation condition using Landsat imagery across grassland, shrubland, and woodland communities in national parks on the Colorado Plateau. We pay particular attention to climate-plant lags (3, 6, 9, and 12 months) and the influence of drought and wet period legacies on vegetation greenness, which may indicate windows of plant vulnerability. Our results show that since 1995, a prolonged, and in several years, intense drought, has occurred across the entire northern Colorado Plateau. Two distinct trends in the condition of vegetation occurred across all plant communities with respect to climate legacy. Areas of the Colorado Plateau that were consistently dry or drying, as compared to the previous time step, had increases in vegetation greenness when conditions were interrupted by wetting events. In contrast, consistently wet or wetting areas of the Colorado Plateau, had no changes, slight decreases, or slight increases in vegetation greenness as they experienced wetting events, depending on the plant community. We show that blackbrush and other shrublands can sustain and even show greening trends under short- and long-term drought conditions; whereas other plant communities, including grasslands, show degradation or loss of greenness even in periods of short-term drought. The results of our study show the importance of climatic legacy effects and lags in vegetation response, which can be used to forecast which plant communities will be vulnerable under future climate change.

Climate change vulnerability and risk assessment framework for cultural resources in the National Park Service's Intermountain Region Vanishing Treasures Program

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Abstract: While extensive research has been conducted regarding the potential impact of climate change on natural resources, no systematic method exists for identifying significant climate change variables and developing predictive management and treatment decisions for National Park Service (NPS) cultural resources. A 2013 NPS brief outlined the agency's commitment to addressing the topic of climate change and cultural resources as well as a call for the development of a survey of climate-vulnerable areas and appropriate management strategies. Concurrently, the NPS Intermountain Region (IMR) initiated a long-term, multi-phase project to develop a climate change vulnerability and risk assessment framework for identifying cultural resources most at risk within the Vanishing Treasures (VT) Program. VT resources include both historic and prehistoric archaeological and architectural resources, comprised of earthen materials (including adobe, earthen mortars, and earthen plasters), stone, and wood, in 46 national park units in the Intermountain Region and Pacific West Region. This long-term project will be conducted in three phases: 1) scope the key challenges facing IMR cultural resources through the compilation of existing data and models, 2) develop scenario planning, adaptation, mitigation, and monitoring options based on use of predictive models and prioritization of the most at-risk resources, and 3)Implement baseline assessment and long-term monitoring protocols to evaluate and refine the modeling and management strategies. This presentation summarizes the results of the first phase of this project, focusing on future regional climate scenarios, the identification of the most at-risk sub-regions and resource types within the Intermountain Region, and the effects of climate change on buried archaeology and architectural resources.

Prestoring for climate change: identifying windows of opportunity for restoration to minimize loss of biodiversity and ecosystem functioning

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Abstract: Ecological restoration efforts often seek to reestablish vegetation that converges on an undisturbed reference type. As climate changes, the objectives of restoration should not be to restore to what was, but rather to establish vegetation that can persist now and into the future. "Prestoring" for climate change presents an opportunity to establish vegetation that is resilient to climate change by incorporating model-informed assisted migration into land management activities. Here, we use ecological niche modeling and an ensemble of climate change scenarios to assess spatial and temporal windows of opportunity for prestoration with grass species on the Colorado Plateau (CP) over the coming century. We identify suitable climatic conditions for the 100 most abundant grass species in the United States and project those models on to the CP to generate rangeland assemblages at the present and for each successive decade through the 2080s, using five different general circulation models. Using a range of potential migration rates, we find that most of the CP is expected to experience significant losses in local (alpha) diversity due to local extinctions and subsequent lags in natural immigration. Across a variety of locations and vegetation types, we identify grass species that are not currently present locally but that could be used in prestoration mixes following a disturbance in order to minimize loss of biodiversity and associated ecosystem functioning. As an added benefit, prestoration sites would also function as nuclei for assisted migration into undisturbed vegetation, thereby benefiting biodiversity maintenance at a landscape scale. We conclude by discussing challenges to prestoration, particularly seed supply and regulatory hurdles, that need to be overcome in order take advantage of the predictions and prescriptions generated by global change research.

The Opportune Extraction Model (OEM) protecting resources and capturing flood flows: how it works

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Abstract: We were retained by the law firm of Fennemore Craig to provide an expert biological opinion in the adjudication of water rights involving Aravaipa Canyon Wilderness Area (ACWA). We were asked to review the best available scientific data relevant to the United States' federal reserved water rights claim that the minimal water need of ACWA is all of the water flowing naturally within Aravaipa Creek. Aravaipa Creek is a large, low elevation watershed located in southeastern Arizona with a hydrograph typified by extreme variations in discharge. Flood events are universally stochastic and short-lived, while almost all floods occur during two discrete seasons (late fall-early spring and summer monsoon). Within those time periods, individual events are neither dependable nor predictable, and the nature of the watershed and climate necessitate resilience in the aquatic and riparian ecosystem. The United States makes the claim that all of the water (base flows and un-impounded flood flows) flowing into the boundaries of the ACWA is required to provide for "the preservation and protection of this relatively undisturbed but fragile complex of desert, riparian and aquatic ecosystems and the native plant, fish and wildlife communities dependent on it" (Public Law 98-406). We reviewed existing hydrographic data for a multi-decade period of record and expert reports on ecosystem processes within the wilderness area and hypothetically propose that ecosystem and social services provided by Aravaipa Creek can be maintained while simultaneously extracting a portion of flood waters. We have developed an Opportune Extraction Model (OEM) that we argue allows limited water harvest while simultaneously (1) preserving the hydrological and physical processes of the natural hydrograph, (2) maintaining integrity of the aquatic and riparian ecosystem that is nurtured by the surface and subsurface waters of Aravaipa Creek, and (3) sustaining the recreational, aesthetic, and ecological values for which Aravaipa Canyon Wilderness was established.

Managing the Pino Fire for resource benefit

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Abstract: Across the nation, fire managers face infinite challenges in a dynamic political, ecological, and operational environment. Santa Fe National Forest fire managers met these challenges head on when managing the 2014 Pino Fire for resource benefit. The Pino Fire was started by lightning on August 13th, 2014 on the Jemez Ranger District of the Santa Fe National Forest and burned a total of 4,287 acres. Highly visible from Albuquerque and the state's capital of Santa Fe, the fire was managed in rugged terrain of the southwest Jemez Mountains in a highly complex area of wildland urban interface (WUI). Coincidentally, this natural ignition was located within the perimeter of a fully prepped and planned high-complexity prescribed fire (RX) unit that has not carried fire in multiple decades. Consistent with historically frequent, low to moderate severity fires, the predominant vegetation type consisted of ponderosa pine (75%) and white fir/Douglas fir (15-20%), with some areas of pinon/juniper and oak. Fire severities for the Pino Fire are as follows: 85.5% was low, 10.5% was moderate, and 4% was high severity. The resulting fire effects created a patchwork mosaic across the landscape; areas of high and moderate severity are included within a large landscape of low severity. Additionally, the Pino Fire is within the boundary of the Southwest Jemez Collaborative Forest Landscape Restoration Project (SWJ CFLRP), which is part of a national priority to prevent uncharacteristic wildfire at a landscape scale. This unplanned ignition presented a unique opportunity to showcase, both internally and externally, a progressive fire management strategy that encourages ecological benefits and does not defer eminent wildfire risk to future generations.

Systematic conservation planning for climate resilience: integrating coarse and fine-filter conservation targets

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Abstract: Land use planning processes increasingly focus on ensuring that management activities are consistent with maintaining resilience and conserving biodiversity under changing climates. Achieving this goal requires comprehensive spatial information at an extent and resolution relevant to planners. AdaptWest is a new spatial database that combines broad geographic extent, relatively high spatial resolution, and a wide range of spatial data relevant to resilience and adaptation potential of natural systems under climate change. But such diverse data is of limited use without a context for comparison and synthesis. In order to integrate diverse perspectives on what areas are important for climate adaptation, a comprehensive planning process should compare priority areas from different approaches, test assumptions (such as the value of coarse filter targets as surrogates for biodiversity), encompass a range of model complexity, and ultimately use a multi-track approach to produce a unified analysis of priority areas. In this talk, I present results from a conservation prioritization for North America that integrates environmental diversity, climate velocity, and species-based metrics, and discuss commonalities and contrasts between areas identified as priorities using alternative metrics.

Simulating fire and vegetation in the Mediterranean: implications for the Southwest

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Abstract: Seasonally dry pine forests have been affected by wildfires in areas with different climates all over the world, hence their fire ecology has been widely studied and described. However, predictions of post-fire vegetation recovery under future climate change are still very uncertain, and more information is necessary for forest managers to make decisions about treatments. This paper focuses on modeling the natural vegetation dynamics in a Mediterranean dry pine forest and comparing it with similar studies in southwestern dry pine forests, through different management actions, under current climate and climate change scenarios. We adapted and applied GREFOS, a forest gap dynamics model developed for the northeastern Mediterranean Basin, to the bioclimatic conditions of northwestern Mediterranean Basin by adjusting its fire and management modules. The model was parameterized with data on growth, structure, and past fire events from a previous tree-ring study developed in a relict forest in northeastern Spain. Moreover, a validation of the model was performed using data from the last national forest inventory and literature review for the dominant tree species in the study area (*Pinus nigra*). We assessed forest compositional and structural shifts of Mediterranean black pine dry forests under alternative management and climate change scenarios and compared the results with modeling simulation studies in Southwestern ponderosa pine dry forests. Results were interpreted in terms of regeneration dynamics and carbon storage of the vegetation under climate change and alternative management regimes. Implications of management actions could be critical for Mediterranean and Southwestern dry pine ecosystems facing changes in drought stress and fire frequency due to climate change. Additionally, GREFOS may be a model suitable for dry fire-prone pine systems around the world, making it a valuable new tool for understanding forest dynamics in an era of climate change in Colorado Plateau.

Two thousand years on the Colorado Plateau: spotted bat genetic diversity revealed by contemporary, historical, and ancient DNA

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Abstract: Spotted bats (*Euderma maculatum*) are cryptic (nocturnal, volant, and roost solitarily) and thus their biology remains largely undescribed. Only 35 specimens were known to science before the mid-1960s. Hence, they are excellent candidates for elucidation of aspects of population biology and natural and evolutionary history via genetic tools. We sought to assess prehistoric, historic, and contemporary population genetic structure. To this end, we applied mitochondrial markers (control region) to 118 recently-collected (years 2009-2014), museum (years 1904-2013), and mummy samples (ages 2084 bp, 1336 bp), with particular emphasis on the Colorado Plateau. We found a total of 16 haplotypes, including a single haplotype for the northwestern U.S. and Canada, and 10 haplotypes in the southwestern U.S. The lack of diversity across Oregon, Washington, and BC, Canada, suggests that this species does not migrate over long distances, and the high haplotype diversity on the Colorado Plateau suggests that the species has been present in this area for a very long time. This study demonstrates the utility of genetic approaches for species that are otherwise scientifically intractable and should lead to a greater understanding of the conservation challenges faced by this species.

Swimming performance of juvenile bonytail chub (*Gila elegans*)

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Abstract: The Colorado River is one of the most visibly altered aquatic systems in the South Western United States. Due to the altered flow regimes, lower average temperatures, and the introduction of highly successful non-native aquatic species, many native fish species have experienced severe population declines or complete extirpation from this river. Species such as bonytail (*Gila elegans*) and humpback chub (*G. cypha*) are tallied among these species, and reintroduction efforts have been relatively unsuccessful. To examine the effects of lower temperatures, which are commonly experienced by the Colorado River, on the swimming performance of *G. elegans*, juvenile fish obtained from the US Fish and Wildlife Dexter National Fish Hatchery and Technology Center

were first separated into two size classes: small, averaging 68.5mm total length (TL), and medium, averaging 127.1mm TL. After size sorting, 10 fish from each size class were acclimated to 10°C, 20°C, and 30°C for a minimum of two weeks. Fish were then placed in a Brett-type respirometer where flow was increased at 2-minute intervals until the fish failed to maintain position not in contact with from rear chamber screen. Initial results have shown that for small *G. elegans*, failure velocity occurred at 5.36, 7.55, and 9.6 body lengths (BL)/sec for 10°C, 20°C, and 30°C, respectively. For medium fish, failure occurred at 4.1, 5.5, and 5.8 BL/sec for 10°C, 20°C, and 30°C, respectively. These results indicated that swimming performance of juvenile fish acclimated to lower temperatures with the range of temperatures currently experienced in the Colorado River is significantly lower than the swimming performance of juveniles acclimated to 20°C and 30°C. Interestingly, these data also indicate that juvenile fish acclimated to 30°C will have a reduced swimming performance compared to fish acclimated to 20°C after they reach 150mm TL.

An overview of invasive predatory fish control in the upper Colorado and Green River subbasins

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Abstract: The Upper Colorado River Endangered Fish Recovery Program (Recovery Program) was established in 1988 and has a long history of efforts to control invasive fish that prey on and compete with the federally listed Colorado River species. In the 1990's, the Recovery Program experimented with controlling nonnative channel catfish (*Ictalurus punctatus*), northern pike (*Esox Lucius*; NP), and nonnative cyprinids. The Recovery Program's focus shifted in the early 2000's to include rapidly increasing numbers of nonnative smallmouth bass (*Micropterus dolomieu*; SMB) in the Yampa River in northwestern Colorado. Smallmouth bass reproduced well during the extended drought and quickly spread through a large portion of the Green River subbasin. A latent population in the Colorado River subbasin also began to increase. Most recently, abundance and distribution of adult and late juvenile walleye (*Sander vitreus*; WE) have greatly increased in the lower portions of the Colorado and Green River mainstems. We review 1) the results of Recovery Program's mechanical removal efforts (currently covering >700 river miles) to control main channel populations of NP, SMB, and WE, 2) population dynamics modeling for NP and SMB and projection tools that were developed to assist researchers with strategic planning, 3) management actions to control off channel sources, and 4) changes in state fishing regulations intended to message the incompatibility of these invasive sport fish with endangered fish recovery. Recovery Program partners recognize that persistent densities of invasive predators represent the greatest threat to recovery and that the current control strategy, although substantial, remains inadequate. We present and discuss the Recovery Program's intentions to adjust and expand nonnative prevention and control efforts moving into the future.

Larval triggered spring releases from Flaming Gorge Reservoir assist in recovery of endangered razorback sucker (*Xyrauchen texanus*) in the Green River, Utah

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Abstract: In 2000, the Upper Colorado River Endangered Fish Recovery Program (Recovery Program) approved flow and temperature recommendations for three reaches (total of 300+ river miles) of the Green River in Colorado and Utah. We provide preliminary results of an ongoing experiment to adjust the timing of spring releases from Flaming Gorge (FG) Reservoir to better meet flow recommendation objectives. The flow recommendations include spring (peak and duration) and base flow targets in five hydrologic categories that correspond to annual snowpack conditions in the upper Green and Yampa river drainages. The primary intent of the spring peak and duration targets were to couple releases from Flaming Gorge Dam on the Green River with flow in an unregulated tributary, the Yampa River, to connect floodplain habitats in the 'Middle Green River' downstream of the confluence. Inundated floodplains provide warm, food-rich habitat for larval razorback sucker that emerge from main channel cobble bars on the ascending limb of the spring hydrograph. Prior to 2012, the Bureau of Reclamation (BOR) timed FG spring releases to coincide with the predicted Yampa River peak to attain the highest combined spring flow in the Middle Green River. A synthesis of larval razorback sucker monitoring (1992-present) revealed that larval emergence often occurs post-Yampa River peak. Since 2012, the Recovery Program and the BR have been coordinating larval triggered operations at FG dam. As the name implies, BR times their spring releases to coincide with the presence of larval razorback sucker. The structure of the Recovery Program's Larval Trigger Study Plan and preliminary results from main channel and floodplain early life stage razorback sucker sampling are presented.

Assassin bug (Hemiptera: Reduviidae) diversity and biogeography in the Colorado River Basin, with an emphasis on the Colorado Plateau ecoregion, southwest USA

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Abstract: Assassin bugs include a diverse group of solitary, predatory, morphologically distinctive, terrestrial true bugs. Despite much taxonomic study, their diversity and distribution in the Colorado River basin are poorly known. Here we provide distributional and elevation range data on the Reduviidae across the 636,865 km2 Colorado River Basin. We used detailed reduviid distribution data in the 144,156 km^2 Grand Canyon ecoregion (GCE) on the southern Colorado Plateau to test the following biogeographic hypotheses. 1) A negative linear relationship exists between species richness and elevation, consonant with the tropical-temperate decrease in richness. 2) Barrier and corridor impacts of escarpments and large deep canyons on ranges predominate over refugial and null landform effects. 3) Reduviid species richness is in part attributable to the generally high vagility of this family. We detected at least 39 species among 20 genera in the Colorado River basin, with at least 32 species among 18 genera in the GCE. We found support for all three hypotheses, with more species in the southern portion of the Colorado River drainage and fewer species upslope and to the north. The decrease in richness across latitude and elevation occurs in a stepwise fashion across the Mogollon Rim at the southern boundary of the Colorado Plateau, but less distinctly across Grand Canyon. We found a stepped hysteresis of species richness up the Colorado River, and we observed a substitution of aposematic coloration for camouflage coloration across latitude and elevation. We compare reduviid distribution with low- versus high-vagility terrestrial insect taxa (Tenebrionidae versus Odonata and butterflies) and aquatic Hemiptera. The lack of localized endemism among Reduviidae contrasts sharply with that reported among aquatic predatory Hemiptera in the Southwest, indicating that species richness is related to elevated vagility and gene flow among assassin bug populations.

Organic matter transfer between litter and soil: the fate of litter in drylands

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Abstract: Leaf litter organic matter (OM) represents a large pool of terrestrial carbon and nutrients, and decomposition of this litter layer is an integral part of fundamental ecosystem function and biogeochemical cycling. Understanding the fate of leaf litter is especially important in dryland ecosystems where, due to the relatively small pool of soil OM, litter inputs may represent a large proportion of carbon and potentially available nutrients. Despite this importance, the factors affecting decomposition and the fate of leaf litter in dryland ecosystems are poorly understood. In order to resolve the above and belowground effects of litter inputs into soil, we implemented a litter manipulation study. Using *Atriplex confertifolia* as our target species, we established plots beneath the shrub canopy or plant interspace adding 0x, 1x, or 2x the normal litter mass. We observed strong seasonal variations in soil CO_2 efflux and found significant effects of litter manipulation treatments that varied with time. We also found strong effects of shrubs on soil respiration and an accumulation of soil OM and microbial biomass beneath the shrubs, which supports the notion of shrubs establishing "islands of fertility" in drylands. However our results suggest that OM from additional leaf litter inputs did not contribute significantly to the pool of soil OM or total microbial biomass over the first year of treatment. To further explore the effect of litter leaching on soil OM, we performed a greenhouse experiment replicating field litter and precipitation patterns. Results suggested that litter inputs are indeed being leached into the soil, but are not fully being utilized by the microbial communities, implying additional limiting factors. Taken together, our results suggest that the relationship between litter decomposition and soil OM may be more complex in drylands and elucidating the controls on this process represents a critical unknown at local, regional, and global scales.

The role of science in collaborative forest restoration: a case study of the USDA Forest Service's Collaborative Forest Landscape Restoration Program

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Abstract: The USDA Forest Service's Collaborative Forest Landscape Restoration Program (CFLRP) was created in 2009 to fund collaborative, science-based forest restoration on priority forest landscapes throughout the United States. The program is a result of emerging trends in natural resource management that emphasize science-based decision-making, long-term engagement between stakeholders and decision-makers, and landscape-scale decision-making and management action. The CFLRP includes a number of ambitious social, economic, and ecological objectives, and central among these is a commitment to use the best-available science to inform decision-making. However, there are often competing notions of what constitutes the best available science, as well as numerous challenges effectively connecting science with decision-making. To that end, it is critical to begin to better understand the role of science within the CFLRP and how it informs decision-making and on-the-ground management. This study asks how science works through the CFLRP to inform decision-making about forest restoration. Data was obtained from semi-structured interviews, a survey questionnaire, participant observation, and document review of five CFLRP projects in the Colorado Plateau region, including the Four Forest Restoration Initiative in Arizona, the Zuni Mountains and Southwest Jemez Mountains in New Mexico, and the Uncompahgre Plateau and Colorado Front Range in Colorado. This presentation outlines sources of scientific information, modes of

scientific information communication, practices for using scientific information, barriers to using scientific information, and perceptions of scientific information within each project. Major similarities across projects are also discussed. Using grounded theory and a cross-case comparison, this study revealed that science intervenes in decision-making in four project phases: the proposal phase, the planning phase, the implementation phase, and the monitoring and adaptive management phase. Within each phase, there are major factors that mediate how science is used. This presentation reviews these factors and concludes with recommendations for effectively connecting science with decision-making in the CFLRP and collaborative forest restoration more broadly.

The last 30,000 years of climate and vegetation change across northern Arizona reconstructed from high elevation fossil records in the Grand Canyon

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Abstract: Study of 146 fossil packrat middens collected within Grand Canyon National Park, mostly between 1974 and 1982, is continuing. These records have been enhanced through the application of improved techniques such as AMS radiocarbon dating, fossil pollen analysis, stable isotope analysis, and more detailed macrobotanical analyses. The improved chronology and more robust analyses allow stronger correlations with regional fossil pollen sequences and continental climate records. This report will summarize the climate and vegetation changes occurring at sites above 1,800 m (about 5,900') elevation representing the canyon rims and habitats likely south to Flagstaff. Comparisons between plant macrofossils, fossil pollen, and stable isotopes emphasize the focus of the different techniques. The most evident change in these records occurred at the end of the Pleistocene climate era, 11,700 years ago, when the climate suddenly warmed about 4°C (~7°F) in a change that is similar in pace and magnitude to the climate shift we are currently initiating. This caused the vegetation to shift from a mixed conifer forest of limber pine, firs, Engelmann spruce, sagebrush, and common juniper to more modern forests of Utah juniper, Colorado pinyon, ponderosa pine, and scrub oak. But further examination reveals more detail within these two main periods. During the early Holocene, between about 11,700 and 10,000 years ago, a unique period of transition occurred where ponderosa pine, Rocky Mountain juniper, and one-seed juniper grew within the canyon where they are absent today. The distributions of these species, and the values of deuterium isotopes from the middens suggest that this was a period of heightened monsoon activity.

Source population, organic matter, and overwintering govern arid land moss establishment

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Abstract: Desert mosses reduce soil erosion and contribute to the water and nutrient cycling of a site. Fire or the introduction nonnative annual grasses such as cheatgrass, *Bromus tectorum*, may kill or reduce desert mosses thereby impacting ecosystem function. Land managers in the sagebrush steppe of the Great Basin frequently seed burned areas following fire in an attempt to rehabilitate native vegetation and hinder invasion by cheatgrass. Despite this current practice, protocols do not exist for reintroducing desert mosses. We examine effects and interactions between some common site amelioration treatments and the establishment of two moss species frequently found in the Great Basin, *Bryum argenteum* and *Syntricia ruralis*. Treatments included irrigation, addition of organic matter, and seasonal timing of moss inoculation. Each moss species was collected from two environmentally distinct locations (populations): the Birds of Prey National Conservation Area near Boise ID, that has a warm and dry climate, and the Steens Mountain Cooperative Management and Protection Area near Burns, OR, that has a wet and cool climate. Treatments were tested on four combinations of moss species by population. Mosses were grown in a common garden, outdoors, in central Oregon (warm and dry climate) between the spring seasons of 2013 and 2014. Preliminary results indicate that *Bryum* from the drier population that only received the addition of the organic matter, had the highest average cover of any combination tested, demonstrating an increase in mean average midpoint cover value of 17.7 percentage points (95% CI 8.1-27.2) over untreated *Bryum* from the same location. Site amelioration treatments had less effect on *Syntrichia* sp. For both species, season of inoculation did not matter if mosses were allowed to overwinter. Mosses collected from the warm/dry location reached greater cover values. Preliminary results from this work can be used to develop protocols for reintroductions.

Bacteria increase arid land soil surface temperature through the production of sunscreens

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Abstract: Biological soil crusts (BSCs) are desert top soil formations built by complex microbial communities and dominated by the filamentous cyanobacterium *Microcoleus* sp. BSCs cover extensive desert areas where they correspond to millimeters-size mantles

responsible for soil stability and fertility. Despite their ecological importance, little is known about how these communities will endure climate change. It has been shown in North America that different species of *Microcoleus* sp. preferred different temperatures and that their continental biogeography could be affected by an increase of a few Celsius degrees, with unknown consequences for the whole ecosystem. In order to better understand the temperature control and effects on BSCs communities, we used a combination of physical, biochemical, and microbiological analyses to describe a set of samples spanning a successional gradient from light to dark BSCs (Moab, Utah). We found that the concentration of scytonemin (a sunscreen pigment) was increasing along the maturity gradient. We also confirmed that scytonemin was by far the major pigment responsible for light absorption in the visible spectrum in BSCs, and is then responsible of the darkening of the BSCs (i.e., decrease of albedo) with maturity. We measured the surface temperature and albedo and found, as predicted, a negative linear relationship between these two parameters. The decrease of albedo within the gradient is responsible of an increase in surface temperature up to 10ºC. This temperature switch is not without consequences for the whole community. SSU rDNA based survey of the microbial communities showed that it was accompanied by a switch of the dominant cyanobacterium, the thermosensitive *Microcoleus* sp. being replaced by the thermotolerant one in darker BSCs. This study supports, at the local scale, the finding previously made at the continental scale, but also sheds light on the importance of scytonemin as a significant warmer of soils with important consequences on the BSCs communities. Based on estimates of the global biomass of cyanobacteria in soil crusts, one can easily calculate that there must currently exist about 15 million metric tons of scytonemin at work, accumulated on the surface of arid soils worldwide.

Adapting Glen Canyon Dam operations to evolving Colorado River resource objectives

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Abstract: The primary purposes of Glen Canyon Dam, as set forth in the 1956 Colorado River Storage Project (CRSP) Act, were to store and release water to the Lower Colorado River Basin and to produce electricity. In the decade following the dam's completion in 1963, laws were passed in response to the public's desire to ensure that federal actions are carried out with the knowledge of their environmental effects. These included the 1992 Grand Canyon Protection Act (GCPA), which required Reclamation to "protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established". In 1996, a record of decision on the final EIS on the Operations of Glen Canyon Dam was issued which implemented the modified fluctuating flow preferred alternative. In January 1995, the U.S. Fish and Wildlife Service (FWS) issued a jeopardy biological opinion that called for testing a more restrictive dam release hydrograph, referred to as a seasonally adjusted steady flow alternative. Reclamation initiated the Glen Canyon Dam Adaptive Management Program (GCDAMP) in 1997 to meet its needs to comply with GCPA, and resolve conflicts over the effects of dam operations. Faced with the challenges of protecting and enhancing the downstream resources while delivering water within the constraints of the "Law of the River", and producing power, the flow regimes defined in the EIS and the biological opinion have allowed the GCDAMP to advance through adaptive management; a program of learning by doing. Science-based advice on operational strategies for the dam has resulted in substantial progress toward restoring beaches, enhancing native fish habitat, and addressing cultural issues, while also allowing Reclamation to meet its needs to sustainably deliver water and produce hydropower.

Developing summer season precipitation monitoring strategies for Arizona ranchers and range managers to manage drought risk

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Abstract: Summer monsoon season (July-August-September) precipitation is a key determinant in the levels of rangeland forage production available for livestock operations across Arizona shaping the background risk of rapidly developing summer drought situations. Simple precipitation monitoring through the summer season is an important management tool, but guidance in optimal precipitation monitoring strategies including types of rain gauges, frequency of monitoring and data analysis approaches are limited. This project explored the use of several different rain gauge monitoring approaches as well as the development of a climatological cumulative precipitation reference chart to aid in interpreting data values through the summer season. Initial results indicate that simple, but frequently read depth gauges used in conjunction with a reference cumulative precipitation curve provide important insight on timing and frequency of summer precipitation events relative to range condition and livestock management decision making. Consultations with ranchers on project results indicate that the combination of an easy to access and monitor depth gauge and a cumulative precipitation reference chart would encourage the deployment of more rain gauges across management units and more frequent monitoring.

Bioavailability of uranium to aquatic invertebrates: how modeling can help to understand U bioaccumulation

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Abstract: To improve our understanding of the ecological risks associated with uranium (U) mining and processing, we are investigating pathways of U exposure and biogeochemical controls on U bioavailability using the freshwater snail *Lymnaea stagnalis* as a model species. Our experimental studies focus on herbivores because they represent an initial, key step in the trophic transfer of contaminants through aquatic food webs. We use a kinetic bioaccumulation model that incorporates geochemical conditions and physiological processes to predict bioaccumulation resulting from aqueous and dietary exposure. We first characterized the bioavailability of dissolved U(VI) in a series of controlled laboratory experiments at various water hardness, pH, and in the presence of dissolved natural organic matter (NOM) as a competing ligand. Results show that dissolved U is bioavailable under all the geochemical conditions tested. In general, U bioavailability decreases with increasing pH, increasing Ca concentrations, and when NOM is present. We then characterized the bioavailability of dietborne U since dietary metal uptake prevails for many aquatic species in nature. For this, we exposed our model organism to benthic diatoms that had been pre-exposed to a range of dissolved U concentrations. We inferred U bioavailability from calculations of U assimilation into tissues. U assimilation efficiency was 70%, indicating that U is greatly bioavailable when ingested with food. Exposure to increasing concentrations of dietborne U did not impair the snail's digestive processes, but did trigger a behavioral response (i.e., food avoidance), which is of significance to higher level processes like growth and reproduction. Using dissolved U concentrations representative of levels measured in Grand Canyon springs and streams, we predict that dietborne exposures contribute to 60-70% of the bioaccumulated U. Additional experiments are planned to determine if the importance of the dietary pathway increases when different forms of particulate U are present.

Issues facing the U.S. Forest Service in the use of small unmanned aircraft systems for natural resource and wildfire missions

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Abstract: The availability and cost of small UAS have recently become more reachable to the general public. According to an article in the Bloomberg Business Report (December 17, 2014), Amazon is selling 10,000 UAS (or drones) a month. USFS employees, researchers, and contractors working for land management agencies see the use of small UAS as a way to gather data and conduct reconnaissance missions. Interest in the use of small unmanned aircraft systems (UAS) to accomplish natural resource and wildfire aviation missions has surged in the last year. Unfortunately, federal policy, both Federal Aviation Administration (FAA) and U.S. Forest Service (USFS) has yet to be fully developed to take advantage of this new technology. All UAS are considered "aircraft" by the FAA and USFS. Consequently, policy regarding the use and operating procedures for UAS are similar, and in some cases identical, to policy regarding "manned" or piloted aircraft. These policies include pilot qualifications and certifications and aircraft airworthiness specifications. UAS that are operated for any other purpose than recreation must be authorized by the FAA. A Certificate of Authorization (COA) must be issued by the FAA. Additionally, UAS used for commercial purposes must be granted a "333 Exemption" by the FAA. Unfortunately, the general public is not aware of the FAA regulations governing the use of UAS. Consequently, the potential for mid-air collisions between UAS and "manned" or piloted aircraft has increased. This is a major cause of concern for land management agencies. Over one dozen incidents with UAS flying in or near firefighting aircraft have been reported to the FAA in 2014 and 2015. Many of these incidents have caused firefighting aircraft to cease operations until the airspace over the fire has been cleared. Aside from obvious safety issues, the ungoverned use of UAS on public lands can cause resource damage (i.e., the 2014 UAS crash in Grand Prismatic geyser in Yellowstone National Park), or threaten wildlife (UAS harassing bighorn sheep in Zion National Park, 2014), or simply ruin a visitor's wilderness experience in a federally designated wilderness area. Land Management agencies (such as the USFS, Bureau of Land Management, National Park Service, etc.) have used aircraft for decades to perform missions such as, wildfire suppression and detection, aerial surveys, mapping, and search and rescue. The cost of using "manned" aircraft to accomplish these missions has increased significantly in the past ten years, just as budgets have been reduced. These cost factors along with the possibility of reduced exposure to the inherent risk in aviation make the use of UAS more attractive to employees. Land Management agencies have dozens of policy documents addressing the use of fixed and rotor wing aircraft on wildfires. To date, there is no guidance or policy for using UAS in wildfire suppression or reconnaissance. One of the major issues in developing standards for UAS over fires is the lack of "See and Avoid" capability of UAS. Fire size and complexity dictate the number of aircraft (fixed and rotor-wing) over a fire at any given time. Many times these aircraft can number into the dozens. All pilots and crew practice "See and Avoid" to avoid mid-air collisions. UAS cannot "See and Avoid", increasing the potential for a mid-air collision with a manned aircraft. Several interagency committees composed of members from federal and state land management agencies are addressing the issues and formulating policy to address integrating UAS into other aircraft operations. These committees are tasked with developing operational guidance language for respective documents, drafting communication for wildland fire stakeholders, and coordinating interagency plans for integration of UAS in fire operations.

The US Geological Survey's developing sUAS program and photogrammetric modeling under the current FAA regulatory environment

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Abstract: The USGS Small Unmanned Aerial Systems (sUAS) Projects Office has begun laying the foundation for sUAS based research by providing airframes to Department of Interior (DOI) and FAA certified sUAS operators. Collaborations between operators and researchers within the USGS, as well as the BLM, The Nature Conservancy, and more have begun. In June of 2015, the DOI approved five new sUAS platforms. This effort has moved the USGS from repurposing archaic military platforms, to modern sUAS systems designed around a suite of sensors that are needed to conduct high quality research. This investment is helping the USGS gather data that were otherwise unattainable. The USGS Flagstaff Science Campus is well positioned to conduct sUAS missions with three carded sUAS operators from three different scientific disciplines. Researchers conduct a wide scope of study on the Colorado Plateau and surrounding area. Recent operations include imaging Cataract Creek to improve flood warning modeling for the Arizona Water Science Center (AZWSC). A very high resolution (<2cm pixels) terrain model was derived using photogrammetric techniques from a sUAS flying at 80 m above ground level. The terrain model developed for the river reach of interest provided good characteristics for hydraulic modeling that will improve understanding of stage-discharge relationships within the flood plain. The AZWSC plans to make sUAS operations a part of their normal work-flow and other groups on the Flagstaff Science Campus would like to do the same. Current FAA regulations and agreements within DOI make sUAS missions a streamlined process, with the primary hindrance being landowner permissions. Because landholding federal agencies have concerns other than purely scientific, such as privacy and resource management, some areas are not open to sUAS based research. Hopefully a safe track record, evolving public opinion, and administrative roadblocks can move forward to create further collaborations for sound scientific research.

Biocrusts of Grand Staircase-Escalante National Monument: past, predicted, and present biocrust cover

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Abstract: Biological soil crusts ("biocrusts"; light and dark cyanobacteria, moss, and lichen) are a critical component of functional arid ecosystems. Biocrusts stabilize soil, increase water infiltration and storage, and contribute to fixation of nitrogen and carbon for vascular plants. Biocrusts are vulnerable to anthropogenic disturbance (e.g., livestock grazing, recreation, and vegetation treatments), particularly when biocrusts are dry. Post-disturbance recovery of biocrusts measures in decades. The Grand Staircase-Escalante National Monument (Monument) surveyed biocrusts between 2000 and 2003 at 425 sites as part of rangeland health assessments (RLH), and we extracted the biocrust measurements for analysis. In 2014, we began a two-year process to reassess a subset of 200 RLH sites, where biocrust potential was high and where biocrust is important to soil stability. In 2014, we remeasured 73 of 200 RLH sites for dark cyanobacteria, moss, and lichen cover and 42 of the 200 RLH sites for moss and lichen cover. We also compare 2003 and 2014 measurements of dark cyanobacteria, moss, and lichen cover with models that predict potential. In 2003 and 2014, the proportion of sites where dark cyanobacteria, moss, or lichen were expected, but absent, was 29% and 32%, respectively. In 2003, 24% of 425 sites met their predicted potential of biocrust cover and, in 2014, 3% of 73 sites met their predicted potential cover.

Engaging diverse, local youth and young adults in stewardship and environmental education

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Abstract: The Canyon Country Youth Corps (CCYC) aims to expand the classic corps experience. In following the mission of its parent organization, the Four Corners School of Outdoor Education, CCYC teaches place-based environmental stewardship and provides hands-on educational experience about our home on the Colorado Plateau. Our crewmembers are members of our community, our projects are based on or near our home in southeastern Utah, and our work improves local economic and environmental development. Much like the diversity of our community, crewmembers are a mix of Native American and rural white; this exposure to diverse crewmembers bridges community ethnic divides and prepares youth and young adult crewmembers for future success in their own community. Participants at this session will learn about our approach and how it improves the experiences of crewmembers and our community.

Soil fungi benefit both plants and biocrusts in arid lands: a test of the fungal loop hypothesis

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Abstract: Species interactions may couple the resource dynamics of primary producers that are disconnected in space and time. Arid ecosystems are characterized by low-density plant communities and soil surfaces colonized by biological crusts. Activity in biocrusts is rapidly stimulated by rainfall events, but plants require precipitation events large enough to infiltrate to root systems. Many biocrusts fix nitrogen and intercept atmospheric N, but this may be inaccessible to plants. The fungal loop hypothesis proposes that fungi transport resources between plants and biocrusts, increasing production. However, this mechanism has not been tested experimentally. We studied how fungi affect the interactions between plants and biocrusts. We transplanted bunchgrasses and biocrusts into pots in the field then manipulated the connections between biocrusts and roots using fungus-excluding mesh below biocrusts. We compared the performance of each producer grown alone and with the other producer. To test for context dependency, pots were given a single monthly or small weekly waterings. We hypothesized that when fungal connections were intact, plants and biocrusts would exchange resources resulting in higher production for both, even in poor conditions. When plants and biocrusts established together, fungal connections improved productivity. With fungal connections intact, plant biomass increased 36% more ($P<0.01$) and biocrust chlorophyll content was 25% higher ($P<0.01$) relative to pots without biotic connections. Unexpectedly, the producers may compete because each had significantly higher performance when growing alone than with the other producer. Fungal connections had stronger effects when the other producer was present (20% biocrusts, 27% plants), than when either was grown alone (16%, 40%). Water regime did not affect the interactions between plants, fungi, and biocrusts. These results support the fungal loop hypothesis because the presence of fungal connections enhanced the performance of both producers, and soil fungi were more beneficial when producers were grown together than when alone.

Using bioenergetic models to determine how water temperature and food consumption influence *Oncorhynchus mykiss* and *Salmo trutta* growth in western U.S. tailwaters

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Abstract: Rainbow and brown trout have been intentionally introduced into regulated rivers to promote angling opportunities downriver of dams across the western United States. However, key aspects of trout fisheries that are important to managers and anglers, such as adult length and population size, can fluctuate erratically in response to environmental conditions, highlighting the need to develop a broader understanding of the effects of ecological and biological variables on trout populations. We recently published a meta-analysis concluding that trout size and recruitment is influenced by factors including seasonal and annual flow, hydropeaking, water velocity, and fish density. In particular, our analysis found that mean adult brown trout size (>350 mm) declined in tailwaters exhibiting a strong age-1 cohort (150-350 mm) in the year prior to capture. Our current analysis builds on previous work by examining potential mechanisms behind those correlations, such as the influence of water temperature and prey availability on trout growth. We used the Wisconsin bioenergetics model and growth parameters from non-reproductive age-1 trout to estimate consumption (i.e., proportion of maximum daily ration for a fish at a particular mass and temperature), which was used as the response variable in subsequent models. We found that consumption in age-1 brown trout was negatively correlated with trout density and hydropeaking and positively correlated with water temperature. Further, consumption was the best predictor of age-1 brown trout cohort strength, with consumption declining in systems exhibiting high catch rates of age-1 trout. These results collectively indicate that food limitation is associated with high densities of age-1 brown trout, the latter of which can decrease adult size the following year. Since consumption and temperature were positively correlated, a future warming climate may enhance food limitation and place additional constraints on trout populations that ultimately influence the size structure of salmonids in western U.S. tailwaters.

Prey size and availability limits maximum size of rainbow trout in a large tailwater: insights from a drift-foraging bioenergetics model

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Abstract: The cold and clear water conditions present below many large dams create ideal conditions for the development of economically important salmonid fisheries. Many of these tailwater fisheries have experienced declines in the abundance and condition of large trout species, yet the causes of these declines remain uncertain. Here, we develop, assess, and apply a drift-foraging bioenergetics model to identify the factors limiting rainbow trout (*Oncorhynchus mykiss*) growth in a large tailwater. We explored the relative importance of temperature, prey quantity, and prey size by constructing scenarios where these variables, both singly and in combination, were altered. Predicted growth matched empirical weight-at-age estimates, particularly for younger ages, demonstrating that the model accurately describes how current temperature and prey conditions interact to determine rainbow trout growth. Modeling scenarios that artificially inflated prey size and abundance demonstrate that rainbow trout growth is limited by the scarcity of large prey items and overall prey availability. For example, shifting 10% of the prey biomass to the 13 mm (large) length class, without increasing overall prey biomass, increased lifetime maximum weight of rainbow trout by 88%. Additionally, warmer temperatures resulted in lower predicted growth at current and lower levels of prey availability; however, growth was similar across all temperatures at higher levels of prey availability. Climate change will likely alter flow and temperature regimes in large rivers with corresponding changes to invertebrate prey resources used by fish. Broader application of drift-foraging bioenergetics models to build a mechanistic understanding of how changes to habitat conditions and prey resources affect growth of salmonids will benefit management of tailwater fisheries.

Measuring forest structural characteristics: restoration treatment effects on snowpack in northern Arizona

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Abstract: As restoration efforts in northern Arizona ponderosa pine forests become commonplace, accurate and efficient methods for quantifying resulting forest structural properties over large areas is necessary. Unmanned aerial vehicles, equipped with sensor technologies for measuring and modeling the earth's surface, are quickly filling that gap. Combined with terrestrially-based sensors, high resolution models can accurately estimate above- and below-canopy structural characteristics. The high resolution data are necessary to understand the relationship between ecological restoration, forest structure, and snow dynamics. At present, we are examining five sites west of Flagstaff, which have been treated using mechanical thinning and burning methods. Examining the structural differences between these treatment plots with highly accurate 3-dimensional data will shed light on how restoration prescriptions develop after treatment. We are further extending this research by examining how those structural characteristics relate to differences in snow dynamics in northern Arizona. Specifically, snow accumulation and melt timing are expected to be affected by tree density and spacing. We are measuring snow distribution and depth in conjunction with tree density and canopy cover at thinned, thinned-and-burned, and control sites to determine optimum forest characteristics for snow accumulation. Modeling snow pack dynamics in conjunction with forest structure will help us understand how restoration is affecting winter precipitation and groundwater recharge in an arid region under threat of climate change. UAVs are a useful tool in local to regional scale remote sensing studies, and will continue to develop and progress science in the future. This presentation will show how they are being utilized in northern Arizona.

Snow trends and spatial variability in Northern Arizona: the effects of climate and forest restoration treatments

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Abstract: Snowpack in Northern Arizona is both variable and ephemeral. At the southern-most extent of western North America's snow extent, Northern Arizona and the Mogollon Rim extending into New Mexico will be an important indicator of climate change impacts on snow. Furthermore, the largest forest restoration effort, Four Forest Restoration Initiative (4FRI), will be taking place in Northern Arizona, which will affect snow dynamics. Using remotely sensed data (MODIS and Landsat) in conjunction with ground data (SNOTEL), we analyze the effects of restoration on snow, as well as trends in snow cover through time. We examine the viability of snow during and after restoration treatments, as well as climatically driven changes in snow. Trend tests were performed on a per-pixel basis to assess spatial variability over the MODIS satellite time period (2002-2014). SNOTEL records are compared to Landsat snow cover at sites that have been thinned, thinned-and-burned, and where no forest treatments have taken place. SNOTEL data correlate well with both MODIS and Landsat data analysis, indicating agreement between ground and satellite measurements. Our results show that during the MODIS analysis period, the majority of significant trends in snow covered days are increasing; however,

these trends are heavily influenced by seasonal outliers. SNOTEL records from the same time period show a similar trend, although overall trends over a longer time period (1982–present) are decreasing. Landsat snow analysis show significant differences in snow accumulation and persistence between restoration treatments and treated versus untreated areas. These analyses indicate restoration treatments will likely affect snow in northern Arizona, but will be moderated by climatic trends. Remote sensing techniques can be utilized to monitor forest restoration and snow at local to regional scales.

Direct effects of seasonal precipitation and temperature on the demography of two dominant bunchgrasses in northern Arizona

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Abstract: Understanding plant population responses to climate and land-use change is fundamental to land management, and demographic analyses accurately predict these responses. While demographic parameters are known for many tree species, they are unknown for most herbaceous plants. Here, we focus on two dominant, perennial bunchgrasses in the ponderosa pine ecosystem of northern Arizona, Arizona fescue (*Festuca arizonica*; C_3) and mountain muhly (*Muhlenbergia montana*; C_4). Mapping individual plants over time provides a precise method of determining demographic parameters, while modeling these data over time is the most realistic way to predict how species might respond to climate or land-use scenarios. We used data from 98 annually remapped quadrats (2002-2014) to examine the effects of seasonal weather on the survival and growth of each species. We constructed life tables to examine their vital rates (e.g., survival probabilities, growth, and life expectancies) and then made population projections using the species' state (size) and weather variables within an integral projection model framework (IPM; *IPMpack* R package) to quantify the direct effects of seasonal precipitation and temperature on those vital rates. Vital rates varied between species, though they both were characterized by a Type III survivorship curve. Plant size was the most important predictor for survival and growth of each species, and larger plant sizes were associated with increased survival and growth. Increased winter and spring precipitation were associated with increased survival and growth for both species. Warmer summer temperatures resulted in increased survival for mountain muhly, perhaps reflecting the C_4 photosynthetic pathway. These models were incorporated into the IPM to estimate population growth rates and stable size distributions for both species. Understanding the controls on demographic parameters of these dominant bunchgrass species will inform their management and conservation.

Cultural resource management and student success on the Colorado Plateau

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Abstract: For the past 20 years, faculty, staff, and students in the Department of Anthropology at Northern Arizona University have engaged in a wide variety of cultural resource management activities at national park units on the Colorado Plateau. These projects, conducted through the CPCESU, have been vitally important to success of students in the NAU program. This paper documents the types of projects conducted over the years, and offers a perspective on how student participation in field, collections, and laboratory work in NPS units has fostered student academic and career success. I will document how students in the CPCESU projects have achieved higher retention and graduation rates than their peers, and I will detail the cumulative impacts that the NAU projects have had on NPS employment and cultural resource management efforts. The collaborative efforts between NAU and NPS constitute an example of symbiotic mutualism. Each party has benefited from the relationship, often in unexpected ways.

Assessing the susceptibility of Rainbow Bridge to aircraft-induced vibrations

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Abstract: Rainbow Bridge National Monument, a unit of the National Park Service (NPS) managed by Glen Canyon National Recreation Area (GCNRA), is a sacred site, with tremendous significance to neighboring Indian tribes. It is also a unique geographic feature with national significance as one of the world's largest known rock spans. Overflights by air tours and the potential effects of aircraft induced vibration on Rainbow Bridge have raised concerns by tribal partners on management practices. To understand the suscep-

tibility of the structure to aircraft vibration, GCNRA partnered with Dr. Jeffrey Moore under a Colorado Plateau CESU Cooperative Agreement. Dr. Moore is also working in Arches and Canyonlands National Parks as a part of his research on the long-term stability of natural rock arches. NPS technical specialists have been crucial team members throughout this study. Intermountain Region acoustic specialist, Randy Stanley, conducted a literature review on similar, past work and provided very low frequency aircraft noise data. Geologic Resources Division guest scientist, John Wood, was contracted to produce a 3-D model of Rainbow Bridge using photogrammetry in order to assist interpretation of vibration measurements. Initial field data were collected on Rainbow Bridge in late March 2015. Results from this effort include determination of the structure's main resonant frequencies; analysis of the potential for aircraft, especially helicopters, to produce noise that may be harmful; and a better understanding of the type and locations of rock failure that could occur. The results support science-based recommendations to GCNRA on how to prevent vibration-induced damage to Rainbow Bridge from aircraft, and will ultimately inform a new air tour voluntary agreement. Additionally, this study has resulted in new data for rock stability research, furthered collaborations between NPS and the scientific community, and produced unique interpretive material.

Dust emissions from uranium mines in the Grand Canyon Region

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Abstract: A primary factor driving the 2012 Department of Interior (DOI) decision to temporarily withdraw over 1 million acres in the Grand Canyon region from new uranium leases was uncertainty in environmental consequences of mining activity. Of particular concern is potential off-site transport of contaminants from mine sites and impacts of those contaminants on regional ecosystems. Aeolian transport may disperse contaminants off site and into the surrounding environments. There is little information, however, on the magnitude of aeolian sediment fluxes from Grand Canyon uranium mine sites, the composition of those sediments, and the fate of contaminants moved off mine sites in dust. To begin to address these concerns, we have initiated dust emission monitoring studies at three uranium mines in the Grand Canyon region (Canyon, Arizona 1, and Pinenut Mines). Dust emissions are being characterized using passive dust traps arranged along three transects at each mine that extend both upwind and downwind of mine sites (one upwind and three downwind sample locations). Dust traps are orientated toward the dominant wind direction, with the upwind samplers providing information on background (non-mine) dust transport, and the downwind samplers characterizing dust attributable to mining activities. Results suggest dust fluxes adjacent to mine sites are highly variable, both among sampling periods and sample locations, but are on average substantially greater at downwind than upwind locations. The majority of downwind locations had measured fluxes that were several times greater than those in upwind locations. Collected dust samples have been saved and composited for chemical characterization and initial laboratory results are expected in fall 2015. The results of dust flux monitoring described here, combined with soil and plant tissue sampling and analysis being conducted in the same vicinities, will address some of the identified information gaps in the DOI decision as well as guide future research efforts.

Ecology and management of Colorado pikeminnow in the San Juan River

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Abstract: The San Juan River Basin Recovery Implementation Program (Program) conducts management activities in the San Juan River to promote the recovery of endangered Colorado pikeminnow (*Ptychocheilus lucius*). Despite stocking over 4 million Colorado pikeminnow since 2002, natural reproduction and recruitment have remained limited. We investigated potential recruitment bottlenecks to inform the Program's adaptive management. Seasonal movements of juvenile stocked Colorado pikeminnow may be associated with maximizing growth along longitudinal and seasonal temperature regimes. Stocked age-1 Colorado pikeminnow are associated with densities of only native prey species, but age-2+ Colorado pikeminnow are associated with densities of both native and non-native prey species. The contemporary trophic position of Colorado pikeminnow in the San Juan River suggests they are not completely piscivorous, possibly due to lower prey densities or the extirpation of historically important prey. Positive associations between age-2+ Colorado pikeminnow and non-native channel catfish competitors may result in negative interactions between the two species. Preying on channel catfish may also pose a choking threat to Colorado pikeminnow. In addition to population augmentation with hatchery-reared fish, the Program removes potential non-native predators and competitors, uses managed flows from Navajo Dam, restores secondary channels, and addresses impediments to fish movement in efforts to recover Colorado pikeminnow in the San Juan River.

Using environmental covariates to predict growth in two contrasting environments: a growth assessment of an endangered desert fish

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Abstract: Relating growth to environmental covariates can help inform management to benefit species of concern. However, the effects of environmental covariates are not always consistent across systems. We present a Bayesian growth model that uses monthly means of environmental covariates to describe subadult growth of endangered humpback chub (*Gila cypha*) in two contrasting environments, the Colorado River (CR) in Grand Canyon and the lower Little Colorado River (LCR). While the thermal and hydrologic regimes in the LCR are mainly influenced by air temperatures and precipitation patterns, respectively, the thermal and hydrologic regimes of the CR are influenced primarily by operations and reservoir level of Glen Canyon Dam and are therefore more seasonally constant. We compared models with discharge, turbidity duration, and temperature effects, as well as models with quadratic temperature and season-specific turbidity effects, in a model selection framework. Results indicated environmental influences on growth differed in the two habitats. While warmer temperatures were associated with increased growth in both systems, the effect was much stronger in the CR than the LCR. Furthermore, turbidity positively affected growth in the CR, but had a slight negative effect in the LCR. Overall, environmental covariates explained most of the variation in growth in the CR, but only a small proportion of the observed variation in growth in the LCR. We conclude by discussing the importance of assessing model performance when relating monthly environmental covariates to growth.

Intergovernmental Internship Cooperative: partnering for youth career development, diversity, and making a difference on the ground

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Abstract: The Intergovernmental Internship Cooperative (IIC) is a partnership organization with a unique organizational structure, which has become a regional tool for land managers, communities, and universities to respond to resource challenges through education and joint projects. Since its creation in 2008, the IIC has hosted over 1,000 interns in a variety of positions within NPS (through the CPCESU), BLM, and US Forest Service agencies throughout our region. Many of these internship positions have helped our public land partners assess and respond to salient scientific and resource management needs while offering students, from 50 different majors, significant learning experiences tied to their education and future careers. In 2014 the IIC hosted 239 students in 23 different disciplines (e.g., historical preservation, wildlife, botany, facilities, engineering, field survey, wilderness, range, and visitor services). This work resulted in 105,493 hours of resource and visitor services related work. In addition to work on the ground, the IIC partnership has allowed public land agencies to respond to many calls from their agencies' leadership to engage diverse youth and develop the next generation of public land leaders. From the IIC's 2010 cohort, one third of the interns are still employed with public land agencies. Due to the significant experience and mentoring IIC interns receive, they have moved on to a diverse range of resource management professions. Even though we operate in a county that is 92% Caucasian, we have partnered with local tribes and diverse student organizations to have 29% of our interns be from diverse backgrounds in 2014. The IIC's mission is to develop future public land leaders. We do this by turning public land managers into mentors who give interns hands-on experiences responding to very real resources management challenges in their field of study.

Dam-induced changes to riparian ecosystems and associated traditional cultural values: results of a pilot study downstream of Glen Canyon Dam, Arizona

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Abstract: Large dams can profoundly alter downstream plant and animal distributions and abundance, sometimes to the point of replacing the original riparian ecosystem with a radically different one. For native people with long-standing cultural ties to the affected river corridor, these ecological changes can significantly impact cultural values tied to place. The Colorado River corridor downstream of Glen Canyon Dam in northern Arizona is an example of a riparian ecosystem that has changed significantly during the 50 years since the dam has been operating. Federal managers would like to understand whether and how changes to the riparian ecosystem may have affected cultural resources within the river corridor, particularly for five Native American tribes with long-standing ties to the Grand Canyon: the Hopi Tribe, Hualapai Tribe, Navajo Nation, Kaibab Band of Paiute Indians, and the Pueblo of Zuni. The US Geological Survey is currently working with these five tribes to document and characterize changes to the riparian ecosystem since closure of Glen Canyon Dam in 1963, with particular emphasis placed on documenting changes in the abundance and distribution of riparian plants that were traditionally utilized by these tribes. One goal of this effort is to characterize changes to culturally-valued riparian plants in terms of how they may affect the broader suite of cultural values that tribes ascribe to this riverine landscape. A

second goal is to acquire sufficient information about the current status of culturally-valued riparian species so that the tribes have a reliable baseline for monitoring them in the future and adequate information for developing future restoration and management plans. Ultimately, this study seeks to bridge an epistemological divide between western scientific approaches to studying riparian ecosystems and traditional ecological knowledge through linking both knowledge systems to the cultural values that diverse Native American tribes ascribe to this iconic riverine landscape.

Designing a monitoring program to inform adaptive management of cultural resources in the context of a changing climate: an example from Glen and Grand Canyons, Arizona

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Abstract: Climate change models applied to the Southwestern United States predict an increase in temperature, with a concomitant increase in the number, spatial variability, and intensity of precipitation events. These predictions have significant implications for the long-term preservation and management of cultural resource sites throughout the region. In Glen and Grand Canyons, USGS scientists have been working with NPS managers to develop long-term, multi-disciplinary, monitoring protocols for the purpose of evaluating how operations of Glen Canyon Dam affect the stability and condition of archaeological sites in the Colorado River corridor over multiple-year timeframes. These protocols include methods for tracking local weather event effects on sand transport, precipitation-induced overland flow erosion, and other land-surface modifying agents to help distinguish the effects of dam operations from those driven primarily by local weather events. This multi-disciplinary approach has potential applicability for monitoring and managing climate change impacts to archaeological resources across the Southwest. We have used the resulting monitoring data from this pilot project to evaluate how well local weather data correlate with observations derived from long-term regional meteorological stations. The monitoring data also has been useful for modeling how various combinations of physical and meteorological attributes affect archaeological sites, and by extension, how variations in these attributes can define differences in archaeological site erosion potential. Our approach and the resulting data may prove useful to resource managers who are seeking new ways to prioritize archaeological sites for future monitoring and treatment in the face of compounded risks due to changing climate.

Evaluating field success of biological soil crust restoration using lab and greenhouse grown inocula and best delivery practices

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Abstract: Biological soil crusts or 'biocrusts' are communities of organisms comprised of cyanobacteria, lichens, and mosses living in the top few millimeters of the soil surface. Critical to ecosystem functions such as soil stability, water retention and nutrient enhancement, these biological communities are found in dryland ecosystems across the globe. Sensitive to disturbance, biocrust communities are easily degraded when compressional forces are applied. Because of their ecological importance, identifying successful biocrust inocula and delivery methods to understand best restoration practices for degraded crusts are also of high importance. To address this need for better understanding biocrust restoration strategies, we have initiated a multi-level restoration project in the Utah Testing and Training range at Hill Air Force Base, UT, USA. The U.S. Department of Defense military installments offer a platform for biocrust restoration studies as they occupy large tracts of land, most of which are found in arid and semi-aridlands. It was here we implemented a field restoration project testing the efficacy of lab and greenhouse cultivated biocrust communities as well as field collected biocrusts to serve as inocula. To aid in the inocula establishment, we utilized the two best delivery methods aimed at improving soil stability and facilitating biocrust growth, as determined through previous field trials. From the field-implemented studies we evaluated plant and soil responses pinpointing interactions between the inoculum type and delivery method through a variety of metrics. Recognizing the abiotic and biotic aspects of biocrust success after restoration allows for a better understanding of how to restore degraded biocrusts at a large scale and facilitate effective land management activities.

From restoration to resilience ecology: Will interactions of landscape disturbance and climate change trigger rapid ecosystem shifts?

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Abstract: The role of disturbance in western, frequent-fire ecosystems is well established, but the extent to which this includes high-severity fire has been debated. Most studies of historical fire regimes in dry and moderate forest types indicate low- to mixed-

severity fire regimes, with high-severity fire occurring in smaller, isolated patches. This understanding becomes critical as we face the challenge of maintaining viable forests in the coming centuries. Modeling and empirical studies predict changes in tree species distributions in response to changing climate, likely expressed at multi-annual to decadal time scales. In contrast, severe large-scale disturbances can reorganize ecosystems on much shorter time scales (weeks to months). We review the impacts of multiple successive fires and post-fire succession in montane forests of southwestern North America, many of which are leaving large areas of landscape with nearly total tree mortality. The emerging combination of climate change and severe disturbance is likely to trigger abrupt ecosystem transitions into novel configurations, exceeding the effects of either factor acting separately. These new configurations can be resilient in their new state, resist return to pre-disturbance conditions. Such abrupt transitions are predicted to become more common under conditions of altered future climate and amplified disturbance regimes; climate provides the envelope within which these dynamics occur, but disturbance provides the trigger for abrupt system reorganization. We explore the implications of potentially irreversible ecosystem responses for land management in the coming century, and the emergence of resilience ecology as a new paradigm in the evolution of restoration ecology.

Climate change and physical disturbance cause similar community shifts in biological soil crusts

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Abstract: Biological soil crusts (biocrusts) - communities of mosses, lichens, cyanobacteria, and heterotrophs living at the soil surface - are fundamental components of drylands worldwide, and destruction of biocrusts dramatically alters biogeochemical processes, hydrology, surface energy balance, and vegetation cover. While there has been long-standing concern over impacts of physical disturbances on biocrusts (e.g., trampling by livestock, damage from vehicles), there is also increasing concern over the potential for climate change to alter biocrust community structure. Using long-term data from the Colorado Plateau, USA, we examined the effects of 10 years of experimental warming and altered precipitation (in full-factorial design) on biocrust communities, and compared the effects of altered climate with those of long-term physical disturbance (>10 years of replicated human trampling). Surprisingly, altered climate and physical disturbance treatments had similar effects on biocrust community structure. Warming (+4°C), altered precipitation frequency (an increase of small (1.2 mm) summer rainfall events), and physical disturbance from trampling all promoted early successional community states marked by dramatic declines in moss cover and increased cyanobacteria cover, with more variable effects on lichens. While the pace of community change varied significantly among treatments, our results suggest that multiple aspects of climate change will affect biocrusts to the same degree as physical disturbance. This is particularly disconcerting in the context of warming, as temperatures for drylands are projected to increase beyond those imposed by the climate treatments used in our study.

Removal of nonnative fish species from disconnected backwaters

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Abstract: The Lower Colorado River Multi-Species Conservation Program will create 360 acres of backwater habitat for bonytail (*Gila elegans*) and razorback sucker (*Xyrauchen texanus*) over 50 years. Disconnected backwaters free of nonnative fish are expected to provide superior habitat for a recruiting population of bonytail and razorback sucker. The Imperial Ponds were constructed on the U.S Fish and Wildlife Services Imperial National Wildlife Refuge in 2007. They are comprised of six ponds totaling 80 acres of disconnected backwaters. Following construction, the Imperial Ponds were surveyed annually; nine nonnative fishes in various concentrations throughout the pond were captured from 2007 through 2014. A renovation plan to include removal of native fish, pond preparations, chemical renovation, and post renovation monitoring was finalized in April 2014. Native fish removal began in February 2014. A total of 146 bonytail and 108 razorback sucker were removed from the ponds. Pond preparations included vegetation removal and increasing the water surface elevation of the ponds to prevent freshwater percolations in an effort to remove areas of refuge for the fish. The piscicide Prenfish® CFT Legumine™ (5-percent rotenone) was used for the treatment of the ponds. The type of use identified for the treatment of the Imperial Ponds was the removal of bullheads or carp in rich organic ponds. The suggested application rate was 2.0 to 4.0 ppm; ponds were treated at 4 ppm mixed at a rate of 1 part toxicant to 10 parts water. Rotenone was applied as a two-part treatment (i.e., one treatment=two chemical applications). The first application was applied in December 2014; the second, follow-up application was applied in January 2015. Monthly post renovation sampling trips began in February 2015 using various net types and electrofishing to evaluate the renovation efforts. No fish have been captured or visually observed during this sampling period. Post renovation sampling efforts indicate successful removal of nonnative fish species from the Imperial Ponds.

Looking back and scanning the horizon: fostering a culture of cooperation and collaboration for public trust science and stewardship

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Abstract: U.S. government mission agencies are charged with protection and management of more than one third of the lands and waters in the United States, with jurisdiction, oversight, and targeted trust resource responsibilities that often transcend physical, political, cultural boundaries. As demands increase for integrated multidisciplinary approaches to inform policy and management, innovative approaches to coordinate and support actionable science and efficient knowledge development are increasingly valued. The Cooperative Ecosystem Studies Units (CESU) Network is one of a number of federal collaborative science programs that leverage partnerships to inform decision-making and enhance public trust resource stewardship. The CESU Network represents a national consortium of federal agencies; academic institutions; tribal, state, and local governments; conservation organizations; and other partners, drawing upon expertise from across the biological, physical, social, cultural, and engineering disciplines (from Anthropology to Zoology) to conduct collaborative applied projects that address natural and cultural heritage issues at multiple scales and in an ecosystem context. This presentation will include discussion of recent program evaluation efforts looking back over the past 15+ years to highlight examples of collaboration and partner engagement, characterize distribution and typology of projects, identify tangible and intangible program outcomes, and invite input from session participants to share lessons learned, explore potential opportunities, and help guide present actions and future directions.

Impacts of long-term stand density management on soil moisture and reproductive success in southwestern ponderosa pine forests

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Abstract: Understanding factors that control ponderosa pine (*Pinus ponderosa*) regeneration is important considering future increases in aridity in the southwestern U.S. that may reduce regeneration. We studied impacts of long-term regulation of tree density via repeated forest thinning over the last 50 years on ponderosa pine reproduction and microenvironment at the Taylor Woods Growing Stock Level (GSL) study in northern Arizona. In 2014 and 2015, we measured the following in three replicate stands of each of six GSL levels: cone production; density, survival and growth of seedlings from the 2013 cohort; soil water content; canopy cover; stand basal area; and tree density. Survival of the 2013 seedling cohort averaged 76% after the first winter, declined to 10% by June 2015, but did not differ significantly among GSLs. Seedling density did not differ significantly among GSLs and averaged 2/m2 in spring 2015. Seedling diameter and height differed significantly among GSLs. Seedling height after one year was greatest in the unthinned control and 23 m2/ha GSL whereas seedling diameter was greatest in the clearings (0 m2/ha GSL). Cone production did not differ significantly among GSLs, but cone weight generally decreased as GSL level increased. Water content of surface soil (0-15 cm) was higher in the 14m²/ha GSL than other GSLs during the pre-monsoon dry season, whereas all GSLs had similar surface soil water content during the monsoon season. Water content of deeper soil (15-30 cm) during summer was highest in clearings (0m²/ha) and lowest in the 34m²/ha GSL. Canopy cover increased linearly with GSL. Results to date suggest ample ponderosa pine natural regeneration over a wide range of stand-level tree density as long as seed sources are close, and a strong influence of macroclimate but not microclimate on seedling survival.

Linking forest landscape management and climate change to the conservation of riparian habitat in the Grand Canyon: Part I. vegetation modeling

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Abstract: The conservation of biologically significant riparian, spring, and seep habitats in lower elevations of the Grand Canyon is inextricably linked to the high elevation forest on the Kaibab Plateau. Currently, the plateau supports a range of forest community types including piñon-juniper, ponderosa pine, mixed conifer, and spruce-fir. However, the spatial extent, composition, and structure of these forest types may be substantially altered by future climate change, with consequences for watershed output. In part one of this project, we employed a multi-model landscape simulation approach to assess the effects of climate change and wildfire on forest

composition, biomass, and landscape pattern across the 300,000 hectare Kaibab Plateau. First, we used the Climate-Forest Vegetation Simulator (C-FVS) to model individual species establishment probability and growth rates according to different environmental site conditions and climate scenarios. Next, we incorporated individual species growth responses from C-FVS into the spatial model LANDIS-II to simulate spatial patterns of fire disturbance, forest growth, regeneration, succession, and dispersal. Model simulations included an initial calibration period replicating the historical fire regime and the fire suppression period, providing an opportunity to compare model output with site-specific dendroecological data. Model simulations were then carried into the future under a series of future climate and fire disturbance scenarios. Climate change scenarios resulted in a decline in mean forest biomass and a compositional shift to forest species typical of the ecoregion directly lower in elevation. Climate change combined with fire restoration resulted in more rapid biomass declines and compositional change followed by an earlier recovery and stabilization of biomass and composition. Landscape maps project that under either climate change scenario the Kaibab Plateau will eventually be dominated by piñon-juniper and ponderosa pine forest types, with a complete loss of mesic conifer species that currently dominate the upper two elevation zones.

Responses of wildlife habitat to climate variability and fire in sagebrush shrubsteppe and pinyon and juniper woodlands

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Abstract: The distribution and abundance of non-native invasive plants, especially bromes, in native shrublands and woodlands in the southwestern United States has increased substantially in response to changes in land use and fire dynamics. Percent cover and biomass of cheatgrass (*Bromus tectorum*) and red brome (*B. rubens*), and in turn fine-fuel loads and the probability of fire, are highly responsive to the timing and amount of precipitation. The frequency of wet days in the southwestern United States is projected to decrease during the 21st century, whereas the amount of precipitation on wet days and variability in precipitation are projected to increase. Thus, changes in climate will continue to affect the evolution of the invasive grass–fire cycle. In the Great Basin, cheatgrass-driven fire is associated with loss of the sagebrush and native grasses and forbs in which many native animals breed and feed. Accordingly, fuels treatments and post-fire restoration have been proposed with the goal of conserving greater sage-grouse (*Centrocercus urophasianus*) and its habitat. However, it is unclear whether planned treatments are likely to meet management objectives for greater sage-grouse. Moreover, data from our long-term research suggest that the responses of other sensitive-status birds and their habitats to fuels treatments may be undesirable. Additionally, responses of different taxonomic groups to changes in climate, fire, and disturbance are highly variable. For example, we found that occupancy of breeding birds in sagebrush shrubsteppe and woodlands in the Great Basin currently may be more sensitive to unusually cool, wet winters than to increases in temperature and decreases in precipitation. It remains challenging to anticipate how native animals may adapt to future changes in land cover and climate, but contemporary responses to changes in land use and vegetation are sufficiently well characterized to inform management.

Science-policy interaction and the Minute 319 environmental flows to the Colorado River Delta

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Abstract: On March 23, 2014, the first environmental flow to cross an international boundary arrived in the Colorado River Delta. What role did science play in the development of the policy in delivering 195 million cubic meters of water? Decision-making in the Colorado River basin is stakeholder-driven. Science is not a stakeholder: water agencies, states, nations, and, to some degree, NGOs are the stakeholders. Scientists within those groups can help shape the group's agenda; scientists outside those groups (e.g., university and federal scientists) sit on the sidelines until asked to play. In the case of the delta, university and NGO scientists had worked to identify the environmental consequences of decades of upstream diversions. They had discovered that small amounts of inadvertent environmental water (e.g., Ciénega de Santa Clara, excess flows during wet years) brought large environmental benefits. A core, binational team of delta scientists developed with NSF support and through monitoring the Ciénega de Santa Clara. Small, NGO-sponsored restoration efforts showed what was possible. Mexico, with the support of NGOs equipped with credible and relevant scientific understanding, advocated for environmental flows as a key element of Minute 319. An expanded team of delta scientists now monitors the hydrologic and environmental effects of the Minute 319 flows. As many authors have noted, an effective science-policy interaction requires scientific credibility, relevance, and legitimacy (respect for stakeholder interests). These three elements often interact, sometimes to the detriment of relevance and credibility. In the case at hand, academic and federal science enhances credibility, the need for relevance focuses monitoring efforts, while legitimacy rules all. A cynic could say that this means that politics trumps science, but Minute 319 is not all about the science - and cynics rarely get stuff done.

Regulatory role of *Purshia tridentata* in spatial biogeochemistry patterns in Mesa Verde's piñon-juniper woodlands

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Abstract: Piñon-juniper woodlands occupy 15% of the American Southwest and have suffered high mortality and weed invasions during recent droughts. Yet, some "persistent" piñon-juniper woodlands are highly resistant to invasion of exotic plants. We investigated physical and biological factors that may contribute to this notable resiliency at Mesa Verde National Park. We addressed whether native plant species diversity and cover and nutrient inputs from actinorhizal (N2-fixing) shrubs or biological soil crusts are components of resistance to invasion. Plant biodiversity, cover, and piñon and juniper recruitment did not increase in the presence of actinorhizal *Purshia tridentata* (Bitterbrush) during 2014 drought conditions or relatively wet 2015. We found significantly lower available phosphorus concentrations from soils beneath Bitterbrush relative to soils beneath non-nitrogen-fixing shrubs, suggestive of active fixation. Low P values also occurred in interspaces with abundant biotic crust cover. We found significantly lower C:N under Bitterbrush than non-fixing shrubs (which were similar to interspaces). C:N was low when biotic crusts were abundant in interspaces, suggesting nitrogen enrichment. Taken together, soil, foliage, and microbial chemical analyses exhibited a complex array of biogeochemical interactions that underscore the importance of Bitterbrush as a regulator of soil fertility, with possible implications for ecosystem invisibility. Our results suggest that the abundance of bitterbrush plays a role in regulating not only the soil carbon and nutrient pools beneath its canopy but also in structuring the soil nutrient spatial patterns within canopy interspaces. Biocrust cover has less impact on spatial patterns of biogeochemical cycling. During drought conditions we documented extensive Bitterbrush mortality and measured significant correlation of size and retrenchment, ($r=.27$ $p<.001$) but retrenchment/size relationship varied significantly across habitats with different Bitterbrush densities. Recovery patterns in 2015 will be discussed. These preliminary ecological and chemical data suggest a key role of Bitterbrush in the resiliency of persistent piñon-juniper woodlands.

Endangered razorback sucker (*Xyrauchen texanus*) occupying Lake Powell, a research project to determine how these fish use this impoundment and how these fish may contribute towards the recovery of this endemic large bodied Colorado River fish

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Abstract: Razorback sucker is one of four Colorado River endangered fishes that have become greatly reduced in numbers and range since the mid 1900's. Physical alterations of riverine habitats, water impoundments, introduction of non-native species, and contaminants have all contributed to the decline of these species. Recovery programs have been formed to direct the management and conservation of these species and to ultimately achieve recovery while water use and development continues in compliance with interstate compacts and applicable federal and state laws. At the upper terminus of critical habitat for razorback sucker there are two recovery programs, one for the San Juan River basin (San Juan River Basin Recovery Implementation Program, SJRIP) and another for the upper Colorado River and associated tributaries (Upper Colorado River Endangered Fish Recovery Program, UCRRP). A majority of these programs' efforts have been directed toward riverine recovery since the disappearance of wild razorback sucker in the early 1990's. In 2011, the SJRIP funded a project to look into the status of all life stages of razorback sucker occupying the San Juan arm of Lake Powell. The San Juan River is isolated from Lake Powell by a waterfall (since 2003) and, unless the lake elevation exceeds ~3,650 feet, the fish in the lake are isolated from the river population. The work in 2011 and again in 2012 found a relatively large population of adult fish that were not only occupying the lake, but were also actively spawning there. In addition, a large proportion of these fish were without a passive integrated transponder tag (PIT, all hatchery reared razorback sucker should have these implanted prior to stocking) suggesting potential wild recruitment. These findings highlighted the need to expand our focus lake wide and in 2014 and 2015 additional research began on the Colorado River arm of Lake Powell.

Ecology and management of razorback sucker in the San Juan River

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Abstract: The San Juan River Basin Recovery Implementation Program (Program) conducts management activities in the San Juan River to promote the recovery of endangered razorback sucker (*Xyrauchen texanus*). Despite stocking over 138,000 razorback sucker since 1994, natural recruitment remains limited. Stocked razorback suckers experienced initial high mortality that abates in later years. Larger razorback suckers had higher survival and there was substantial variation in survival among stocking years, hatchery

sources, and stocking locations. Razorback sucker demonstrated limited movement following initial movement downstream after stocking. Efforts are ongoing to improve the efficiency of the augmentation program by disentangling the effects of hatchery source and stocking locations, assessing hard versus soft releases, and conditioning razorback sucker to flow prior to stocking. The augmentation program appears to have resulted in an increase in a razorback sucker population size. However, despite regularly documenting razorback sucker natural reproduction that has recently been within an order of magnitude of other native suckers, wild juvenile razorback suckers remain rare. Additional management actions to benefit razorback sucker recovery in the San Juan River included control of non-native predators and competitors, managed flow releases from Navajo Dam, restoration of disconnected secondary channels, addressing impediments to fish movement, and expanding stocking locations further upstream in the San Juan River and tributaries.

The effects of prescribed fire and thinning restoration treatments on forest floor fuel loading in warm/dry mixed conifer forests in southwestern Colorado, USA

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Abstract: Mixed conifer is one of the most complex forest types in the western United States and is dominated by diverse stands of ponderosa pine, Douglas-fir, white fir, and quaking aspen. Fire has played a key role in shaping species composition and stand structure in these forests before fire disruption in the late 20th century. Fire suppression in warm/dry mixed conifer forests disrupted natural fire regimes and feedback interactions between vegetation composition and structure, which has resulted in forests that are dominated by small-diameter trees and increased surface fuels that have increased the potential for higher intensity crown fires. Thin/burn treatments can have positive ecological results by reducing aerial fuels and restoring forest structure. Fuel loading contributes to important ecosystem processes such as nutrient and carbon cycling, soil formation and stabilization. In the summer of 2015, we will quantify forest floor fuel loading using Brown's planar intercept method for three different treatments units in four replicated blocks: (1) thin/burn, (2) burn alone, and (3) untreated control. Within each treatment unit, five random plots will be sampled, for a total of 60 plots. We will analyze litter and duff depth along with fine and sound and rotten coarse woody debris. We will also quantify differences in fuel loading over an 11-year period (pre-treatment, post-harvest, post-burn) for all three treatments to assess how the fuels change over time. Rates of fuel buildup and decomposition can be used to define temporal limits to fire hazard reduction treatments and could also help land managers determine how fast treated landscapes would reach undesirable fuel loadings to warrant additional treatments.

Insight into pre- and post-fire management in the face of climate change

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Abstract: Driven by converging factors of warming climate and increased fuel, many forest landscapes are burning in severe megafires, prompting management treatments aimed at restoring ecosystems resilient to fire. This management approach is based in historical ecology and shows positive results in reducing wildfire severity, but future climate is altering the environment for vegetation and the role of fire. We used climate-sensitive forest models to assess the utility of actual treatments prior to a severe wildfire (Rodeo-Chediski, Arizona 2002) and simulated future treatments. While model results are highly uncertain, patterns and trends in the simulated results may be helpful in identifying thresholds for selecting among alternative management approaches.

Session introduction: collaborative environmental research in the Southwest

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Abstract: A wide range of complex environmental challenges are confronting resource managers and other decision makers across the Southwest. In many cases there is a role for science to play in helping to address these problems, but commonly the research being carried out in universities is too disconnected from decision contexts to have as much impact as it could. This short introductory talk will introduce key questions we want to address through presentations and the facilitated discussion that will follow. Those questions include: How do these collaborations develop and evolve? How do scientists develop research questions that have potential to be useful for decision making? What are some of the best approaches to carrying out collaborative research useful for both scientists and practitioners?

A methodology for using LiDAR data to model Mexican Spotted Owl (*Strix occidentalis lucida*) Nesting/Roosting habitat on the North Rim of Grand Canyon National Park

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Abstract: The current (2012) Mexican Spotted Owl (*Strix occidentalis lucida)* recovery plan calls for 25% of identified mixed conifer MSO recovery habitat identified within the Colorado Plateau to be designated as "Nesting/Roosting habitat." The criteria required for designation as Nesting/Roosting habitat is based on percent basal area by tree size class, minimum tree basal area, and minimum densities of large trees. Because Grand Canyon National Park's vegetation map lacks any reference to basal area, a new methodology based on 2012 LiDAR data was developed to map those areas that meet the recovery criteria. The LiDAR point cloud data was converted to a series of 25 meter grids, by tree diameter size classes, where the cell value represented the number of trees in that given cell by size class. The point cloud conversion was based on a series of equations developed by the USGS-EROS data center, and developed from 54 fire effects field plots with individual tree data collected on site. Each grid was then converted to an estimate of basal area per hectare, per size class. The grids were then combined, basal area classes were summed, percent of BA/size class was calculated, and the total number of trees per cell estimated. The resulting combined grid was queried based on the MSO recovery definitions, and exported to polygons. The polygons where then aggregated to eliminate "holes" and connect dis-continuous data within an acceptable distance. Expert opinion incorporating canopy cover values and the Shannon Diversity Index were used to identify a subset of these aggregated polygons which has now been determined to be Nesting/Roosting habitat within the North Rim mixed conifer forests of Grand Canyon.

Using monitoring data and predictive modeling to identify, assess, and respond to climate change impacts to archeological sites at Flagstaff Area National Monuments

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Abstract: In 2013, the cultural resources division at the Flagstaff Area National Monuments reinstated a monitoring program that aims to assess the sites within the monuments, including those that may be affected by climate change impacts, generate reliable and comparable data, and provide practical and feasible recommendations about how to better manage the archaeological resources with the monuments. While monitoring in itself does not mitigate impacts to sites, the monitoring program is built to provide realistic and feasible recommendations on ways in which to address site degradation, and help inform future actions and projects at archaeological sites within the monuments. In 2012 and 2014, the cultural resources division conducted climate change vulnerability assessments for archaeological sites at Wupatki and Walnut Canyon National Monuments. These assessments suggest the possibility of increased impacts to sites as monsoonal storms intensify. In order to test this prediction and to address climate change, the monitoring program at Flagstaff Area National Monument has begun to monitor areas that are being especially hard-hit by monsoonal rains. Using predictive modeling, archeologists can find areas with moderate to steep slopes, and then monitor archaeological sites within those areas. If these sites are being impacted, monitors can precisely measure active erosion through measurements and depths. Monitors can also provide photographic representation with scales, so that erosion can be visually assessed and measured. Furthermore, annual monitoring reports can include weather and precipitation data from the year in order to determine if, how, and when monsoon storms are affecting sites within the monuments. With additional data and more assessed sites, the Flagstaff Area National Monuments can begin to develop responses to climate change and determine how to best manage sites that are actively eroding.

Host tree genetics influences fungal communities and drought tolerance in pinyon pine

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Abstracts: Populations of pinyon pine (*Pinus edulis*) have experienced high mortality during drought events in the US southwest, and many models predict a significant range contraction in this species. However, a northern Arizona population of *P. edulis* shows dramatic variation in drought tolerance that has been associated with particular communities of root-associated fungal communities. We used field, common garden, and greenhouse studies of pinyon pine to examine how plant genetic variation affected drought tolerance, belowground fungal species composition and their interaction. We found that: 1) the mortality and growth patterns of the offspring of drought tolerant and drought intolerant trees were similar to that of their mothers, suggesting a strong genetic basis to performance during drought. 2) Also similar to patterns observed in their mothers, seedlings of drought tolerant versus intolerant mothers had different ectomycorrhizal fungal communities as measured using Sanger sequencing of root tips and next generation sequencing of the surrounding soil. 3) Greenhouse inoculation experiments showed that the soil communities associated with drought tolerant pinyons promote growth significantly more than those of drought intolerant pinyons under dry conditions. Taken together, these results

show that soil fungal communities vary among host genotypes grown in a common environment and that this variation influences host plant performance. Our results also indicate that maintenance of forest genetic diversity will promote greater soil fungal diversity.

Effects of Sudden Aspen Decline on Large Mammalian Activity in Southwestern Colorado, USA

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Abstract: Sudden aspen decline (SAD) is when aspen experience branch dieback, crown loss, and rapid mortality due to increased temperatures and reduced moisture availability. Aspen forests provide key habitat for a variety of plant and animal species. We conducted a study to quantify species richness and abundance of large mammals among different SAD levels based on recent crown loss (RCL): low SAD (0-25% RCL), moderate SAD (25.1-50% RCL) and high SAD (50.1-100% RCL) and in coppice harvest treatments on the San Juan National Forest, southwestern Colorado (N=7/SAD level/coppice harvest). We used motion-sensor cameras and scat counts to quantify large mammalian richness and abundance throughout the summer. Native large mammalian communities were significantly different between low SAD and harvest stands and between moderate and high SAD and harvest stands. Deer abundance was significantly greater in high SAD stands. Deer utilized high SAD stands at night more often than during the morning or afternoon. Elk abundance was significantly greater in moderate SAD stands than other SAD levels or harvest stands with the highest abundance in June when snowberry (*Symphoricarpos oreophilus*) provides food resources early in the growing season. There were no differences in bear abundance amongst SAD levels; however, no bears were recorded in harvest stands. Cattle were significantly greater in high SAD and harvest stands than other SAD levels. Our results provide land managers information on how changes in aspen forest structure due to SAD or coppice harvest treatments alter both native and non-native large mammalian activity, in addition to the influence native and non-native mammalian activity could have on SAD and aspen restoration.

Resolving post-fire debris flow response in rangelands of the western US

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Abstract: Fire greatly increases the potential for a landscape to produce large erosive events, including hazardous debris flows. In the coming decades, it is anticipated that the western US will host fires of increasing size and severity. As a result, anticipating the likelihood and magnitude of debris flows within burned watersheds grows in necessity, especially at the wildland urban interface, where life and property are most at risk to hazards such as wildfire and fire-induced runoff and erosion events. While it is known that fire increases erosion on burned watersheds, not all watersheds respond with hazardous post-fire debris flow activity. Recognizing this, attempts to model post-fire debris flow probability and resulting volume have been made; however, such attempts exclude rangeland systems, which, occupying >50% of the greater western US, pose a significant gap in our understanding of debris flow activity. Presented here is work attempting to better quantify post-fire debris flow response of rangeland systems. We hypothesize that vegetation, soil, and climate characteristics of rangelands influence debris flow likelihood and magnitude differently than other regions that have been modeled (S. California, Intermountain West). Topographic, soils, fire, and precipitation data are currently being collected from rangeland debris flow sites from which empirically derived multivariate models will be developed to describe under what conditions debris flows may occur in future burn areas. We are also assessing the utility of current models in quantifying debris flow hazards of the rangeland foothills of Boise, Idaho by comparing model results with what is deposited in alluvial fans to determine whether these models identify fire-induced debris flow-prone watersheds as reflected in the depositional record. Ultimately, the modeling and assessment efforts will be used to anticipate where burned areas in rangeland systems of the western US may experience debris flows in the future.

Climate change vulnerability assessments of the Great Basin: linking science to decision making

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Abstract: The use of climate science in decision making requires a complex interaction between the science provider and potential user. Vulnerability assessments (VAs) are tools aimed to aid this interaction by informing stakeholders of the sensitivity, exposure, and adaptive capacity of a species or ecosystem of interest. The Great Basin, USA contains a diverse set of stakeholders whose use of VAs is affected by conflicting interests and opinions in regards to the ecosystem services the Basin provides. While VAs are meant to aid in the decision making process in regards to respond to climate change, several barriers to their use have been identified. These barriers include a lack of resources and guidance when implementing VAs as well as limits to integrating new information into preexisting processes and institutional structures. Additionally, there is a lack of consistency in the design, style, and implementation of VAs. This can lead to potential conflict among

stakeholders with overlapping jurisdictions, whose assessments promote different reactionary policy proposals. Recognizing these issues, the goal of this study is to understand the development, implementation and unintended obstacles, and information gaps associated with VAs throughout the Great Basin through secondary analysis and systematic interactions with stakeholders. As the use of science in decision making is becoming more critical, maximizing the time and effort put into developing decision making tools like VAs must be achieved and can be accomplished by understanding the interaction between science and policy. This work, encompassing the Great Basin, will ultimately inform the use of science in decision making far beyond the immediate Great Basin decision arena.

Effects of changing water resources on four species of riparian reptiles and birds in the southwestern United States

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Abstract: The Lower Colorado River and Rio Grande Basins are home to many riparian species of different degrees of rarity. In our study, we focused on two species of birds and two species of gartersnakes that are associated with water: the yellow-breasted chat (*Icteria virens*), the American yellow warbler (*Setophaga petechia*), the Mexican gartersnake (*Thamnophis eques*), and the narrow-headed gartersnake (*T. rufipunctatus*). While the extent of distributions of these species is relatively large, they are often patchily distributed in populations that are small; in addition, both gartersnake species are listed under the Endangered Species Act. Aside from detrimental effects of direct habitat loss and degradation, future changes in hydrology might threaten the long-term persistence of populations of any one of these species. To evaluate this vulnerability at a landscape scale, we built models of suitability of current and future landscapes for these species. For this, we relied on climatic and hydrological predictions developed by the Bureau of Reclamation as part of the WATERSmart program. We also relied on the NASA's Moderate-Resolution Imaging Spectroradiometer (MODIS) to derive spatially-explicit metrics that quantify the availability of riparian vegetation in time. Using WATERSmart data, we were able to project these metrics in time. The projected changes in water availability by end of the century will directly affect the availability of permanent water and riparian vegetation that surrounds suitable habitats of our study species. Our results at a species level suggest significant changes in future landscape suitability (up to 64% of area) for all species that are in addition to already identified threats facing these species. Best models included riparian vegetation (linked to water availability) as an important component of the predictions, but we also note that finer scale examination of hydrology and climate effects on habitats would be more useful for effective management.

Nursing the biological soil crust restoration: cyanobacteria isolation, lab cultivation, scaling up, and inoculum conditioning

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Abstract: Biological soil crust (BSC) ecosystems contribute to soil surface stabilization against wind and water erosion, and increase soil nutrient and water retention in arid lands around the globe. Large filamentous cyanobacteria, such as *Microcoleus vaginatus* and *M. steenstrupii,* are early colonizers of soil surfaces and assist in soil stabilization. Soil stabilization allows the successional establishment of other BSC organisms, including other cyanobacteria. Human activities, ranging from cattle grazing to military training, have resulted in the significant deterioration of BSC surface cover of soils. Aiming at developing an effective BSC restoration strategy we established a "biocrust nursery" that serves as an inoculum supply for restoration. We isolated and grew large quantities of the main biological soil crust-forming cyanobacteria from a variety of soil types (sandy and silty) in both cold and warm deserts of military lands in the southwest of United States. Our cyanobacterial cultures match the microbial community structure of the original sites. Traditional scale up methods from the biofuel and biomedical industry gave good outcomes when growing some of the target cyanobacteria (*Nostoc* sp., *Tolypothrix* sp., and *Scytonema* sp.). Yet, when growing *M. vaginatus* and *M. steenstrupii*, which are the main biological component of these ecosystems, biomass yields using traditional scale up methods were very low. We developed a method that gives excellent biomass outcomes. By implementing this new approach, we were able to obtain exponential and fast growth of the BSC pioneers *M. vaginatus* and *M. steenstrupii*. Our inoculum formulation is based on pedigreed laboratory cultures that match the cyanobacterial relative abundance of the original sites, and additionally, have been conditioned to dry-wet cycles and increasing light exposure, with the goal of increasing field adaptation and survival rates. Ultimately, this nursery approach should help us to increase field recovery rates.

How the Minute 319 environmental flows affected the establishment of riparian vegetation in the Colorado River delta, Mexico

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Abstract: In the spring of 2014, 130 million cubic meters of water was delivered to the Colorado River delta's riparian corridor. This first-ever transboundary environmental flow was part of Minute 319 – a new agreement between Mexico and the U.S. regarding the river's management. The aim of this pulse flow was to promote the establishment of native vegetation and to enhance riparian habitat quality in both passive and active restoration sites. We surveyed for new vegetation before and after the pulse flow in 21 passive restoration sites along 92 river km downstream of Morelos Dam. We used a line-intercept method to detect germination and recruitment on the floodplain and to document changes in cover of the established vegetation. We measured seed availability by using sticky traps and observing tree phenology. We also monitored the extent of inundation and groundwater level in the survey sites. We detected germination of native trees (Cottonwoods and Willows) in four of the 21 transects after the pulse flow and at the start of the growing season. Non-native Tamarisk germinants were present in 14 transects at that time. At the end of the growing season, seedlings of native trees were present in one transect; Tamarisk seedlings survived in 12 transects. The extent of the seedling zones was reduced up to 90% in all tree species. Seedling establishment and survival of native trees was likely limited by 1) the availability of bare ground, 2) competition with fast-growing species in some areas of the riparian corridor, 3) availability of soil moisture, and 4) availability of seeds. We can use these results to identify sites for future restoration efforts: areas along the riparian corridor where most of the requirements for establishment of native vegetation can be met.

Incorporating the evolutionary outcomes of plant interactions into restoration during exotic invasion and climate change

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Abstract: Plant interactions can lead to natural selection when they alter plant fitness or performance. Including this evolutionary knowledge into restoration has high potential to increase restoration effectiveness. For instance, we have found that *Tamarix* spp. invasion alters the genetic composition of *Salix exigua* and *Populus fremontii* populations with highly competitive genotypes surviving the invasion and weak ones dying. These competitive genotypes may be well-suited for restoration in weed-infested areas. For highly clonal *S. exigua* plants, we have found strong evidence that genetically similar plants, those with very similar niches, are not competitive but are, in fact, strongly facilitative. This facilitation results in increased growth, seed production, and herbivore and pathogen resistance. This 'kinship' facilitation also stimulates growth of neighboring confamilial species such as P. *fremontii* and *S. gooddingii*. This facilitation helps trees that are adapted to warm temperatures survive the cooler temperatures that are present following assisted migration. Also, higher growth rates of native species suppress weed growth. Although the mechanisms of facilitation are not well known, whether via chemical signaling among plants to induce defensive responses, belowground resource networks, or root exudation of growth hormones, they merit further study and inclusion into restoration projects.

Comparison of arthropod communities in two blackbrush habitats, University of Utah Rio Mesa Field Station, southeastern Utah

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Abstract: "If invertebrates became extinct, the world as we know it would cease to exist." (Wilson 1987). Invertebrates represent all trophic levels above primary producers, performing many ecosystem functions, and thus provide a large pool from which to draw potential indicator taxa to monitor ecosystem condition. However, before they can be used as indicators, we must know which taxa are present, how they function in particular ecosystems, and how they respond to natural and anthropogenic disturbances. As part of regional opportunistic surveys of ground-dwelling arthropods on the Colorado Plateau, pitfall traps were deployed in two blackbrush habitats in southeastern Utah near the Dolores River in July 2013. One habitat was found on perched alluvial deposits isolated on sandstone knobs adjacent to the Dolores River; the other habitat consisted of blackbrush near monoculture stands embedded within a piñon-juniper matrix. Pitfall traps were open for 28 days, collected, cleaned and sorted; specimens were identified to family

and assigned unique morphospecies labels, and counted. Total number of arthropod specimens collected in the two habitats were roughly similar (600, 561), but composition of the two communities were quite different. A total of 83 morphospecies taxa were found during the study. The dome alluvial community contained 52 morphospecies while the piñon-juniper community had 62 taxa, with only 31 shared taxa; Sorensen's Similarity Index is 0.27. Non-metric Multidimensional Scaling ordination separated samples from riverine alluvial deposits almost completely from the piñon-juniper habitat samples in ordination space. Alluvial habitat supported an arthropod community distinguished by the presence of two ant taxa and a wasp, while the piñon-juniper community was characterized by single morphospecies each of ant, fly, Jerusalem cricket and silverfish.

Discovering common ground in climate change impacts and adaptation: lessons from the Asian highlands and the southern Colorado Plateau

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Abstract: The Asian highlands from Pakistan in the west to China's Yunnan Province in the east appear to share little in common with the Arizona Strip subregion of the Colorado Plateau north of the Grand Canyon. But both are global hotspots of current and projected climate change, and both regions are actively being studied to better understand links between modeled climate projections, conservation science and management issues, and likely human vulnerabilities. As a contributor to two such studies that explore these links and offer recommendations to reduce vulnerabilities to climate impacts, I highlight results common to both regions. These include using downscaled model projections of temperature and precipitation out to 2050 as a framework for understanding and communicating potential ecosystem changes, prioritizing water resources through the creation of specific plans for how to mitigate potential water use conflicts, identifying specific areas of high climate risk and low climate resiliency, building partnerships between scientists and managers, and the importance of communicating study results to a variety of targeted audiences. The application of conservation science to climate issues challenges the traditional roles of researchers in science/policy exchanges.

Developing a service-wide approach to understanding climate change-related cultural resource impacts at National Park Service units

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Abstract: This presentation will address the development of a National Park Service (NPS) strategy to understand and respond to climate change-related impacts to cultural resources. The National Park Service manages 407 units with cultural resources representing the diverse history of the United States and its territories. Depending on location, catastrophic climate change impacts such as sea level rise, coastal inundation, or wildland fire may result in major effects to individual resources. Additionally, the severity of an individual impact is also related to other site specific variables such as construction materials, past management techniques, or age. Considering the complexity created by factors such as changing regional weather patterns and locally specific resource types, how does the NPS begin to understand and respond to climate change as an agency? Similarly, how does the NPS create and maintain a scientifically robust program capable of providing guidance to other agencies, organizations and institutions in these conditions? A successful strategy for understanding and responding to climate change impacts has already been implemented for NPS natural resource programs. The success of these existing programs suggests that understanding diverse climate change impacts must begin from the bottom up, that is from the individual resource and park level. As such, the development of interagency and academic partnerships at individual parks is absolutely critical to the success of such a strategy.

Climate sensitivity of Navajo forests: use-inspired research to guide tribal forest management

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Abstract: The Navajo Nation contains roughly 5.4 million acres of semi-arid woodland and forest ecosystems. Similar ecosystems across the southwest region have experienced substantial mortality from recent droughts, insect outbreaks, and high-severity fire. Future projections of climate-induced drought stress paint a grim picture for the future of these forests, with significant implications for the sustainability of tribal communities depending on the ecosystem services provided by local forests. Tasked with managing this vast resource and concerned about the potential effects of near-future climate, the Navajo Forestry Department has partnered with tree-ring researchers from the University of Arizona to study the sensitivities of their forests to climate extremes. We present on the genesis and implementation of this collaboration, the design of our study to address questions posed by the forest managers, and the preliminary results from two field seasons in the Chuska Mountains and Defiance Plateau. We then discuss the plan for how the

scientific results, combined with the rich ecological and local knowledge of the Navajo foresters, will be integrated into the next 10-year forest management plan being drafted by the Navajo Forestry Department.

Novel ecosystems in northern New Mexico

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Abstract: Novel ecosystems are developing across northern New Mexico landscapes, driven by interactions among hotter droughts, more severe fires, and historical land uses. These novel systems are developing at all scales, ranging from forest stands to extensive landscapes. In the Jemez Mountains in particular, rapid and widespread disturbances have transformed much of the previously forested eastern flank into shrublands and grasslands, with the emergence of new species assemblages and dominant species. Ecological processes also appear to be changing along with the ecosystem patterns. Fire regimes for example, have shifted from frequent low-severity fire, to infrequent high-severity fire, and now potentially to frequent high-severity fire. These changes have occurred in little over a century and could facilitate the long-term persistence of the novel systems. We will highlight some of those novel systems and the different temporal and spatial scales at which we may be experiencing dramatic reshuffling and developing along potentially novel trajectories. Jemez Mountains landscapes certainly have undergone similarly dramatic changes over past millennia, and human alterations of these mesas and mountains are nothing new. Today, with nearly constant and diverse societal demands on natural resources, land managers are challenged to effectively manage these novel systems in a time of limited budgets and greater uncertainty. At the place-based Jemez Mountains Field Station, we aim to work together with other scientists and managers and learn how local novel ecosystems can be better managed, in some cases restored toward more historic conditions, or used as barometers of climate change adaptation.

Characterization of tephra-origin soils and the relation to Sunset Crater/Wupatki ecology

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Abstract: Tephra-origin soils that have formed as a result of the 1065 eruption of Sunset Crater cinder cone possess high water infiltration rates, high water retention percentages, and overall water holding capacities that belong in an exclusive tier among soils. Infiltration and retention tests on soil columns of ash demonstrate that among a range of soils, ash dominated soils result in approximately the highest levels of both water infiltration and water retention at the same time. Water infiltration rates of ash soils compare favorably with infiltration rates of loamy sand columns. A soil of high infiltration results in low water surface runoff. Water retention rates of ash soils compare favorably with retention rates of clay loams. A soil of high water retention results in low rates of deep soil profile drainage. Taken together, these two soil qualities contribute to an overall water holding capacity that exceeds soils formed by sedimentary origins, or soils formed by intrusive and other extrusive igneous origins. In field sites of ash soils at Wupatki National Monument, and in the adjacent vicinity, size and density levels of one-seed juniper, *Juniperus monosperma*, compare favorably to areas in which precipitation levels are approximately five inches greater (or approximately 60% higher) than soils without tephra cover. Increased water holding capacity in conjunction with other factors, including neutral pH levels, which allows for greater phosphorous, allows for seed germination and subsequent growth of *J. monosperma* at low precipitation levels that have not been previously anticipated. Levels of organic enrichment provide additional evidence of enhanced soil productivity. Our findings demonstrate that the soil qualities of high water infiltration and high water retention in volcanic ash found in Sunset Crater combine to cause an unusually high effective soil water availability resulting in an ecological state that is currently uncharacterized.

Projecting effects of climate and habitat fragmentation on bird and reptile ranges in western USA

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Abstract: We modeled current and future breeding ranges of 15 bird and 16 reptile species in the southwestern United States. Rather than taking a broad-scale, vulnerability-assessment approach, we created a species distribution model (SDM) for each focal species with climatic, landscape, and plant variables. Baseline climate (1950 - 2009) was characterized with PRISM data and future climate with global circulation model data under an A1B emission scenario. Climatic variables included monthly and seasonal temperature and precipitation; landscape variables included terrain ruggedness, soil type, and insolation; plant variables included trees and shrubs commonly associated with a focal species. We included in our species distribution models a built-in annual migration rate for plants based upon paleo-ecological data. We conducted a group meta-analysis to determine how habitat fragmentation and life-history traits affect range projections. Projected changes in bird and reptile ranges varied widely among species without respect to taxa, with a third predicted to expand and two-thirds predicted to contract. Climatic variables explained the most variability in individual

bird and reptile models, followed by landscape and plant variables, respectively. Several species that are common today are projected to experience significant range contractions this century (e.g., pygmy nuthatch and Arizona black rattlesnake). A group meta-analysis revealed that habitat fragmentation and life-history variables were the most significant trans-specific drivers of projected range for birds (e.g., patch isolation and clutch size), while climate was most significant for reptiles. Patch isolation was an important trans-specific driver of projected bird ranges, and weakly correlated with reptile ranges, suggesting that strategic actions should focus on restoration and enhancement of habitat at local and regional scales to promote landscape connectivity and conservation of core areas. Our projected range maps include locations that appear highly resilient to change (refugia).

The role of biocrusts in regulating dryland plant communities and exotic plant invasibility

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Abstract: Biological soil crusts (biocrusts) play a critical role in the ecological function of global dryland ecosystems through provision of a suite of ecosystem services. Most importantly to dryland vascular plant communities, biocrusts can enhance soil water availability through modification of the soil environment (e.g., microtopography, porosity), and contribute to soil fertility via nitrogen fixation. Although biocrusts modify important plant limiting resources, the influence of biocrusts on surrounding vascular plants is mixed, whereby biocrusts have been shown to have both facilitory and inhibitory effects on plant establishment and growth. Specifically, evidence suggests that biocrusts may promote native plant establishment while inhibiting exotic plant establishment. Disturbance may profoundly disrupt biocrust-plant interactions through alteration of the cover, composition, and functioning of biocrust communities, creating possible pathways for exotic plant establishment. Recently, new methods have emerged to restore biocrust communities following disturbance, yet it is unknown how biocrust restoration may biocrust-plant relationships. In this experiment, we evaluated the role of biocrust community composition and integrity in regulating dryland native plant community composition and site-specific exotic plant invasibility. To achieve this, we conducted complementary greenhouse experiments to measure germination and establishment of native (*Aristida purpurea*, *Bouteloua eriopoda*) and exotic (*Eragrostis lehmanniana*) grass species on cyanobacteria or lichen-dominated biocrusts of contrasting soil textures (sandy, silty) from a hot (Chihuahuan) desert in response to biocrust disturbance and restoration treatments compared to untreated controls. Following seedling establishment, we investigated interspecific competition between native and exotic plant species by measuring growth and nutrient levels of seedlings grown in the presence and absence of competition across all biocrust treatments. Ultimately, the findings from this study will aid our understanding of the role biocrusts play in structuring xeric vascular plant communities, and the potential of biocrust restoration to be used as a tool to defend against exotic plant invasion in drylands.

Cooperative Ecosystem Studies Units support fisheries management planning at Grand Canyon National Park

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Abstract: Fish communities within Grand Canyon National Park were altered by construction of Glen Canyon Dam and the establishment of nonnative species. Humpback chub (*Gila cypha*), a federally endangered fish, was once widely distributed throughout the Colorado River Basin, but reproduction and population viability in the lower basin is now reliant on habitat within a single tributary to the Colorado River in Grand Canyon. Led by a group of cooperators including National Park Service (NPS) fisheries biologists, experimental conservation activities included establishing a second humpback chub spawning population, providing for additional rearing opportunities through translocations of juveniles, and removal of nonnative fish to reduce predation. Results from these conservation actions were used to inform the development of a long-term fisheries management plan for Grand Canyon National Park. Two Cooperative Ecosystem Studies Units were key to facilitating these efforts and helped us integrate a range of technical expertise from graduate students, the public, and a variety of cooperators. Through the Great Rivers CESU, the NPS collaborated with the University of Missouri to assess how juvenile humpback chub translocations met conservation needs through an evaluation of survival, growth, and outmigration of translocated fish from a tributary. A humpback chub population viability model was developed during a workshop led by the University of Florida in collaboration with the Gulf Coast CESU, and included fisheries biologists from the NPS and other agencies, which was used to evaluate the impacts of "cropping" different age classes from the Little Colorado River population. Four peer-reviewed publications and over 15 presentations were generated from these collaborations, and were relied upon during the development of the NPS Comprehensive Fisheries Management Plan for Grand Canyon National Park. Using the CESUs was a critical step in providing the diverse expertise needed to make sound management decisions for humpback chub recovery in Grand Canyon.

Watershed-scale assessment of native fish survival related to fire, flooding, and nonnative species in a Grand Canyon tributary

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Abstract: Management of natural resources within national parks is focused on preservation of physical and biological processes, as well as restoration of native plant and animal communities. To comply with NPS ecological restoration mandates, Grand Canyon National Park has completed long-term adaptive plans for management and conservation of native fish communities, and for the re-establishment of fire's natural role on the landscape. Actions included in these plans include nonnative species removal, translocations of endangered humpback chub (*Gila cypha*), and management of fuels resulting from managed fires, among others. Monitoring conducted under the fisheries and fire management plans determines whether plan objectives are being met, and new information is incorporated into annual project planning. The objective of this study was to integrate monitoring data collected between 2009 and 2015 in a watershed-scale analysis in order to inform future fisheries and fire management activities. Primary questions addressed included: 1) whether native fish survival in a Colorado River tributary varied over time, and if so, what factors influenced survival, and 2) what potential effects do fire management activities have on native fish communities? Mark-recapture and electrofishing depletion methodologies were employed to assess native and nonnative fish population dynamics, while streamflow gauge and National Weather Service precipitation data along with long-term vegetation plots and monitoring trends in burn severity (MTBS) data were used in the analysis. Preliminary analyses suggest that environmental and biological factors influenced annual survival of both humpback chub and bluehead sucker (*Catostomus discobolus*) over time, and that early summer (pre-monsoon season) high severity fire near or below the canyon rim may result in higher risk of impacts on survival of native fish through ash deposition or altered hydrology in Grand Canyon tributaries. However, short-term impacts to native fish survival as a result of low-severity fires, which reduce fuels, is likely an appropriate trade-off over the impacts of higher severity fires.

Bark beetles, outbreaks, and drought: causes of widespread tree mortality in the Southwest

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Abstract: Widespread tree mortality caused by drought and bark beetles has occurred in recent decades across the Southwest. Here we will review the largest die-off events to assess the contribution of drought, beetles, and their interaction. Some events such as sudden aspen decline and Texas oak and juniper mortality have been primarily associated with drought, with biotic agents taking a secondary role where known. Other events such as the piñon pine mortality in the early 2000s were a combination of severe drought and bark beetles. Other events such as mountain pine beetle outbreaks were initiated by droughts, but continued after the drought ended. Finally, background tree mortality (widespread but not locally severe) has been linked to drought. We describe these events, the state of the science, and prospects for the future.

Chemical and radiochemical characterization in biota at the Canyon Uranium Mine, Kaibab National Forest, Coconino County, Arizona

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Abstract: Recent restrictions on uranium mining on federal lands within the Grand Canyon watershed have drawn attention to scientific data gaps in evaluating possible effects of ore extraction to humans and wildlife. Uranium mines are potential sources of increased radiation exposure from uranium and its daughter products when ore is brought to the surface. In addition to concerns about radiation, mobilization of the non-radioactive forms of uranium and other co-occurring inorganic constituents in the ore may be of ecological concern. Tissue contaminant concentrations, one of the basic data requirements to determine exposure, are not available for biota from any historical or active uranium mines in the Grand Canyon watershed. Uranium and co-occurring inorganic constituents in mined ores may not pose radiation hazards in field exposures, but some co-occurring elements are as toxic, if not more toxic, to biota than uranium. The Canyon Uranium Mine is under development, providing a unique opportunity to characterize pre-mining concentrations of uranium and other trace elements, as well as radiation levels in biota found in the vicinity of the mine. Small mammals, herpetofauna, invertebrates, and vegetation were collected in 2013 to characterize baseline chemical concentrations and radiation levels in local food webs. Primary contaminants of potential concern were arsenic, cadmium, chromium, copper, lead, mercury, nickel, selenium, thallium, uranium, and zinc for chemical toxicity and uranium and associated radionuclides for radiation toxicity. Tissue concentrations of these contaminants will be presented. These are currently the only baseline data for biota in the Grand Canyon watershed and are therefore critical to future exposure and risk assessments. These data subsequently will be compared with concentrations in biological samples collected during active mining (estimated to last several years), after mining has ended, and after the site has been reclaimed.

TEK applications in Indian forestry: a model for forest stewardship and sustainability

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Abstract: Forest ecosystems provide some of the most valuable resources to tribal communities. Tribal forests exceed 18 million acres and sustain cultural, social, economic, and environmental values for Indian people. The National Indian Forest Resource Management Act (NIFRMA) was passed in the early 1990's and required decadal, independent assessments of tribal forestry programs. Since then, three decadal Indian Forest Management Assessment Team (IFMAT) reports have been provided to Congress regarding tribal forest management and tribal forests. As reported in the recent IFMAT report, federal investments in tribal forest management was significantly below the level of investment for the US Forest Service, Bureau of Land Management, and other private forest land management, which indicates that the US federal government inadequately fulfills its trust responsibility to tribes. Despite this, tribes on a national scale are assuming greater leadership through self-determination and self-governance and continue to serve as models for sustainable forestry and resource management by incorporating components such as traditional ecological knowledge, community support for integrated resource management plans, and a holistic, dedicated, long-term vision for forests. On a local scale, the Mescalero Apache Indian tribe in south-central New Mexico balances economic, environmental, and social values and is uniquely poised to serve as a case study for balancing multiple objectives and forest and tribal community needs. This presentation will provide an overview of the recent IFMAT report findings and will highlight local examples of use of traditional ecological knowledge and tribal perspectives regarding forest management on the Mescalero Apache Indian Reservation.

Strengthening adaptive capacity at a landscape scale: developing climate adaptation actions on the North Rim Ranches in Northern Arizona

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Abstract: The Southwest is considered to be one of the most "climate-challenged" landscapes in the United States, and regions like the Colorado Plateau are on the front lines of projected climate change impacts. This region is projected to experience hotter temperatures, increased aridity and precipitation variability, and severe droughts. These climate change impacts will exacerbate existing land uses, and each species and ecosystem will respond in unique and complex ways. This complexity presents a challenge for land stewards and land managers alike, who must work to reduce the extent of climate change impacts and to improve the ability of species and ecosystems to adapt to change. Effective adaptation planning can aid in maximizing proactive, "no regrets" strategies to reduce the impacts of climate change. In this context, we present a snapshot of landscape-scale climate adaptation planning that seeks to characterize climate vulnerability and on-the-ground adaptation actions for the North Rim Ranches - an 850,000-acre public lands area north of the Grand Canyon that is of significant ecological, cultural, and scenic importance. Within this context, we outline our vulnerability assessment framework and highlight an example of an on-the-ground adaptation action, an ongoing restoration effort of low-elevation springs that seeks to balance wildlife water availability while maintaining livestock water access during arid months. Ongoing monitoring of ecosystem integrity indicators, such as wildlife presence as documented by wildlife camera trapping, provides feedback on these efforts as we aim to expand this and other adaptation actions across this landscape. We suggest that these key steps of vulnerability assessment, on-the-ground action, and ongoing monitoring can fit neatly within an existing adaptive management framework and can provide a foundation for an effective adaptation strategy.

An integrated multi-platform approach for assessing brush management conservation efforts in semiarid rangelands

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Abstract: Millions of dollars have been spent on brush management, or removal of unwanted woody vegetation, as a conservation practice to control the presence of woody species. Land managers need an inexpensive means of monitoring the effects of brush management conservation methods for decreasing degradation in rangeland systems. In this study, free, publically available, high-resolution (1 m) imagery from the National Agricultural Imagery Program (NAIP) and moderate resolution (30 m) Landsat-5 thematic mapper imagery were combined to produce a large-scale technique for mapping woody cover. Landsat-based scenes of woody cover were produced and validated using NAIP and ground-based data. Results showed that the produced maps of woody cover could be used to successfully track the occurrence of brush removal, as well as monitor presence or lack of subsequent reemergence. This work provides land managers with an operational means of determining where to allocate resources to implement brush management, as well as a cost-effective method of monitoring the effects of their efforts.

Use of camera traps and citizen scientists to measure and monitor patterns of wildlife habitat occupancy on the Kaibab Plateau, northern Arizona

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Abstract: With ongoing climate and land cover changes in the Southwest, sensitive populations of wildlife and their habitats are expected to be adversely impacted. Non-native plant invasions, more frequent large-scale fire events, and intensive grazing practices could further exacerbate this problem. In northern Arizona, a century of timber harvesting, cattle grazing, and human alteration of natural fire regimes have helped to shape the structure and function of important wildlife habitats. This is particularly evident on the vast Kaibab Plateau, north of Grand Canyon National Park. The higher elevation areas of the Kaibab Plateau provide summer habitat for a variety of species, including the Kaibab mule deer herd, made famous by Aldo Leopold in the 1940's. Nevertheless, mule deer on the Kaibab Plateau - like other populations of wildlife - are responding to changes to their habitat by shifting to less desirable locations or resources. Thus, it is necessary to develop an improved understanding of current and anticipated future patterns of wildlife habitat occupancy. In this context, our objective was to estimate and monitor the occupancy rates of mule deer and other mammals on the Kaibab Plateau, namely those species occupying the higher elevations (>2100 m) of the North Kaibab Ranger District in the summer months. We hypothesized that occupancy rates were determined by multiple landscape-level factors, such as time since last burn or treatment, proximity to water and roads, heterogeneity in forage availability, and cattle presence, among others. We demonstrate the use of a network of 100 wildlife camera 'traps' and teams of 'citizen scientists' to inform statistically robust estimates of detection probability and occupancy for mule deer and other species. Our approach can be used to implement an efficient and repeatable sampling effort, and to generate statistically reliable estimates of habitat occupancy for multiple species in other systems.

Desert bighorn sheep in the Big Ditch

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Abstract: Grand Canyon National Park presumably contains one of the largest and most continuous, naturally-persisting populations of desert bighorn sheep. Moreover, bighorn sheep in Grand Canyon occupy an environment that is unique relative to most desert bighorn sheep range, living in a highly lineated, very deep canyon with abundant free water along the bottom. In this system, bighorn habitat extends across 280 river miles of the Colorado River and covers roughly 5,000 feet of relief, with observed densities of bighorns changing across different geomorphological gradients. Although historically considered a species of special concern for the Park, virtually nothing has been known about population trend, habitat use, demographic structure, and disease exposure until recently. Information obtained from telemetered bighorns, fecal pellets, and biological samples have provided the first insight into the population status and health of bighorns in Grand Canyon, including seasonal distributions, genetic connectivity, pathogen exposure and disease risks, and survival. Here we report on the current knowledge of desert bighorn sheep in Grand Canyon and present preliminary results from a study initiated in 2011 investigating the ecology of and potential threats to bighorn sheep in Grand Canyon.

Sensitivities of dominant plants to chronic drought in the Colorado Plateau

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Abstract: Drylands of the Southwestern US, such as the Colorado Plateau, are predicted to experience greater water limitations with climate change due to changes in precipitation and increased warming. Dominant plants and plant functional types (PFTs) may be at or near their physiological limits in these ecosystems, and thus subtle changes in water availability may have dramatic ecological effects. We imposed a four year, chronic, but subtle drought (35% precipitation reduction) using passive removal shelters, across a wide geographic region of the Colorado Plateau. Over four years, we examined plant cover changes and mortality of four dominant PFTs: C_3 grasses, C_4 grasses, C_3 shrubs, and C_4 shrubs. We hypothesized that, overall, grasses would be more sensitive to drought than shrubs, and that within these two groups, plants with C_3 photosynthesis would be more sensitive than plants with C_4 photosynthesis. There were three responses to drought observed in this experiment: 1. change in cover with mortality (C_3 grasses), 2. change in cover without mortality (C_4 grasses and C_4 shrubs), or 3. no change in cover or mortality (C_3 shrubs). In 2014, we investigated the mechanisms behind the drought tolerances of the C_4 grasses and C_3 shrubs by measuring the ecophysiological responses of three dominant species: *Pleuraphis jamensii* (C_4 grass), *Coleogyne ramosissima* (C_3 shrub), and *Ephedra viridis* (C_3 shrub). Overall, *P. jamensii* was the most sensitive to drought as evidenced by reductions in leaf water potential and photosynthesis, while neither of the C_3 shrubs showed any

responses to the drought treatments. These results provide mechanistic evidence behind the ecosystem-level effects; the drought treatments were causing stress in C_4 grasses but not C_3 shrubs. Overall, results suggest that chronic changes in water availability may alter the structure and function of the Colorado Plateau ecosystem by differentially impacting key plant functional types.

U.S. Geological Survey response to the Gold King Mine release

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Abstract: On August 5th, workers disturbed a plugged mine portal accidentally releasing 3 million gallons of acid mine water into Cement Creek a tributary of the Animas River near Silverton Colorado. The mine water has a low pH and contains high levels of metals including iron, lead, copper, and zinc. The discharge turned the Animas River orange. At Farmington, the Animas flows into the San Juan River which flows westerly into Lake Powell. The affected rivers provide domestic water to numerous communities and are extensively used for irrigation and livestock. The USGS estimated the volume of the release at just over 3 million gallons using streamgage data from Cement Creek. USGS Centers in Colorado, New Mexico, and Utah deployed field crews to collect samples and install additional monitoring instruments. Crews arrived at Farmington ahead of the plume and were able to sample before and after it passed. The USGS is responding to this event to determine 1) whether there are short-term effects of trace metal release from sediments deposited by the pulse of mining effluent, 2) whether there is a long-term increase in trace metal concentrations, above historical mining impacts, as the result of this event, and 3) whether there is a detectable impact on aquatic life. The U.S. Geological Survey has conducted multiple studies of historical mining impacts on water quality, sediment chemistry, and aquatic life in the Animas River. These studies provide background data critical in determining whether there are continued short-term releases of material subsequent to this event, or whether there is any discernable impact directly from this event over cumulative impacts from historical mining. Sediment and water chemistry collected at sites previously studied on Cement Creek and the Animas River are being resampled in the short term, and longer-term monitoring will be used to evaluate potential longer-term impacts.

Well now what? Connecting the past, present and future through national service

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Abstract: Conservation Corps programs provide opportunities for members to engage in service, job training, and teamwork through hands-on project work in the outdoors. However, the experience for most members is so much more. In this presentation, learn firsthand how the Corps life can influence members and help chart the course their life takes.

Environmental and health benefits of utilizing woody biomass for electricity generation in Arizona

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Abstract: The majority of national forests in the Southwest need fuel-reduction treatments that have not kept pace with tree growth and fuels accumulation. The harvested, small-sized trees are commonly disposed of through pile burning on the site due to their low market values. We investigated the environmental and health benefits of using small-diameter wood from the fuel-reduction treatments as a renewable energy source for electricity production to increase forest health and environmental quality. The specific objectives were to 1) compare the amount of air pollutants emitted between pile burning and a wood to energy alternative and between three types of fuel sources: wood, coal, and natural gas, 2) calculate the total external costs (damage costs) of electricity generation associated with these three types of fuel sources, and 3) assess the economic benefit (damage costs avoided) of using available woody biomass as a renewable energy source in Arizona. Our study area was within the Four Forest Restoration Initiative project area and located in the Flagstaff Ranger District of the Coconino National Forest. We projected volume removed, determined available electricity production from ponderosa pine removals, and calculated total damage costs from fossil-fueled power plants based on marginal damage costs of pollutants, density of exposed populations, and effective stack height. We investigated eight air pollutants: carbon dioxide, methane, nitrous oxide, nitrogen oxides, sulfur dioxide, particulate matter less than 2.5 micrometers in diameter, ammonia, and volatile organic compounds. Using Coconino County as an example, our results indicate that the total damage costs of pile burning small woody biomass, generating 1 MW electricity using coal, and generating same amount of electricity using removed biomass are $1.4, $0.6, and $0.5 million, respectively. We estimated the total environmental- and health-damage cost avoided by employing unutilized wood for electricity production and increasing energy sustainability at $1.5 million.

Exploring opportunities for collaboration, research, and climate change vulnerability assessment on plants traditionally harvested within Flagstaff Area National Monuments by culturally and historically affiliated tribes

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Abstract: As the National Park Service proposes a new rule allowing designated tribal members to gather and remove plants or plant parts traditionally harvested by Native American tribes, I explore opportunities to enhance collaboration with traditionally and historically affiliated Native communities and expand our understanding of climate change impacts on ethnographic resources of the Flagstaff region. A Climate Change Vulnerability Assessment of these non-archaeological cultural resources could contribute information essential to adaptive park management, refine techniques for assessing cultural resource vulnerability to climate change, and provide guidance for responding to climate impacts on natural resources collected for medicinal, ceremonial, and subsistence purposes. Several studies could provide background for such an endeavor. For example, in 2004, several affiliated Native American communities collaborated with the Bureau of Applied Research in Anthropology and Flagstaff Area National Monuments (FLAG) on a traditional use study to identify natural resources used for traditional purposes and describe their cultural importance. Additionally, in 2012 and 2014, FLAG produced Climate Change Vulnerability Assessments on archaeological resources at Wupatki and Walnut Canyon National Monuments finding a likelihood of increased adverse impacts under current climate predictions. These studies provide a solid foundation upon which to build additional collaboration, research, and climate assessment in preparation for implementing the proposed expansion of traditional plant gathering and collection rules while facilitating management of ethnographic resources in a manner that maintains cultural traditions and relationships and provides tools for the protection and stewardship of such resources.

Functional changes associated with fire regime disruption in a mixed conifer forest of Arizona

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Abstract: Mixed conifer forests of the Colorado Plateau are diverse ecosystems that provide important services such as wildlife habitat, recreation, watershed protection, and carbon sequestration. Conservation of these ecosystems depends on understanding the impacts of intensive land use, and developing management strategies that promote resilience to disturbance, particularly those expected with climate change. To characterize conditions occurring prior to Euro-American settlement of the Southwest and the onset of modern, industrial land-use practices, we used dendrochronology to reconstruct the fire history and presettlement structural characteristics of a mixed conifer forest located on the Mogollon Rim in northern Arizona. To understand functional implications of structural changes, we compared functional diversity metrics and community-weighted mean trait values between historical and contemporary forests. Complementary analyses of composited fire scar dates, point fire intervals, and natural fire rotation all indicated a frequent, surface fire regime prior to 1879. Plot reconstructions showed that the historical overstory was dominated by shade-intolerant and fire-tolerant species such as ponderosa pine, Douglas-fir, and Gamble oak. Evidence of surface fire was lacking after 1879. After this date, tree recruitment increased remarkably, and relative importance shifted toward shade-tolerant and fire-intolerant species. The historical community showed significantly higher multi-trait functional diversity as well as higher mean trait values for specific leaf area, leaf nitrogen, wood density, and bark thickness than the contemporary community. Implications of these functional changes for restoration and conservation will be discussed.

Root-associated fungal mutualists as a potential mechanism for facilitation between native willow and cottonwood in tamarisk legacy soil

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Abstract: Tamarisk (*Tamarix* spp.), an exotic and highly invasive genus of plants, has displaced native plants in many riparian areas. Tamarisk is competitively superior, in part, because it disrupts the mutualisms between native plants and beneficial root-associated fungi that aid in soil resource acquisition. This disruption can result in soils that are low in mutualistic fungi, even when tamarisk has been removed as part of native plant restoration. We examined the performance of native cottonwoods (*Populus fremontii*) and coyote willows (*Salix exigua*) grown singly and in pairs in soils previously invaded for ~60 years by tamarisk. We found that paired cottonwoods, i.e., planted within 0.3 m of a willow, were significantly taller and had significantly lower mortality than cottonwoods

grown singly. We are now examining the prevalence and species composition of root-associated fungi as a potential mechanism for this facilitation. As a pilot study, we collected root samples from the following: single willows, single cottonwoods, paired willows, paired cottonwoods, and single tamarisk (n=5 for all species combinations). We observed ectomycorrhizas (EM) on 100% of cottonwood, 90% of willow, and none of the tamarisk that have recolonized the area. Arbuscular mycorrhizas (AM) were not observed in any of the plant species, which is of interest because willows and cottonwoods typically have AM associates. Dark septate endophytes (DSE) were present in all samples of each tree species, with preliminary results indicating differential colonization in paired and single plantings. Molecular analyses are underway to determine if fungal communities are more similar on paired trees than on those planted singly. Previous studies have shown that EM are more sensitive to tamarisk invasion than AM, suggesting that patterns of root-associated fungal colonization of recovering sites may differ from those experiencing invasion. A greenhouse experiment will be conducted to further define the role of fungi in willow-cottonwood facilitation.

Plant allocation strategies and mortality of *Tamarix* spp. in response to a specialist herbivore (*Diorhabda carinulata*)

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Abstract: The northern tamarisk beetle, *Diorhabda carinulata*, was introduced in 2001 as a biological control agent for tamarisk or saltcedar (*Tamarix* spp.), a noxious plant widely distributed across western North America, but with mixed success. In some regions herbivory has resulted in extensive canopy dieback and substantial mortality in tamarisk stands, but in others mortality has been low or absent. The landscape mosaic of tamarisk mortality associated with beetle herbivory leads to the question: What is responsible for the observed variation in tamarisk mortality in response to herbivory? The primary hypothesis of this research is that the outcome of beetle herbivory is controlled by genetic variation in carbon allocation patterns within and across tamarisk populations, while landscape-scale variation in growing conditions and in the timing of defoliation contribute significantly to probability of mortality. A multi-tiered protocol is being used to characterize plant physiological responses to herbivory, including tightly controlled experiments using state-of-the art growth chambers and a common garden containing a range of tamarisk genotypes from multiple source populations, various field surveys and genetic analysis of tamarisk hybrid introgression. To date, specific findings suggest that: 1) fast growing plants with high radial growth rates are more susceptable to herbivory than slower growing plants (presumably as a consequence of reduced labile carbon storage), 2) rates of canopy dieback and mortality are correlated with edaphic condition and water-related stress, and 3) rates of dieback and mortality are not related to hybrid introgression between the two major parent species in North America, *T. ramosissima* and *T. chinenses*. Results from the current study address how ecological processes interact with a widespread biocontrol program in managed riparian forests of the arid western US where water resources and riparian habitat conservation are a critical concern.

The importance of monitoring the impacts of wildfire in a changing climate

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Abstract: As the pace of climate change continues to intensify, wildfire will likely play an important role in shaping the composition and structure of Southwest ecosystems. Frequently, our assessments of wildfire and its effects to resources are qualitative (i.e., this looks great, this looks horrible). This presentation will highlight important discussion points from the prior presentations regarding adaptations to a changing climate and will make suggestions on how to move the monitoring component of adaptation forward. Adaptively managing, by definition, must include monitoring, so that as changes occur, we will have a detection system in place and can modify management as necessary. Monitoring plays a key role in understanding, predicting and evaluating pre- and post-fire conditions. We will outline suggested roles and responsibilities for researchers and managers in developing a monitoring system. We will also provide a conceptual framework for monitoring the impacts of fire as well as highlighting the need for monitoring. We will use examples of existing monitoring systems, including their strengths and weaknesses, and will make suggestions of how these can be modified and used to make more informed decisions regarding the sustainability across agency on our public lands.

GPS telemetry detection rates: addressing the probability of successful acquisitions for bias correction

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Abstract: Wildlife studies utilizing Global Positioning System (GPS) telemetry rarely result in 100% fix success rates (FSR). Many assessments of wildlife resource use do not account for missing data, either assuming data loss is random or because a lack of practical treatment for systematic data loss. Several studies have explored how the environment, technological features, and animal behavior influence rates of missing data in GPS telemetry, but previous spatially explicit models developed to correct for sampling bias have been specified to small study areas, on a small range of data loss, or to be species-specific, limiting their general utility. Here we explore environmental effects on GPS fix acquisition rates across a wide range of environmental conditions and detection rates for bias correction of terrestrial GPS-derived, large mammal habitat use. We also evaluate patterns in missing data that relate to potential animal activities that change the orientation of the antennae and characterize home-range probability of GPS detection for 4 focal species: cougars (*Puma concolor*), desert bighorn sheep (*Ovis canadensis nelsoni*), Rocky Mountain elk (*Cervus elaphus* ssp. *nelsoni*), and mule deer (*Odocoileus hemionus*). We found topographic exposure combined with tall over-story vegetation were the most influential factors on FSR. Model evaluation showed a strong Pearson's correlation coefficient (0.924) between observed and predicted FSR and showed little bias in predictions. The model's predictive ability was evaluated using two independent datasets from stationary test collars of different make/model, fix interval programing, and placed at different study sites. No statistically significant differences (95% CI) between predicted and observed FSRs were found, suggesting that changes in technological factors have minor influence on the model's ability to predict FSR in new study areas in the southwestern US. Animal preference or avoidance of these environmental features is yet another factor in FSRs of animal deployed collars.

The importance of recursive movements in identifying behaviors for a food caching predator, *Puma concolor*

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Abstract: Wildlife GPS telemetry is providing a wealth of information on animal locations across space and time and likewise a variety of approaches have been developed to interpret these often large and complicated datasets. Investigations of random search behavior versus directed movement has dominated the movement ecology literature, while investigations into cognitive processes related to movement are few. Many modeling approaches focusing on directed versus searching movement rely on correlations between turning and velocity as well as a degree of statistical stationarity in movements for periods of time to define states. Though these approaches may work well for grazing foraging strategies in a patchy landscape, species that do not spend a significant amount of time searching for dispersed food items, but instead are efficient in obtaining food items, particularly large concentrated items, and/or return regularly to food caches, and/or den sites may have movements that are difficult to fit into the state-space or correlated random-walk modeling frameworks. Here we explore the use of four-movement metrics in a partial sum index of movement to quantify circadian movements, foraging activities, reproductive behavior, and seasonal movements related to changes in prey availability. We use cougar, *Puma concolor*, GPS telemetry datasets to explore quantification of site recursion and site fidelity and find them to be important metrics in describing cougar movement over the landscape. The use of indices has been limited in movement ecology, but show promise here for identifying behaviors in species that frequently return to particular locations for various reasons such as food caches, watering, or dens, and highlights the roles that memory and cognitive abilities play in movements of these highly intelligent top predators.

Fire moss as a tool for post-wildfire ecosystem restoration

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Abstract: Increasingly large and severe fires across the western United States are creating difficult restoration challenges for land managers to address. Despite the wide usage of current fire restoration techniques, many studies have shown little to no benefit when compared with a no action alternative and some studies have even shown negative impacts, such as the spread of invasive species. The use of select disturbance colonizing mosses or "fire moss" is a promising alternative restoration tool that has never been investigated for use in post-fire environments. Fire moss refer to the moss species *Funaria hygrometrica*, *Ceratodon purpureus*, and *Bryum argenteum*, which have been found colonizing post-fire environments, worldwide, within several months to years following a fire. Many mosses possess traits that make them ideal candidates for restoration purposes such as, universal distribution, high desiccation tolerance, asexual growth ability, water holding capacity, and soil aggregation ability. Fire moss has also been observed to have no negative effects on the return of native vascular plants. Harnessing their restoration power, finding ways to bring them to additional critical post-fire sites, and hastening their arrival on scene could provide a valuable restoration service not currently being utilized. Our research addresses the basic questions surrounding the effectiveness of fire moss as a restoration tool. Greenhouse experiments are in progress to determine optimal water and fertilization regimes for growth, and to determine if the presence of ash aids the cultivation of fire moss. Field experiments are being conducted to identify appropriate application techniques for using fire moss on restoration sites. Initial greenhouse results show greater moss growth under five and seven day per week watering regimes. Additionally, the moss *Bryum argenteum* constituted a larger part of overall moss growth under the five day per week watering regime than under the seven day per week watering regime.

Response of riparian vegetation to the Minute 319 environmental pulse flows to Mexico: greenup and evapotranspiration by remote sensing

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Abstract: During the spring of 2014, 130 million cubic meters of water were released from Morelos Dam on the lower Colorado River, allowing water to reach the Gulf of California for the first time in 13 years. A year later, we continue to analyze the effects of this historic experiment, the result of a new U.S.-Mexico agreement. Based on MODIS and Landsat 8 satellite imagery and field observations, initial findings show an overall positive response by vegetation (i.e., increased greening) to the pulse flows within the river's riparian corridor. This reverses an overall decline in the normalized difference vegetation index (NDVI) and evapotranspiration (ET) since the last major flood in 2000. In addition to the current status of this experiment and effects of these pulse flows, we will present a conceptual model of the role of groundwater and surface flows in maintaining the riparian corridor in Mexico. Based on preliminary findings, pulse flows could be an effective tool for restoring the lower Colorado River's riparian zone.

Impacts of roads on gene flow and genetic diversity of two kangaroo rat species

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Abstract: In the last 100 years, roads have proliferated across the earth to connect human settlements. Meanwhile, habitat for the vast majority of wildlife species has become highly fragmented. Habitat fragmentation prevents wildlife movement, with severe effects, including preventing access to resources and mates, as well as limiting gene flow across landscapes. When gene flow is limited among individuals that are spread across large areas, the effects could include increased genetic differentiation. An additional, but less studied, potential effect is the spatial distribution of genetic diversity in neighborhoods across landscapes that are divided by roads. We studied genetic variation among individuals of two species of kangaroo rats (*Dipodomys deserti* and *D. merriami*) in Sonoran desert ecosystems divided by frequently traveled highways. We collected ear tissue samples from *D. deserti* and *D. merriami* individuals distributed across two 800-hectare plots, and we collected microsatellite data for both species. We also modeled scenarios of kangaroo rat movement across natural habitat and road. Our analyses indicated genetic differentiation and inbreeding, indicative of a barrier effect. Our current work involves determining genetic diversity across the populations. We are also generating models of kangaroo rats in an individual based, spatially explicit computer simulation framework to make inferences about impacts of roadkill and road avoidance on these species.

Using Hydrologic Landscape Classification to Evaluate the Hydrologic Effects of Climate in the Southwestern United States

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Abstract: Hydrologic landscapes (HLs) have been an active area of research at regional and national scales in the United States. The concept has been used to make spatially distributed assessments of variability in streamflow and climatic response in Oregon, Alaska, and the Pacific Northwest, and is currently being applied to the southwestern U.S. The HL classification process analyzes the primary drivers (climate, seasonality, aquifer permeability, terrain, and soil permeability) that are associated with large scale hydrologic processes (storage, conveyance, and flow of water into or out of the watershed). Hypotheses regarding the dominant hydrologic pathways derived from the HL classification system are tested to corroborate or falsify these assumptions. Changes in climate are more likely to affect certain hydrogeologic parameters than others. For instance, changes in climate may result in changes in the magnitude, timing, or type of precipitation (snow vs. rain). Air temperature and the seasonality of dominant hydrologic processes may also be impacted. However, the effect of these changes on streamflow will depend on soil and aquifer permeability. In this presentation, we summarize 1) the HL classification methodology and 2) how HL methods are being used to examine regional vulnerability to climate based on climate model outputs for past and future conditions.

Climate change and wetlands on the Colorado Plateau: rebuilding wetlands to withstand a drier future

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Abstract: Natural wetlands impacted by the construction of deep ponds and ditches can be rebuilt to withstand the effects of climate change. Repaired wetlands can increase the quantity and quality of water available to wildlife and livestock. Our repairs focus on stopping leaks made by humans in natural wetlands. The construction of ditches and stock tanks has occurred in numerous natural wetlands across the Colorado Plateau in northern Arizona. Duck Lake is a 55 acre ephemeral wetland on the Williams Ranger District of the Kaibab National Forest. The wetland was historically altered in the 1930s by the excavation of a 15-foot deep stock pond. In 1989, a series of ditches over 1,300 feet in length were created by using explosives in an effort to improve waterfowl habitat. However, instead of creating deep pools that could be used by ducks, the hydro-period of Duck Lake was shortened due to fracking of the clay underlying Duck Lake. Drought spread across the region in the 1990s, turning conditions from bad to worse. The ditches draining Duck Lake were repaired in 2014 in a major partnership project. This was done by removing topsoil from each ditch, reshaping each ditch into a shallow basin with gradual slopes, and then lining each basin with over 24-inches of compacted clay. Excess soil was used to create nesting mounds adjacent to shallow water wetlands made from the ditches. Natural wetlands in other locations that were compromised by the construction of deep ponds are being repaired by placing thick layers of compacted clay in the bottom of leaky ponds. In addition, complexes of smaller wetlands with longer hydro-periods are being created in historically modified wetlands. The wetlands with longer hydro-periods are being made by compacting areas of loose-clay texture soils. The compacted clay reduces water soaking into the ground, lengthening hydro-periods to benefit a diversity of amphibians, birds, and crustaceans. Precipitation readily collects in these shallow basins containing the compacted clay soils. These modifications are allowing us to maintain water in wetlands under drought conditions. The techniques can be applied to numerous other wetlands modified by humans across the Colorado Plateau.

Long-term arthropod pitfall study reveals selective community resilience along an elevational gradient in northern New Mexico

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Abstract: Arthropod community assemblages play a vital role in the health of an ecosystem. Changes in an arthropod community directly affect the plants and animals of an area through a shift in food resources and community services. Many studies have linked arthropod community structure to an ecosystem's elevation and vegetation community, annual precipitation and temperature range, and the incidence and intensity of fire. Arthropods have also been shown to respond to environmental changes more rapidly than vertebrate indicator species. Thus, rapid changes observed in arthropod community structure can drastically shift the function and recovery of an ecosystem. There are very few studies that examine the response of arthropod communities to higher temperatures, shifting vegetation regimes, and fires in Southwestern forests, where environmental variables are reshaping ecosystems at a rapid rate. We utilized a long-term arthropod diversity dataset collected in Bandelier National Monument, New Mexico to examine how environmental variables, vegetation type, and fire influence arthropod community assemblages across elevational gradients. The data collected in Bandelier National Monument encompasses three dominant vegetation types and provides an in-depth look at the long-term relationship between fire, vegetation, and arthropod communities. We conducted a preliminary investigation to correlate

large-scale environmental processes to smaller scale shifts in ecosystem health and function by examining arthropod community assemblage and biodiversity as a function of environmental processes including annual precipitation, average summer temperature, mean vegetation type, and the fire regime at high, medium, and low elevation pitfall sites. Our exploratory analysis of this long-term study sought to establish the usefulness of arthropod community assemblage data as a tool for land managers to identify and respond to fire-initiated shifts in the ecosystem. This could give land managers the opportunity to respond to disturbances more quickly than typical vegetation or large mammal indicators allow.

Estimating landscape resistance from habitat suitability

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Abstract: Least-cost models are used to identify areas that support long-distance movement and therefore should be conserved as wildlife corridors. These models rely on estimates of landscape resistance to long-distance movement. Resistance is usually calculated as a linear function of habitat suitability, but two recent studies suggest a nonlinear function may be more appropriate. Suitability is typically estimated in one of three ways (in order of increasing cost: expert opinion, resource selection functions of animal locations, or step selection functions of animal movements within the home range). Few studies have compared suitability estimates against observed long-distance movements to determine whether the more expensive procedures perform better. We used linear and nonlinear functions to convert all three types of habitat-suitability estimates into resistance for two species in Arizona, namely elk (*Cervus canadensis*) and desert bighorn sheep (*Ovis canadensis nelsoni*). We evaluated the resulting resistance maps on an independent set of observed long-distance movements in the same study areas. A negative exponential function best described the relationship between habitat suitability and resistance values, indicating that long-distance movers readily travel through moderately suitable areas and avoid only the least suitable habitat. For elk (a habitat generalist), all three suitability estimates performed about the same as chance. For desert bighorn sheep (a habitat specialist), all three suitability estimates performed better than chance, and resource and step selection functions outperformed expert opinion. Resistance to long-distance movement may be a negative exponential function of habitat suitability for most species. Elk (and probably other habitat generalists) are of little utility in a multi-species corridor design. For desert bighorn sheep, any of the habitat-suitability estimates can inform corridors. Studies of additional habitat specialists are needed to quantify the tradeoff between cost and reliability of different suitability estimates.

The effects of restoration treatments on richness, diversity, and abundance of ungulates in southwestern Colorado

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Abstract: Warm-dry mixed conifer forests offer a suitable habitat to a wide array of diverse plants and wildlife. Historically, these forests were subjected to frequent low-intensity fires. The stability created by frequent burning maintained a heterogeneous, fire-tolerant stand structure. However, fire suppression and livestock grazing first introduced in the late 1800s has been continuously shifting warm-dry mixed conifer forests toward a primarily homogeneous landscape. Anthropogenic effects can be seen in the increased tree density and shifts towards shade tolerant mesic species. Many large ungulates rely on the nutritional resources essential to mammalian development that certain plant species offer. Resources diminish over time, along with the wildlife population across different habitats when basic needs for survival are not met. An open habitat provides a higher abundance of understory food resources, while dense stands provide protection through canopy cover. There is a need to quantify how the long-term changes in forest dynamics and forest restoration treatments in warm-dry mixed conifer have impacted the ungulate populations in southwestern Colorado. We will quantify species richness and abundance of ungulates across three replicated restoration treatments (untreated control, thin/burn, burn alone) in warm-dry mixed conifer in the San Juan Forest near Pagosa Springs, Colorado, using motion-sensor cameras and scat counts (4 blocks x 3 treatments x 4 plots/treatment), for a total of 48 motion cameras and scat plots. We will also quantify which 2015 growing season periods (early, mid, late) and times of day ungulates utilize different habitats. We hypothesize that there will be the highest species richness and abundance of ungulates in the thin/burn treatment sites, which favor ecological diversity by replicating historical conditions. The response of wildlife to restoration treatments will be valuable in making future sustainable forest restoration and wildlife management decisions.

A century of change in Southeastern Utah: What has allowed some ecosystems to thrive while others collapsed?

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Abstract: The distinct physiography of the Colorado Plateau has created a hotspot of biodiversity and rich cultural and ecotourism resources. Natural habitat fragmentation, an arid climate, and abundant extractable resources combine to create a high degree of vulnerability to human impacts and changing climate. Land-use and climatic events that occurred in the 20th century, including intensive and extensive grazing by domestic livestock and a multidecadal drought the 1940s to 1970s, have left a legacy on plant and soil communities of the Colorado Plateau. In response to these drivers of change, some local ecosystems collapsed and been invaded by exotic species, while others have remained almost unchanged. More recently, drought in the early 21st century has brought further changes including dramatic regional pinyon die-off. The IPCC predicts drought on the Colorado Plateau will intensify in the coming decades, with increasing potential for further landscape-level vegetation change. We use historic rephotography from Southeastern Utah from the past 60-100 years to understand how past drought and land use, particularly grazing, continues to affect the landscape. Approximately 1,300 photo locations span most major regional ecosystem types, soil types, microclimates, and land use histories. Vegetation change measured in the photos is compared to LANDSAT time-series data, soil maps, and field measurements to identify important climatic and edaphic characteristics of sites that have been vulnerable or resilient to drought and grazing pressure. These characteristics can be used to inform conservation and management decisions, with more or less likelihood of successful response to intervention and restoration, and sites prone to type conversion under future climate and management scenarios.

Science-based land-use planning and broad community support leads to an integrated approach to protecting the Sonoran Desert in Pima County, Arizona

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Abstract: Like many regions in the Southwest, the Sonoran Desert in Pima County, Arizona is threatened by a growing population, an expanding roadway network, climate change, and an ongoing drought. All of these threats have resulted in increasingly fragmented wildlife habitat, decreasing biodiversity, and a reduction in water resources. In response to this, Pima County has prioritized science-based urban land-use planning for the past seventeen years. By basing land-use decisions on the best available biological science, Pima County is making significant strides towards the mitigation of the many current threats to the local Sonoran Desert ecosystem. In 1998, Pima County adopted the groundbreaking Sonoran Desert Conservation Plan (SDCP), a nationally-recognized regional conservation plan that prioritizes the protection of Pima County's most biologically-rich lands and directs development to the most appropriate areas. Conservation efforts under the umbrella of the SDCP have included the protection of over 200,000 acres of open space lands with local bond funds, the development of a Multi-Species Habitat Conservation Plan to protect endangered desert species, the incorporation of a science-based Conservation Lands System into decisions about public and private development projects, and the protection and re-connection of local wildlife linkages through open space purchases and the construction of large-scale wildlife crossings. Community support for all of these initiatives has remained strong over the years, along with broad backing from local elected officials. In addition, local non-governmental organizations continue to play a critical role in keeping Pima County and local municipalities focused on the goals and vision of the SDCP. Challenges ahead include passing a new bond election in November 2015 that includes $95 million for more open space purchases, raising additional funds for wildlife linkage infrastructure, and continuing to work constructively with private property owners on including connected natural open space in their projects.

Little bugs, big data, and Grand Canyon: light trapping by river rafters yields insights into Colorado River aquatic insect dynamics

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Abstract: Glen Canyon Dam has greatly altered the discharge and temperature regimes of the Colorado River in Grand Canyon, which may explain why only two aquatic insect taxa—midges and blackflies—are common in this river segment. In 2012, we initiated a citizen science project in collaboration with river rafters to quantify insect emergence for the 386 km Grand Canyon segment of the Colorado River. Rafters conducted standardized light trapping each night in camp, yielding an unprecedented emergence dataset (750+ samples each year). This dataset has elucidated insect emergence patterns related to dam operations, including pronounced decreases in midge emergence (catch per hour) coincident with abrupt increases in regulated discharge. Longitudinal patterns of emergence for midges were sinusoidal and appear related to the time of day when low versus high water associated with hydropeaking waves occurs in different reaches. Specifically, we observed higher and lower rates of insect emergence in locations of the Canyon where afternoon flows represented the daily minima and maxima, respectively. Because mating and egg-laying by aquatic insects often occurs in late afternoon/evening, these sinusoidal patterns in emergence may reflect differences in the quality of the egg-laying environment for aquatic insects. These results indicate that frequent hydropeaking may represent a bottleneck that limits aquatic insects by causing high mortality at the egg stage. Our findings suggest that aquatic insect assemblages might be enhanced through changes in flow management alone, even without more natural temperature regimes.

Bridging the gap: science and art collaboratives for more holistic communication

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Abstract: Education and engagement are key elements to successful conservation efforts. For many of our community members, the science of climate change and landscape-scale ecological processes like fire are intimidatingly complex. Social science has shown that humans respond to overwhelming, or contradictory, information by dismissing it. The science and management communities face a difficult task of relaying pivotal information about our changing ecosystems to a wider community that is perhaps unable or unwilling to delve into scientific journals or management publications. We are experimenting with art and science partnerships as a potential way to communicate with the public about important topics. Art can cultivate engagement by fostering our shared sense of place and attachment to the unique landscapes of the Colorado Plateau. In an effort to make the scientific information and management realities of changing ecosystems more accessible and pertinent to our wider communities, LCI and the Olajos-Goslow Endowment, along with a few crucial partners, have created a number of science-art collaborative projects. In doing so we hope to a) facilitate the creation of art inspired by science and management that captures the complexity of contemporary ecological changes, b) infuse creativity and fresh perspective into the work that our scientists and managers do, and c) increasingly bridge the divide between the science and art communities so that both these groups become more holistic in their approach to their respective fields. LCI and the Olajos-Goslow Endowment have been instrumental in three such exhibits to date: The Burnished Landscape and Uplift: Conservation on the Plateau, both featuring the art of artist Kate Aitchison, and Fires of Change, our ongoing collaborative exhibit partnered with the Southwest Fire Science Consortium and Flagstaff Cultural Partners.

Ecosystem recovery following flow restoration in Fossil Creek, Arizona

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Abstract: Disruptions to natural flow regimes are the most common causes of river and stream impairment worldwide, though restoration efforts have rarely explored how and when stream ecosystems can recover after reinstating natural flows. A diversion dam constructed near the spring-fed headwaters of Fossil Creek, Arizona diverted approximately 95% of base flow from 1909 until 2005 when the dam was decommissioned. We quantified the in-stream responses of ecosystem metabolism and dissolved nitrogen dynamics to the restoration of natural stream flow in this travertine-forming river. The geochemical process of travertine deposition increased up to 100-fold in the 11-km study reach after flows were reinstated. Restoration of flow and the re-establishment of travertine terraces and pools resulted in dramatic increases in gross primary production and nitrogen uptake that were comparable to rates measured in an upstream, reference reach and other southwestern streams. Community respiration did not change, indicating that oxidation of organic matter in the river shifted from heterotrophic to autotrophic sources. Concurrent field studies confirmed that these rapid (<3 years) and sustained (≥6 years) changes in the fundamental biogeochemical fluxes of the Fossil Creek ecosystem propagated throughout the aquatic food web. The near-complete recovery of travertine deposition, primary production, and nitrogen uptake in Fossil Creek is encouraging for the practice of river restoration, and reiterates the primacy of the natural flow regime in shaping stream ecosystems.

Using conceptual ecological models as a framework to guide decision making for the LCR MSCP

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Abstract: The Lower Colorado River Multi-Species Conservation Program is developing conceptual ecological models (CEMs) for species that are covered under the Habitat Conservation Plan. CEMs are widely recognized and utilized in natural resource management and structured decision making, as they provide a clear framework for guiding management actions. CEMs were developed for the southwestern willow flycatcher, yellow-billed cuckoo, and razorback sucker at the end of 2014. Each CEM comprises a collection of hypotheses concerning species' life cycles, species' habitat requirements and limitations, the factors that control the abundance, spatial and temporal distribution, quality of these habitat conditions, and the causal relationships among them. The level of understanding of these elements and how they relate vary, with a high level of certainty in some cases, and a great deal of uncertainty in others. CEMs collectively and individually provide managers with a record of 1) the current knowledge and level of uncertainty, 2) critical areas of uncertain or conflicting science, 3) crucial attributes to use while monitoring and predicting the effects of experiments and

management actions, and 4) how characteristics of a resource are expected to change as a result of altering its shaping/controlling factors, including those resulting from management actions. Through the development and implementation of the CEMs, the LCR MSCP will reduce costs of research and monitoring and improve its science-based management in conservation areas.

Causes and patterns in boom and bust cycles of the rainbow trout population in the Glen Canyon Dam tailwater as determined by an intensive mark-recapture study

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Abstract: The reach of the Colorado River from Glen Canyon Dam (GCD) to Lees Ferry supports a large non-native rainbow trout population and a renowned trout fishery. We PIT-tagged nearly 60,000 trout in the Lees Ferry reach between November 2011 and July 2015 and recaptured 4,000 marked fish. Catch and mark-recapture data were used in a Jolly-Seber model to estimate abundance, juvenile recruitment, survival, and growth by 50-mm size class. A large number of juveniles were produced in 2011 owing to high and steady releases from GCD over spring and summer, leading to a peak abundance of nearly 1 million trout across all size classes. Juvenile fish produced in 2011 grew into large size classes and became available to the fishery by late 2012 and in 2013, leading to exceptionally high catch rates at that time. Total abundance declined over the 4-year study period due to natural mortality to its current abundance of approximately 150,000 trout. Trout growth and condition were both high in 2012, but declined in 2013 and 2014 as the bioenergetic demand of the large 2011 cohort outstripped the available food supply. Very poor condition of larger trout led to a decrease in their survival rate. Cyclic patterns in catch rates and condition of trout in the Lees Ferry fishery can likely be avoided by limiting the magnitude of large recruitment events that appear to be driven by high flows. The sampling protocol and modelling approaches developed as part of this project provides a much more resolute picture of population dynamics for rainbow trout in the Lees Ferry reach relative to the current monitoring program. A large scale mark-recapture effort, such as our sampling protocol, is the only means of addressing questions concerning the trout population in the Lees Ferry reach posed by the Glen Canyon Dam Adaptive Management Program.

The Bosque Ecosystem Monitoring Program: how young citizen scientists are contributing to the Rio Grande's health

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Abstract: Citizen Science is a burgeoning field and is an exceptional way for citizen volunteers to build direct connections to their local environment and in so doing, increase public understanding of a complex ecosystem as well as fulfill essential research needs. The Bosque Ecosystem Monitoring Program (BEMP) of Albuquerque, NM is a joint effort coordinated by the University of New Mexico's (UNM) Long Term Ecological Research (LTER) network and The Bosque School. BEMP's monitoring research is conducted by student and citizen volunteers along the Middle Rio Grande and its associated riparian forest, known locally by its Spanish name 'bosque'. Citizens accept responsibility for gathering meaningful, long-term data related to the overall condition of the forest ecosystem located along New Mexico's most prominent river. Primary program start up funding was through the National Science Foundation, and BEMP has now generated a robust data-set with 17 years worth of monthly monitoring data points. The program consists of a series of 30 research sites along 560 km (350 miles) of the middle Rio Grande. Monitoring activities are synchronized between sites with volunteers (primarily grade K-12 students and their teachers) collecting long-term data on: 1) core weather data, 2) shallow groundwater table depth, 3) monthly precipitation, 4) surface active arthropod activity, and 5) measurements of forest production, including leaf litter biomass/plant productivity, tree diameter and growth rates, and woody and herbaceous plant distribution. Data gathered by volunteers is incorporated into larger UNM sponsored research efforts and is shared with other researchers, as well as land and other natural resource managers including the US Army Corps of Engineers and the US Fish and Wildlife Service. In April of this year, BEMP received the NM Governor's Award for Land and Ecosystem Stewardship. This program is an excellent model of thoughtful resource conservation through citizen science for other southwestern rivers and watersheds.

Pollinator richness and abundance in different fire restoration treatments of a warm/dry mixed conifer forest, southwestern Colorado

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Abstract: As the climate of the southwestern United States continues to have increased temperature and decreased precipitation, the forests of this region are at risk for large scale, stand-replacing forest fires. These types of fires put the ecosystem at risk for vegetation type conversion, which would impact pollinator species. Bees are a pollinator sensitive to changes in forest stand struc-

ture. Current forest conditions are affecting bee populations negatively due to dense forest vegetation, which reduces colonization sites. To study the effects of forest restoration treatments, we will use three different treatments (control, thin/burn, and burn only) in warm, dry mixed conifer in southwestern Colorado replicated four times. We will quantify the effects of forest restoration treatments during the summer of 2015, seven years post fire with six pollination traps established along five permanently located 50 m transects (4 blocks x 3 treatment units x 5 transects/unit). Previous research has illustrated that thinning and prescribed burning is the most effective treatment at increasing pollinator richness and abundance due to increased understory vegetation. Our research objectives are: 1) to compare richness/abundance of pollinators in three forest restoration treatments in warm, dry mixed conifer, 2) quantify if there are differences in pollinator communities and if there are indicator species that are uniquely associated with one of the treatment types, and 3) observe temporal changes in pollinators across the growing season (early, mid, late). We hypothesized that pollinator richness/abundance will be significantly higher in the thin/burn treatments with higher bee diversity and that control and burn only treatments will have relatively similar abundance/richness of pollinator species with higher numbers of pollinator generalists (i.e. flies) due to closed forest canopy structure. Potential management implications of our research is to illustrate that more open stand structure increases landscape forest structure heterogeneity and thus pollinator abundance and diversity.

Combining species distribution models and predicted disturbance to select native plant species for restoration use

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Abstract: Identifying which native species to evaluate is a basic but critical step in the development of native plant materials for restoration. Species selection is especially important given the extreme resource limitations that managers face and the finite number of species and lines that the seed market can sustain. We present a method for prioritizing species for development that utilizes species distribution models (SDMs) and spatial data layers that are inferred to predict where restoration species may need to be used. This method is applicable at varying spatial scales, explicitly considers match between predicted habitat suitability and likelihood of restoration need, and can be used to rank, quantitatively, a pool of species based on their expected future utility. We applied this approach to eleven native plant species identified by managers as useful for restoration on the Colorado Plateau (CP). First, each species was ranked based on the order of their predicted probability of occurrence for each cell in a raster of CP-extent. We then intersected these rankings with spatial layers that may predict future disturbance, i.e., past seeding treatments, Landfire vegetation disturbance, and oil and gas leasing areas. By calculating the area over which each species is most likely to occur and identifying which species have broadest match with a given disturbance, relative to the other species, we provide quantitative, disturbance-specific criteria for prioritizing species for evaluation, commercial increase, and/or wildland collection. While the resolution of the disturbance layers we used was not ideal, bootstrapped intersection computations suggested that the results are reasonably robust. This method can be applied to any species by predictor combination for which SDM and disturbance rasters are available. Importantly, the approach can also be merged with "seed zoning" approaches to compare the relative utility of multiple intraspecific partitions.

Native grass seedlings differ greatly in establishment ability in dry, invaded field sites

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Abstract: Seeds used for restoration in disturbed sagebrush steppe communities face many challenges to establishment, including highly variable precipitation and competition with invasive plants. Because limiting resources in these sites are primarily belowground, root allocation and root morphology are likely to be very important for successful seed establishment. Using a combination of greenhouse and field experiments, we asked whether it is possible to identify specific root strategies that improve establishment rates of native perennial grass seedlings in dry, disturbed areas. We described early seedling traits of *Elymus elymoides* collected from 35 populations from Nevada, Oregon, and California, and then planted these collections across five restoration sites in Nevada and Oregon. There was a high degree of variation in root traits among populations, and very strong links between seed and seedling root traits (including root length of 10-day old seedlings, emergence phenology, and seed size, among other traits) and performance in the field. While establishing plants from seed in the driest cold desert communities will always be challenging, these results demonstrate that is possible to identify seedling strategies that improve our chances of restoration in dry, invaded sites.

Germination and growth of native and invasive plants following dieback of *Tamarix* resulting from biological control

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Abstract: Introductions of biocontrol beetles in the genus *Diorhabda* are causing dieback of exotic *Tamarix* species in riparian zones across the western U.S., yet factors that determine plant communities that follow *Tamarix* dieback are poorly understood. *Tamarix*-dominated soils are generally higher in nutrients, organic matter, and salts than nearby soils, and these soil attributes may influence the trajectory of community change. To assess physical and chemical drivers of secondary invasion after beetle-induced *Tamarix* dieback, we conducted separate germination and growth experiments using soil and litter collected beneath defoliated *Tamarix* trees. We focused on a number of treatments, including fertilization and varying litter depth, that assessed how altered physical and chemical environments affected native and exotic plant germination and growth. Focal species were two native (*Aristida purpurea*, *Sporobolus cryptandrus*) and two common invasive exotic plants (*Acroptilon repens*, *Bromus tectorum*), planted alone and in combination. Nutrient, salinity, wood chip, and litter manipulations examined how *Tamarix* litter affects the growth of other species in a context of riparian zone management. Generally, litter and wood chip treatments delayed and decreased germination; however, a thinner layer of wood chips increased growth slightly. Time to germination was lengthened by most treatments for natives, was not affected in the exotic plant *Acroptilon*, and was sometimes decreased in *B. tectorum*. *Tamarix* litter, *Tamarix* litter leachate, and fertilization with inorganic nutrients increased growth in all species, but the effect was larger in exotic plants. Salinity of 4 dS/m benefitted *Acroptilon*, which also showed the largest positive responses to added nutrients. As natives showed only small positive responses to litter and fertilization and large negative responses to competition, these data suggest *Acroptilon* and *Bromus* are likely to perform better than native species in riparian zones following *Tamarix* dieback.

Testing four low-cost petroglyph sketching methods at Petrified Forest National Park, Arizona

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Abstract: The preservation and protection of cultural resources forms a significant portion of the National Park Service's mission. While other types of archaeological sites may be excavated or protected in place underground, rock art sites are exposed to natural and human-caused destructive impacts. Complete and accurate documentation of rock art is necessary to protect the information provided by the images for current and future research and management purposes. Land managers often express a concern about the amount of time required to document rock art sites, and current low-cost, easy to employ, rock art sketching methods exhibit significant differences in the degree of accuracy, amount time required, and associated costs. During the course of a summer internship at Petrified Forest National Park in 2014, I conducted preliminary testing of four low-cost petroglyph sketching methods to aid the park in developing a standardized rock art recording strategy. The methods tested include the use of two rulers, a string grid, tracing a photo on acetate, and digitally tracing a photograph on an iPad. Ten sketching tests of each method conducted at two sites within Petrified Forest National Park and at Picture Canyon in Flagstaff, Arizona, revealed patterns in the amounts of time and accuracy associated with each method. The results of the preliminary tests suggest that the acetate tracing method produces the most accurate results in the least amount of time, but is not suitable for all recording situations and conditions. The results of the tests formed the framework for developing an adaptable multi-scalar rock art recording approach sensitive to changes in the needs, time-constraints, required materials, and budget of future rock art recording projects conducted at Petrified Forest National Park.

Repeated landscape-scale treatments following fire suppress a non-native annual grass and promote recovery of native perennial vegetation

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Abstract: Invasive non-native species pose a large threat to restoration efforts following large-scale disturbances. *Bromus tectorum* (cheatgrass) is a non-native annual grass in the western U.S. that both spreads quickly following fire and accelerates the fire cycle. Herbicide and seeding applications are common restoration practices to break the positive fire-invasion feedback loop and recover native

perennial species, but their interactive effects have infrequently been tested at the landscape-scale and repeated in time to encourage long-lasting effects. To guide effective management practices following large disturbances, there is a tremendous need to assess the successes and failures of landscape-scale restoration treatments. In this study, we determined the efficacy of repeated post-fire application of the herbicide imazapic and seeding treatments to suppress *Bromus* abundance and promote perennial vegetation recovery. We found that the selective herbicide reduced *Bromus* cover by ~30% and density by >50% across our study sites, but had a strong initial negative effect on seeded species. The most effective treatment to promote perennial seeded species cover was seeding them alone followed by herbicide application 3 years later when the seeded species had established. The efficacy of the treatments was strongly influenced by water availability, as precipitation positively affected the density and cover of *Bromus*; soil texture and aspect secondarily influenced *Bromus* abundance and seeded species cover by modifying water retention in this semi-arid region. Warmer temperatures positively affected the nonnative annual grass in the cool-season, but negatively affected seeded perennial species in the warm-season, suggesting an important role of seasonality in a region projected to experience large increases in warming in the future. Our results highlight the importance of environmental interactions and repeated treatments in influencing restoration outcomes at the landscape scale.

Data driving decisions about fire management

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Abstract: A presentation on a wildfire briefing led by the Grand Canyon National Park (GRCA) Fire Management Officer (FMO) and the GRCA Superintendent (hereafter referred to as the Agency Administrator) utilizing fire history, burn severity, fuels, and loading data from fire effects plots, fuel moisture data, vegetation data, fire behavior modeling, habitat and sensitive resource mapping data, and weather forecasts. The FMO will present the work and technology behind the data, and how it is presented at the briefing, and then the AA will present how he interprets the data and the roll it plays in making a management decision about the fire. The FMO and AA will use a past wildfire as an example to describe each portion of the briefing and the data used to support the decision.

Looking to our past, working together for our future: Hopi Tribe/Kaibab National Forest partnership on land management

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Abstract: In 2014, the Kaibab National Forest implemented a new forest land management plan that was developed in close consultation with area tribes. Due to the ecological and cultural importance of natural springs to tribal communities, restoration and management of natural springs became one of four priority areas in the new plan. During the summer of 2014, the Hopi Tribe, Kaibab National Forest, and other partners collaborated on the first natural spring restoration project implemented under the new plan. For one week, approximately 40 Hopi technical specialists, tribal elders, and youth worked with Forest Service staff and partner organizations to restore hydrological function at two springs on the North Kaibab Ranger District. Both springs were restored using traditional Hopi techniques to maximize water flow and retention. During the week, Hopi cultural advisors shared traditional ecological knowledge about the appropriate management of water and springs. The Forest and Tribe are conducting long-term monitoring of these springs to assess the ecological benefits of incorporating traditional techniques in natural spring restoration projects. Based on that data, such techniques may be integrated into future spring management plans. The Hopi Tribe and U.S. Forest Service have collaboratively produced a short film about this project, which will be shown during the session.

Baseline soundscape conditions in the Grand Staircase-Escalante National Monument

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Abstract: Natural quiet and the sounds of nature are important to visitors, ecosystem health, and the welfare of non-human species who reside in protected natural areas. The Grand Staircase-Escalante National Monument (GSENM) is the largest and most diverse unit managed for science and research on the Colorado Plateau. GSENM is also one of the most remote protected areas in the lower 48 states. Due to the size of the monument and the distance from major urban areas, GSENM is hypothesized to be one of the quietest areas in the nation. Working in cooperation with GSENM staff and acoustic technicians from the National Park Service Natural Sounds and Night Skies Division (NSNSD), acoustic monitoring sites were selected in the fall of 2014. Sites were chosen to represent the variety of acoustic zones of the monument, including heavily visited areas and wilderness study areas. Acoustic monitoring equipment from the National Park Service NSNSD was used to monitor eight sites. Sound pressure levels (dB), frequency readings in the range of 12.5 to 40,000 Hz range, digital audio recordings, and wind data were collected at each site over a one to three month interval to gather base-

line soundscape conditions at each monitored location. Methodological protocols are the gold standard used in protected areas, with this being the first data of its kind collected in a Bureau of Land Management administered area. Sites include Calf Creek Falls, Dry Forks, Wahweap Hoodoos, Deer Creek, Dance Hall Rock, Paria Townsite, Hackberry Canyon, and Yellow Rock. Analysis for each site includes day and night mean decibel levels and sound source audibility percentages. Sound pressure levels were found to be very low at several locations (10-20 dB(A)). Based on these results, GSENM is one of the quietest natural areas in the USA.

Natural and anthropogenic sounds in the Grand Staircase-Escalante National Monument

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Abstract: Ambient natural soundscapes are resources to be protected and managed using the best available scientific knowledge and procedures. Research protocols developed by social scientists, acousticians, and resource managers have established a means to identify dominant sound sources in protected areas. Acoustic monitoring and attended audibility logging were conducted at seven sites in the Grand Staircase-Escalante National Monument in southern Utah. Sites were chosen to reflect varying acoustic zones based on visitor use levels and diverse ecological niches. Sites include Calf Creek Falls, Dry Forks, Wahweap Hoodoos, Deer Creek, Dance Hall Rock, Paria Townsite, and Hackberry Canyon. Acoustic monitoring and attended audibility results show a complex soundscape composed of natural quiet and the sounds of many distinct species, as well as the sounds produced by visitors. In addition, at all monitored sites the most prominent anthropogenic sound is that of high altitude jets. Results from each site will show how natural and human caused sound varies based on location.

Integrating complex adaptive patterns and levels of inbreeding in ponderosa pine to refine species vulnerability assessments and seed transfer guidelines for reforestation

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Abstract: Ponderosa pine (*Pinus ponderosa* Douglas ex Lawson) is the most broadly distributed conifer in western North America, exhibiting complex adaptive strategies both by variety (var. *ponderosa* and *scopulorum*) and geographic location. Longer growing seasons accompanied by more intense droughts, increasing fire severity and occurrence, and higher levels of inbreeding in disjunct populations increases the species' vulnerability under climate change. Adaptive trait data from two, 100-year old racial variation trials located on the Fort Valley Experimental Forest in Flagstaff, Arizona and the Priest River Experimental Forest in Priest River, Idaho, molecular marker data from a range-wide Ponderosa pine study, and provenance trials throughout the Inland West were analyzed using spatially explicit geostatistical hybrid regressions models. While survival was anticipated to be low in both racial variation trials (9.2% and 1%, respectively), moderate geographic and climatic clines were found for survival and height (R^2=0.32 to 0.54) among regions. Key drivers impacting survival at the Fort Valley study included mean temperature in the coldest month, the summer precipitation balance, longitude and elevation; whereas for height, most of the model variation was explained by longitude, mean annual precipitation, elevation, and the annual summer dryness index. Our models identify key geographic and climate drivers influencing patterns of genetic variation based on long-term field data, but more importantly provide integrated seed transfer guidelines throughout the Inland West to better address appropriate planting stock to meet the increasing reforestation backlog. Our findings will facilitate decision-making in prioritizing areas for conservation, weighing the tradeoffs of natural versus artificial regeneration, and where loss of seed sources or natural regeneration is not appropriate, providing guidance in developing silvicultural prescriptions for utilizing proper seed sources for reforestation.

Investigating the effects of biocontrol of an invasive species on riparian bird communities

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Abstract: Tamarisk (*Tamarix* spp.) are among the most successful invasive plants in southwestern United States riparian systems, and *Tamarix* control has become a high management priority in the American Southwest. In 2001, the tamarisk leaf beetle (*Diorhabda carinulata*) was released as a biological control agent to combat *Tamarix* invasion. Since 2001, *D. carinulata* has spread throughout southwestern riparian habitat, including our study sites in the Virgin River drainage of Arizona, Nevada, and Utah. The primary effect of the tamarisk leaf beetle on tamarisk is defoliation, and this can potentially change habitat structure and insect food base for riparian nesting birds. Currently very little information is available on how birds respond to the tamarisk leaf beetle and the changes it causes to riparian areas. In spring and summer of 2013 and 2014, we used point counts to determine avian species richness in tamarisk stands at eight study areas along the Virgin River, while simultaneously monitoring *Tamarix* associated insect abundance using

sweep nets. In addition, we collected fecal samples from two warbler species to determine diet using traditional methods. I will present data on differences in bird species density, warbler diets, and insect abundance between *Tamarix* dominated and native-*Tamarix* mixed sites. Our study will offer insight into how biocontrol affects riparian birds both at a community level and at a diet level.

"The fingers have it:" the case for Pleistocene mammoth petroglyphs near Bluff, Utah, USA

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Abstract: The recent identification of two Columbian mammoth depictions at the Upper Sand Island petroglyph site along the San Juan River near the town of Bluff, southeast Utah, could be a watershed event for North American rock art studies. Testifying pictorially to the co-existence of early Paleoamericans with now-extinct Pleistocene megafauna, the proboscidean images, if accepted, would establish the site as the only currently reported rock art location in the Western Hemisphere with figurative imagery datable to the Ice Age. The anatomical traits observable on the proboscidean depictions—domed heads, paired tusks, trunks and, specifically, the prehensile "fingers" at the tip of the trunks—clearly show that the paleoartists were intimately familiar with the living beasts. In the absence of absolute dating methods for petroglyphs, the accurately rendered animals serve as primary evidence for "self-dating" of the images. Considering that the established extinction threshold for Mammuthus in the American Southwest is ca. 13,000–12,500 cal yr BP, this temporal window can also be assumed as a "best-estimate" for the creation of the engravings. In addition to stylistic details that mark the entire paleopanel as a "stylistic isolate," there is sound secondary evidence for the Pleistocene antiquity of the images. This evidence includes numerous Clovis culture projectile points found in the general vicinity of Upper Sand Island dating to the Paleoindian period of ca. 13,200 – 12,800 cal yr BP, as well as several mammoth fossil sites (complete skeleton, dung, tusk fragment and femur) on the southeast Utah portion of the Colorado Plateau, all dated to between ca. 13,800 and 12,200 cal yr BP.

The U.S. Marine Corps versus the Sahara mustard

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Abstract: Up-to-date spatial data is key to controlling any invasive, particularly if your method of control is seek-and-destroy. In the case of the invasive Sahara mustard on the Barry M. Goldwater Range in southwestern Arizona, the problem was in coordinating the seekers and the destroyers. The solution was a simple phone app. Previous control efforts by the range managers, the United States Marine Corps, have been thwarted by logistics; the people most likely to encounter the mustard, the range wardens, were not certified to spray glyphosate, the most effective control method. In contrast, the National Park Service (NPS) Exotic Plant Management Team based in Boulder City, Nevada, gladly takes on the task of spraying, if they know where to go. A cloud-based mapping app called GISCloud, which works on Android or Apple phones, allows the user to customize the data collection form. We opted for the simplest possible, it takes about one minute to collect a datum, which includes a geo-referenced photo, and optional audio recording of observations. The phone stores the data locally until within range of a cell tower or wireless network, then uploads the data to a base map. The map is thus updated on-the-fly by the wardens, who are in the field daily. Quality control is the responsibility of the project manager. Everyone else, from the wardens to the NPS weed killers, need only to visit the webpage at https://editor.giscloud.com/ and type 'Goldwater' in the field called Search Maps. No password is required. To limit costs, the GISCloud subscription can be deactivated during the dry season. Total costs of this survey method, including GISCloud subscription and service for four phones, but not including purchase of phones, is $1,500/year, based on six months of active use during the wet seasons. A full year's service would be $2,000.

Can a river be restored after a century of disturbance? Lessons from Fossil Creek

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Abstract: Fossil Creek was dammed and water was diverted for hydropower production for almost a century. Non-native bass and sunfish dominated the fish assemblage. Managers removed non-native fish, returned full flows, and dismantled the diversion dam. Here we demonstrate that multiple attributes of the river rebounded when the primary threats were reversed. Native fish increased quickly and remained high. Both removal of non-natives and return of flow was essential to fish recovery. Food web structure, measured using stable isotopes, showed that natives replaced non-natives at the top of the food chain. The contribution of algae in fish diets increased concurrent with increases in primary productivity. Primary productivity and nitrogen uptake increased in response to flow and travertine deposition. Populations of non-native crayfish increased immediately following restoration but subsequently declined in most sites. Non-native crayfish appear to be controlled by fish predation and travertine deposition. The primary remaining threat to Fossil Creek is unsustainable recreation. Because Fossil Creek is designated as a Wild and Scenic River, managers will be required to develop and enforce an adequate management plan.

Multi-disciplinary approaches to climate change communication

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Abstract: Communicating climate change to a broad audience poses many challenges. For one, climate change is a hyperobject as defined by Timothy Morton; it is massively distributed in time and space and is not easily perceived directly, but is revealed by its interaction with other objects. The Yale Project on Climate Change Perceptions reveals that climate change is an ongoing public debate. This means outreach is still needed as part of research outcomes. Additionally, there are many impediments to communication on climate change such as world views, political affiliation, race, and socio-economic status. Multi-disciplinary research and outreach offers an alternative to purely science based communication and outreach. Combining music, fiction, and the arts with scientific data allows researchers to broaden their impact and reach audiences that would not normally be reached through standard scientific channels. Some examples include the Crossroads Project at Utah State University where music and research are combined in powerful live performances, and regional fiction on climate change by Paolo Bacigalupi. Through the arts a broader audience is able to have their own unique experience or relationship with the science, thus making the topic and scientific content more meaningful for a greater number of people. Researchers, managers, and educators can benefit from multi-disciplinary approaches to climate change research and communication in order to broaden their public and policy impact.

Wide "local" genetic variation in drought resistance in ponderosa pine seedlings

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Abstract: This study examined variation in the drought resistance of ponderosa pine (*Pinus ponderosa*) collected from 20 sites in the vicinity of Flagstaff, AZ, in order to 1) identify populations for use in future reforestation projects under increasingly arid conditions in the southwestern US, and 2) understand traits of ponderosa pine associated with aridity adaptation. Seedlings were propagated from seed in a greenhouse and exposed to two treatments, lethal drought and well-watered. During the four-month drought study, we visually assessed browning of needles to identify date of death. We measured seedling growth and structural traits in the well-water seedlings. Population means of drought survival duration were not significantly related to population site climatic characteristics, seedling growth, or structural traits. The same was true for family means of drought survival. However, drought survival differed significantly among families within populations, which explained 10 times more phenotypic variation (12.3%) than populations (1.2%). Survival of the most drought tolerant family from each population was negatively related to population elevation and positively to mean temperature. Populations from dry sites generally allocated more growth to roots and less to leaves than populations from wet sites. The high amount of variation among families within populations for growth and survival traits suggests that ponderosa populations produce seedlings with a wide range of adaptive traits, and that gene flow is high across the study area. Efforts to improve drought tolerance should focus on identifying individual trees within populations that consistently produce desired traits.

Do biocrusts differentially influence native and non-native grass establishment?

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Abstract: Biological soil crusts (biocrusts) can have a positive, negative, or neutral effect on the germination and establishment of vascular plants. We recently established field and semi-controlled environment experiments to determine the extent to which variation in grass seed morphology (e.g., size, shape, mass, and appendages) interacts with biocrust characteristics (e.g., species composition, microtopography) that could differentially affect the establishment of native and nonnative grasses in the Colorado Plateau and in the Sonoran Desert. Seed morphology varies widely among native grasses of the Southwestern rangelands. Among 50 common native rangeland grasses in Arizona and on the Colorado Plateau, more than half have small seeds (>250,000 seeds/pound) and 75% have no or small (≤10 mm) appendages. In contrast, the seeds of some of the most threatening nonnative grasses in the Southwest (cheatgrass [*Bromus tectorum*], red brome [*B. rubens*], and buffelgrass [*Pennisetum ciliare*]) are somewhat larger (150,000-260,000 seeds/pound) and have moderate sized awns or bristles (14-25mm). Through a series of manipulative experiments, we seek to understand if these differences affect seed-soil contact on biocrusts and hence the probabilities for establishment. Our experiments are being conducted on the Colorado Plateau, where biocrusts are pinnacled, and in the Sonoran Desert, where biocrusts are comparatively smoother, to understand the role of biocrust microtopography in grass establishment outcomes. Additionally, we evaluate whether biocrust integrity (intact, trampled, or restored) differentially influences native and nonnative grass establishment. We will present late breaking results from our study.

Lessons learned from evaluating use-inspired research projects

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Abstract: As is clear from the other speakers in this session, collaborative science research is a growing, challenging, and promising approach to solving policy- and management-relevant environmental problems. However, as the practice continues to evolve, practitioners of the approach are seeking greater specificity about the actions, activities, and strategies that lead to the best management outcomes and optimize resources. Researchers in particular are also seeking ways to evaluate the outcomes of this kind of work to better understand how and under what conditions their research is used by decision makers. Through the Southwest Climate Science Center, we have begun a process of studying a series of collaborative research projects in order to both identify common "best practices" across a range of projects and develop an evaluative framework that will help researchers, funders, and federal agencies track the process, outcomes, and impacts of collaborative science research. We will present our proposed evaluative framework as well as some of the preliminary findings from our case studies.

Use and usability of experimental monitoring data and temperature modeling to inform adaptive management of the Colorado River's thermal regime for native fish conservation below Glen Canyon Dam

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Abstract: Seasonal thermal variability of the Colorado River was severely decreased by closure of Glen Canyon Dam and filling of Lake Powell by 1980. From 1973 to 2002, downstream summer river temperatures at Lees Ferry were about 18°C below pre-dam conditions, and likely limited juvenile native fish survival. A large-scale flow experiment to improve the river's thermal regime for spawning and rearing habitat of native humpback chub eastern Grand Canyon was conducted in 2000. Monitoring revealed warming, but below the 16-18°C optimum for chub 124 km below the dam near the Little Colorado River confluence, and no measurable chub population increase in Grand Canyon. Fall-timed stable flow experiments to improve shoreline chub nursery habitat (2008-2012) were also inconclusive relative to juvenile chub growth and recruitment. Studies showed that daytime warming of shoreline habitats used by fish under steady flows is limited by high exchange rates with main channel water. A monthly average temperature model has also been developed and used to support more recent experimental management planning. Temperature simulations have been useful for screening dam release scenarios under varied reservoir storage conditions with and without use of previously proposed, but never constructed, multilevel intake structures on the dam's hydroelectric units. Most importantly, modeling revealed the geophysical limits on downstream warming under existing water management and dam operating policies. Hourly unsteady flow simulations in 2006 predicted equivalent levels of average downstream river warming under fluctuating or steady flows for a given monthly release volume. River warming since 2002 has resulted from reduced Lake Powell storage, and temperature models have informed managers that it is possible for the river to approach near-optimal temperatures for native fish in eastern Grand Canyon when Lake Powell storage is higher, but only if summer releases are below current release policies, or multilevel intake structures are used.

Surprise and opportunity for learning in Grand Canyon: the Glen Canyon Dam Adaptive Management Program

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Abstract: With focus on resources of the Colorado River ecosystem below Glen Canyon Dam, the Glen Canyon Dam Adaptive Management Program has evaluated experimental policy tests since 1990. Flow experiments have consisted of various dam releases within pre-existing annual downstream delivery agreements. The daily experimental dam operation, termed the Modified Low Fluctuating Flow (MLFF), implemented in 1996 to increase daily low flows and decrease daily peaks were intended to limit daily flow range to conserve tributary sand inputs and improve navigation among other objectives, including hydropower energy. Other flow tests have included controlled floods with some larger releases bypassing the dam's hydropower plant to rebuild and maintain eroded sandbars in GCNP. Experimental daily hydropeaking tests beyond MLFF have also been evaluated for managing the exotic recreational rainbow trout fishery in the dam's GCNRA tailwater. Experimental nonflow policies, such as physical removal of exotic fish below the tailwater, and translocation of native humpback chub (*Gila cypha*) from spawning habitats in the Little Colorado River to other Grand Canyon tributaries are ongoing. None of these large-scale field experiments has yet produced unambiguous results in terms of management prescriptions, owing to inadequate monitoring programs and confounding of treatment effects with effects of ongoing natural changes, most notably, a persistent warming of the river resulting from reduced storage in the dam's reservoir after 2003. But there

have been several surprising results relative to predictions from models developed to identify monitoring needs and evaluate experimental design options at the start of the adaptive ecosystem assessment and management program in 1997. The repeated surprises were initially viewed with dismay by some managers and stakeholders who had unrealistic expectations about science and modeling to start with, yet actually represent scientific successes in terms of revealing new opportunities for developing better flow and non-flow policies.

Phenology and life history plasticity of the bivoltine angel lichen moth (Erebidae: *Cisthene angelus*) in Grand Canyon, AZ, US

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Abstract: Bivoltine moths, which produce two non-overlapping generations each year, often exhibit sexual dimorphism (males larger than females) and protandry (males eclosing earlier than females leading to male biased sex ratios). We investigated the life history of the bivoltine angel lichen moth (*Cisthene angelus*) along an elevation gradient throughout Marble and Grand Canyons using a unique dataset of light trap catches collected by citizen scientists. We predicted that this species would show evidence of both sexual dimorphism and protandry. We also predicted that the degree of dimorphism and protandry would increase along the downstream gradient through Marble and Grand Canyons as air temperatures increase since these environmental conditions typically allow for more rapid growth rates. We found that the spring generation of angel lichen moth exhibited these life history characteristics while the fall generation did not, and the degree of dimorphism and protandry was unrelated to location along the elevation gradient. On average, moths of both sexes of the spring generation had greater wing length than the fall generation. Furthermore, the disparity between male and female wing length was greater in spring than in fall, with spring males having wing lengths almost 5 percent longer than females. In addition, the males of the spring generation were protandrous with male:female sex ratios of 3, while fall males were not protandrous (sex ratios of 1). We propose that the longer developmental time available to the spring cohort (approximately 8-10 months vs. 3 months) allows it to simultaneously achieve large size and invest energy into a strategy of sexual selection that increases mating success.

A regional analysis of Areas of Critical Environmental Concern as a strategy for landscape-level conservation and special designations

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Abstract: Due to the expanding human footprint, the rate of land use change in the western United States is projected to increase. Land use change, coupled with ongoing climatic changes, is leading to increased habitat fragmentation and loss of connectivity of otherwise intact areas. Many of the largest remaining roadless areas in the West are unprotected and managed by the Bureau of Land Management (BLM). Yet, many of these areas have been identified as having very high conservation value. In this context, the BLM is well positioned to allocate important landscapes for protection and conservation by utilizing a special designation called an Area of Critical Environmental Concern (ACEC). Nevertheless, there is no systematic national strategy or tracking system for ACEC designation and management. Across all BLM field offices in the Colorado Plateau region, our research seeks to characterize existing ACECs as a systematic 'network' of conserved landscapes. We developed a spatially explicit database of currently designated ACECs within the Colorado Plateau Region and utilized this information to generate descriptive statistics that quantified designation characteristics. We also derived a range of structural characteristics and landscape metrics important to understanding protected area design and successful designation. Our results reveal new areas where resource planning and management processes present both real-time and future opportunities for ACEC nominations on BLM lands with high conservation value.

Application of BLM's assessment, inventory, and monitoring strategy for multi-scale land health assessment on Grand Staircase-Escalante National Monument, Utah

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Abstract: Grand Staircase-Escalante National Monument (GSENM), a unit of the Bureau of Land Management's National Conservation Lands, has been implementing the Bureau's Assessment, Inventory and Monitoring (AIM) strategy over the past three years.

The purpose of the strategy is to provide scientifically sound and technically defensible multi-scale monitoring of multiple resource conditions to support management and decision-making. This is done partly through improved probabilistic sampling design and standardized inventory, assessment and monitoring methods. Initially, the strategy has been applied to assess and monitor land health for both land use planning (large scale) and grazing administration (smaller, allotment scale). Applications include determining plant community composition to allow spatially-explicit estimates of forage availability using ecological site descriptions (ESDs), and evaluating options for integrating AIM's probabilistic sampling design into the existing key area-based monitoring framework while preserving the utility of historic data to establish trends in vegetation condition and plant community structure. Results compare production estimates from ESDs based on determination of state and community phase from AIM data with those determined from rangeland health monitoring. Resampling and simulation modeling of existing non-probabilistic data provide estimates of the temporal and spatial representativeness of those data and allow comparison with those from AIM sampling. Evaluations of allotment condition for grazing management based on existing, key area-based data can be supplemented with AIM data. Future improvements include incorporating remote sensing into sampling design to allow variation in sampling density based on heterogeneity of vegetation condition and plant community composition, and adding indicators of aquatic resource condition. AIM applications on GSENM will eventually extend to other resources such as cultural (archaeological), wildlife and recreational resources.

Butterfly species richness and abundance in relation to fire treatments in warm, dry mixed conifer in southwestern, Colorado

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Abstract: Fire suppression in warm/dry mixed conifer forests over the past century has impacted forest structure and therefore the biota associated with these forests. Species such as butterflies (Lepidoptera) can be used as an indicator species to quantify the effects of forest restoration treatments on microclimate changes. Butterflies are an ideal indicator species because they are sensitive to environmental conditions. In 2004 tree thinning treatments and in 2007-8 prescribed fire treatments were implemented to restore a warm/dry mixed conifer stand in the San Juan Mountains, Colorado. The main purpose of our research is to address the following questions: 1) do various forest restoration treatments (thin/burn, burn only, and control) affect butterfly species richness, abundance, and community assemblages, 2) is there a change in butterfly species richness, abundance, and community assemblages across the growing season (June, July, August), and 3) are there unique species associated with the three restoration forest treatments. We will quantify the effects of forest restoration treatments during the summer of 2015, seven years post fire. We hypothesized that thin/burn forest restoration treatments will have the highest butterfly species richness and abundance because increased understory plant productivity and altered warmer micro-climates. In addition, we also hypothesized that butterfly richness and abundance will be highest during the peak of the growing season (July) in all treatments due to peak plant productivity. Our study consists of four replicated blocks of each forest restoration treatment (4 blocks x 3 treatment units) that were established in 2002. Within each treatment unit, we will sample 5 permanently located 50 m transects to quantify butterfly responses. Each transect will be surveyed for a 20 minute sampling period three times across the growing season. Butterfly response can inform land managers on how restoration treatments influence microclimate and biota associated with warm-dry conifer stands in southwest Colorado.

The effect of fire restoration treatments on understory species richness and abundance in warm/dry mixed conifer, southwestern Colorado, USA

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Abstract: Warm/dry mixed conifer stands in the American Southwest are dominated by ponderosa pine (Pinus ponderosa), Douglas-fir (*Pseudotsuga menziesii*), and mesic species such as white fir (*Abies concolor*) and aspen (*Populus tremuloides*). Fire suppression has caused increases in forest density and surface fuels resulting in decreased understory vegetation productivity and diversity. Understory vegetation provides biological diversity and unique habitats for ground dwelling insects, pollinators and small and large mammals in warm-dry mixed conifer forests. The main objectives for this study are: 1) quantify the richness and abundance of herbaceous understory vegetation, shrubs, and surface substrates in three restoration treatments (control, burn only, thin/burn) seven years post-fire treatments and 2) quantify changes across time (pre-treatment in 2004 to post-treatment in 2015) for richness and abundance of herbaceous understory vegetation, shrubs ,and surface substrates in the same three restoration treatments. We will characterize understory characteristics using the point-intercept method along a permanently located 50 m transect and will also quantify shrub density using a 66.7 m2 circular plot within each treatment unit (4 blocks x 3 treatments x 5 sample points/treatment) during the summer of 2015 during peak understory productivity. We hypothesized that there will be higher richness and abundance in thin/burn treatments than control or burn only treatments seven years post-fire due to increased variation in microhabitats in thin/burn treatments. We also hypothesized there will be increased litter cover in the controls over the 11-year sampling period with the greatest change across the 11-year sampling period in the thin/burn treatments for understory vegetation. The results from this study will provide land managers with long-term understory vegetation responses to forest restoration treatments.

Effects of forest restoration treatments on avian communities in warm/dry mixed conifer forests, southwest Colorado

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Abstract: Warm/dry mixed conifer forests are dominated by fire-tolerant ponderosa pine (*Pinus ponderosa*), Douglas-fir (*Pseudotsuga menziesii*), and mesic species such as white fir (*Abies concolor*) and aspen (*Populus tremuloides*). However, the abundance of these species has shifted due to a fire-free interval of >100 years making these forests more susceptible to crown fires and novel ecosystems. The main objectives of this study are: 1) quantify differences in avian richness, abundance, and communities among three forest restoration treatments (control, burn only, and thin/burn) in warm/dry mixed conifer in southwestern Colorado, 2) identify indicator avian species associated with each forest restoration treatment, and 3) quantify how avian richness and abundance changes across the growing season in the different forest restoration treatments. Avian indicators are an effective way to monitor biotic responses to environmental change and detection of environmental patterns. The vegetative structures of forests can change the presence, abundance, and type of avian species thriving within an area allowing us to compare communities among treatments. Research will be conducted seven years following prescribed fire treatments allowing us to look at long-term treatment effects on birds. Observations will be made in June, July, and August 2015 to quantify differences across the growing season. We will use the point count method (20 m circle plot) to quantify birds in each treatment (4 blocks x 3 treatments x 5 plots=60 plots). We hypothesized that there will be unique, indicator species associated with different treatments such as cavity-dwellers in thin/burn and/or burn only sites. In more dense stands, like the control, we predict to see more seed specialists, foliage insectivores, and red-breasted nuthatches. Results from this study will assist land managers in better understanding the long-term effects on avian species and communities following forest restoration treatments and to promote avian diversity within conifer forests.

Facilitating beneficial fire within a suppression strategy: the Slide Fire

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Abstract: Wildfire management complexity has increased dramatically over the last two decades. With larger and more active fires burning around the wildland urban interface (WUI), fire managers work to decrease negative potential consequences (e.g., loss of infrastructure, uncharacteristic fire effects, and post-fire flooding) and increase desirable fire effects when possible. The Slide Fire, a human-caused fire, started immediately north of Slide Rock State Park on May 20th, 2014 and forced immediate evacuations of adjacent communities. Red flag weather conditions (due to high temperature, low relative humidity, and high wind) were observed for first two days. In addition, the fire was located in a steep drainage - Oak Creek Canyon. Despite these volatile conditions and immediate and downwind WUI values at risk, the Slide Fire was managed to a favorable outcome. For example, no serious accident/injuries reported, no loss of structures and less than 10% of the ponderosa pine burned at high severity (RAVG results). Good interagency working relationships, pre-planning, and swift, effective actions taken by local and regional Incident Management Teams, sound tactical planning, and effective implementation led to success. An example of a successful strategy includes developing a proposed fire boundary that reduced firefighter exposure and had a high probability of success. Some examples of tactical success included night-time burning that ensured desired fire effects in the ponderosa pine and increased the probability of maintaining fire control. In addition, helicopter ignition operations allowed the steep West Fork drainage to be ignited in a manner that ensured positive fire effects and maintained fire control. Although fire effects were not the highest priority (given the weather, fuels, topography, values at risk, and public and firefighter safety objectives), efforts were made to minimize negative fire effects and resultant downstream post-fire impacts.

Can grass phenology in the western U.S. track climate change?

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Abstract: Grasslands are important sources of biodiversity and productivity, but may be vulnerable to climate change because they contain many shallow-rooted, short-lived species. The capacity of grass species to alter life cycle events in response to changes in their environment can be an important indicator of their ability to persist under climate change. We used long-term records (1878-present) of grass reproductive phenology for over 100 species in the western U.S. to assess which species had the highest responses to climate, where these responses were most pronounced, and which aspects of climate were associated with phenological shifts. We also explored how grass responses to climate varied by grass photosynthetic pathway, longevity, and other traits. Our results demonstrate high variability in the degree to which perennial grasses in the western U.S. shifted their phenology in response to climate. Increasing temperatures accelerated reproduction of C3 grasses by as much as 7 days °C-1 but generally delayed reproduction of C4 grasses. Seasonality of precipitation influenced phenology, as increases in summer precipitation delayed reproduction of C4 grasses and had little effect on C3 grasses. The timing of reproduction in many annual grasses was over 2x as plastic as perennial grasses. We also found that phenological shifts and associated precipitation and temperature drivers were not uniform across ecoregions and were largely influenced by climatic regime. Our results suggest that grasses have different capacities to track climate, which has important implications for future grassland composition and resilience.

Successional patterns in northern New Mexico mixed conifer forests following recent high-severity fires

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Abstract: Wildfires play a vital role in the production, management, and overall health of mixed conifer forests. In northern New Mexico, fire history reconstructions of mixed conifer forests have shown variability within natural fire regimes including frequent surface fire, mixed severity fire, and stand replacing fire. We have lost much of this historic variability in mixed conifer fire regimes due to human intervention (e.g., fire exclusion) and homogenization of forest structure and connectivity. Today, high-severity fires burn across large landscapes resulting in massive treeless burned patches. These burned patches leave few to no viable seed sources, are recovering in hotter drought conditions, and therefore have a reduced chance of returning to pre-fire forest conditions. We examined high severity burn patches from multiple fires across the Jemez and Sangre de Cristo Mountains of New Mexico to assess the regeneration of mixed conifer tree species. Data from each fire were collected using plots in which vegetation cover type, dominant vegetation, distance to seed source, and topographic variables were collected. We will present a preliminary data analysis of our 2015 field season to show the current state of large, post-burn patches in New Mexico, and use such information to point to the long-term likelihood of these areas to return to pre-fire forest types. With recent research suggesting an increase in severe disturbances, including stand-replacing fire, which could force systems toward non-forested conditions, land management will become increasingly reactive. Such disturbances will require a simultaneous management focus on successional communities and intact forests, all while working with high levels of uncertainty and processes that may be outside of the historic range of variability.

Integrating traditional ecological knowledge in watershed restoration at Canyon de Chelly National Monument, Chinle, AZ

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Abstract: Canyon de Chelly residents face the challenge of increasing invasive species such as tamarisk and Russian olive and limited resources to control these species and restore the ecological and cultural functioning of the canyon ecosystem. We used qualitative research methods with canyon residents to understand local perspectives of ecological changes in the canyon and how these changes are linked to changes in cultural livelihoods. We also attempted to document critical culturally significant plants that need to be reintroduced to the wash as part of the restoration project and the vision that local resident have for a restored canyon. We found that cultural and ecological changes are strongly linked to the impacts of these invasive species and interact in complex ways over time. These changes in livelihoods are deeply related to the changes in the environment, but not solely caused by invasive plants. We also found that many culturally significant plants have been extirpated in the canyon by these invasive plants and drought and should be priorities as part of a restoration vegetation pallet. Finally, residents envision much greater role of locals in the planning, management, and restoration of the Canyon de Chelly. These findings indicate that restoration of life back into the canyon depends on integrated ecological restoration - including community and culture. Recommendations include a broader inclusion of canyon residents in planning and implementation of watershed co-management with the NPS and relevant Navajo agencies.

Monitoring vegetation recovery at river restoration sites with small unmanned aerial systems and LiDAR

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Abstract: At locations in the Madrean Archipelago ecoregion, land managers are implementing a variety of river restoration techniques meant to reestablish native plants, increase surface-water availability, and nurture habitats for species of concern. The Sky Island Restoration Cooperative, a bi-national community-based collaboration of agencies, non-governmental organizations, private landowners, ranchers, students, volunteers, scientists, and restoration practitioners, was formed to facilitate information sharing, training, and project implementation. Two approaches are being employed, which are complimentary yet contradictory: one suite of practices installs check dams and gabion-style rock structures directly into channels to detain water and capture sediment while another suite of practices slows stream flow by inducing meander and lengthening flow paths by constructing new flow channels and ponds. Both approaches share a goal to increase recharge that would help the establishment of vegetation. We have established six study sites in the southern Arizona to monitor the changes in vegetation around sites using these different restoration practices. Methodology includes analysis of four decades of satellite imagery, surveying landscapes using Terrestrial and Airborne LiDAR, capturing images using small, unmanned aerial systems (sUAS), and conducting regular field surveys on the ground. A temporal analysis of derived Digital Surface Models (DSMs), geographic elevations of natural terrain features and vegetation, digital elevation models

(DEMs), and simulations of vegetation structure are being compared to identify subtle changes in the landscape. Field studies support these analyses to quantify changes in species abundance/cover, structure, and composition using line transects and frequency plots at restoration sites and nearby controls. Procedures, products, and comparisons will be presented.

Discovering metabolic webs within biological soil crusts using exometabolomics

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Abstract: Biological soil crusts (BSCs) are communities of organisms inhabiting the upper layer of soil in arid environments. BSCs persist in a dessicated dormant state for extended periods of time and experience pulsed periods of activity facilitated by infrequent rainfall. *Microcoleus vaginatus*, a non-diazotrophic filamentous cyanobacterium, is the key primary producer in BSCs in the Colorado Plateau and is an early pioneer in colonizing arid environments. Over decades, BSCs proceed through developmental stages with increasing complexity of constituent microorganisms and macroscopic properties. Metabolic interactions among BSC microorganisms are thought to play a key role in determining the community dynamics and cycling of carbon and nitrogen. However, these metabolic interactions have not been studied systematically. Towards this goal, exometabolomic analysis was performed using liquid chromatography coupled to tandem mass spectrometry on biological soil crust pore water and spent media of key soil bacterial isolates. Comparison of spent versus fresh media was used to determine uptake or release of metabolites by specific microbes. To link pore water experiments with isolate studies, metabolite extracts of authentic soil were used as supplements for isolate exometabolomic profiling. Our soil metabolomics methods detected hundreds of metabolites from soils including many novel compounds. Overall, *M. vaginatus* was found to release and utilize a broad range of metabolites. Many of these metabolites were also taken up by heterotrophs, but there were surprisingly few metabolites uptaken by all isolates. This points to a competition for a small set of central metabolites and specialization of individual heterotrophs towards a diverse pool of available organic nutrients. Overall, these data suggest that understanding the substrate specialization of biological soil crust bacteria can help link community structure to nutrient cycling.

Linking forest landscape management and climate change to the conversation of riparian habitat in the Grand Canyon: Part II. hydrologic modeling

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Abstract: Forest management, wildfires, and vegetation type conversions have a direct effect on the runoff and recharge emanating from semi-arid ecosystems. The objective of part II of this study is to model water resources in the Grand Canyon under the future forest, fire, and climate conditions predicted for the Kaibab Plateau by C-FVS, LANDIS II, and the RCP 4.5 and 8.5 models in part I. We developed hydrologic models relating watershed output to forest composition and structure based on data from paired watershed experiments that were performed in a range of vegetation types in Arizona in the 1950s-1980s. Additionally, several of the sites were reinstrumented after wildfire, providing information on the effects of fire. For each raster cell in the vegetation model output, we identified and applied the appropriate model for runoff and recharge based on the predicted dominant vegetation type and applied a model for runoff and recharge change if the cell is fire- or treatment-affected. We extended the Northern Arizona Regional Groundwater Flow Model to include the portion of the Redwall-Muav aquifer underlying the Kaibab Plateau and used it to translate runoff and recharge estimates to streamflow and spring discharge projections for Grand Canyon National Park. Initial results show a decline in runoff and recharge, primarily due to vegetation change, with climate change also having a small direct effect. This suggests that forest management plans that delay vegetation type shifts are best for maintaining flows and conserving riparian habitat.

Conditioning hatchery-reared fish to recognize non-native predators

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Abstract: Predation by non-native fish may be the main mortality source for stocked bonytail (*Gila elegans*) and razorback sucker (*Xyrauchen texanus*) in the Lower Colorado River. Hatchery-reared fish are naive to this risk and may not survive their first encounter with a predator. We used a conspecific alarm pheromone to condition groups of predator-naive prey fish to recognize a non-native fish predator. Prior to conditioning, the jaw muscle of a predator fish was incapacitated with botulinum toxin, preventing it from cap-

turing prey fish during conditioning. Fish were conditioned by simultaneously adding a hindered predator and alarm pheromone into their tank. Predator recognition conditioning significantly improved survival of bonytail and razorback in 24 hour survival trials with largemouth bass (*Micropterus salmoides*), channel catfish (*Ictalurus punctatus*), and mixed bass and catfish. Survival of conditioned fish averaged 20% higher than unconditioned fish. There was no change in mean prey fish size, suggesting that all prey fish were susceptible to predation and conditioning benefitted all prey fish sizes. This novel conditioning method improved survival without prey fish seeing or experiencing predation during the conditioning process, suggesting this methodology may be successful at training large groups of these endangered fish in hatchery production ponds.

The constant flux of adaptive management at a landscape scale

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Abstract: Adaptive management of landscapes requires not only adopting multiple tools to accomplish restoration, but also adopting new viewpoints on how to manage the landscape. As larger restoration areas are focused upon for treatment and funding, land managers must balance desired results with past management practices and current organizational structures. Since the signing of the Bluewater Ecosystem Management Project's decision in 2003, shifts in management practices and perspectives have adjusted to reflect the myriad of land management obligations and challenges. Land managers celebrate successes achieved thus far with a recount of past events and shifts, which paved the way for current and future restoration within the two landscape scale projects that comprise the Zuni Mountain Collaborative Forest Landscape Restoration Project.

Holocene and late-Pleistocene paleoenvironmental history using lake sediment from the Chuska Mountains, Navajo Nation, New Mexico

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Abstract: The paleoecological record of the Chuska Mountains of Arizona and New Mexico is critical to understanding environmental change in the southeastern Colorado Plateau. Relatively little is known about plant communities during and following the Pleistocene-Holocene transition there. One particular question concerns when the ponderosa pine forest arrived in the region. Although there is one published paleoecology study in the Chuska Mountains, our preliminary results depict a much different picture of historical ponderosa pine distribution. Furthermore, the environmental response in this region to events such as the Bølling-Allerød, Younger Dryas, and the Little Ice Age is also unknown. Using new and updated dating and analysis techniques, we are addressing these questions. A 3.47 m sediment core from a small pond in the Chuska Mountains, informally named Beaver Run, is the centerpiece of this study and is being used for multiple analyses. These analyses include pollen and macrofossil analysis, organic matter content, carbonate content, magnetic susceptibility, and charcoal particle stratigraphy. A plant macrofossil record has the potential to reveal plant species composition that other proxies cannot, especially with regard to species of pine. Additionally, charcoal analysis will create a comprehensive fire history that may reveal changes in fire frequency and monsoonal activity. Without a clear understanding of the changing environment of the past, we can never fully understand current and impending environmental changes. In addition to helping fill gaps in the paleoecological record for the Colorado Plateau, this study will also advise Navajo Nation forest managers, supplying them with fire history data and information about changes in species composition through time.

The California condor in a novel ecosystem: complexities from A to Z

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Abstract: Historic evidence suggests humans have impacted North American ecosystems and created novel conditions that have altered evolutionary trajectories of single species. Although the Pleistocene overkill hypothesis has been heavily debated, evidence supports the observation that global climate change and the extinction of megafauna coincided with extinction of the Pleistocene era condor of the Grand Canyon region at the end of the last ice age. Thanks to a successful captive breeding and reintroduction program, the California condor has been artificially saved from the brink of extinction, but can the condor be recovered to a self-sustaining population in this novel ecosystem? Despite continued anthropogenic forcings of negative effect i.e., overharvest of native ungulates, the repatriation of the condor to its Pleistocene haunts appears possible. Studies have shown that reintroduced populations of California condors will consume the carrion of both native and non-native mammals; availability of domestic stock has replaced much of the native carrion. A relatively new anthropogenic threat hidden within their food supply holds the condors' recovery at bay - lead bullet fragments left in carrion. At current levels of documented lead exposure and lead-caused death, the condor remains a conservation-reliant species throughout its range. I offer a review of a seemingly simple problem and simple solutions both proposed and implemented since the inception of Arizona's Condor Recovery Program in 1996.

Plant genetic versus environmental determinants of ectomycorrhizal fungal community composition and growth in Colorado pinyon pine (*Pinus edulis*)

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Abstract: Climate change has resulted in significant tree mortality throughout the world with models predicting further mortality and large-scale vegetation shifts. However, intraspecific genetic variation and interactions with fungal mutualists may alter these projections. We examined interactions among plant genetics, ectomycorrhizal fungi, and drought in Colorado pinyon pine (*Pinus edulis*), a species with known sensitivity to climate variability. Previous studies have identified drought tolerant and drought intolerant pinyon trees growing side by side in the field. Drought tolerant trees had significantly higher survival and growth than drought intolerant trees during the past two decades of drier than average conditions. The communities of ectomycorrhizal fungi that occur on these two pinyon types also differ dramatically, with drought intolerant trees colonized mainly by basidiomycetes, and drought tolerant trees colonized mainly by ascomycetes. To test if these patterns had a genetic basis, we grew seedlings from drought tolerant and drought intolerant mothers in a common garden in northern Arizona in which soil moisture was manipulated. As with adult pinyons in the field, seedlings from drought tolerant mothers had significantly higher growth and survival and different ectomycorrhizal fungal communities than seedlings from drought intolerant mothers. Significant plant genetics by environment interactions were also observed. Seedlings from drought tolerant mothers showed a strong positive growth response to even low levels of supplemental water while retaining a similar ascomycete dominated community of ectomycorrhizal fungi regardless of water treatment. In contrast, seedlings of drought intolerant mothers showed a significant shift in ectomycorrhizal fungal community composition that was associated with a small growth response to watering. These results show that ectomycorrhizal fungal communities vary among host genotypes grown in a common environment and that this variation may be associated with host plant performance.

Too big to measure: rethinking conservation measures in the Landscape Conservation Cooperatives

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Abstract: Climate change and other global pressures to conservation have recently shifted conservation focus from site level (species, jurisdiction) to landscape scale endeavors. The US Department of Interior created the Landscape Conservation Cooperatives (LCC) in 2009 specifically to shape the federal government's approach to meeting the challenges posed by climate change and other large scale drivers to conservation efforts. The network includes 22 regional entities across North America. Each network represents a stakeholder partnership, comprised of regional actors (federal and state agencies, tribes, NGOs, universities), designed to collectively address conservation challenges that individual actors could not effectively address on their own. Interviews with 21 of the 22 LCC coordinators suggest that this shift to landscape level coordination and focus necessitates a shift in thinking about how to measure their effectiveness. In the past, measures focused on specific metrics related to conservation planning and management (i.e., breeding pairs, acres of habitat restored). Conservation efforts like the LCC represent a higher-level conservation function. By creating networks, facilitating communication, and disseminating information, their efforts set the stage for effective conservation but do not directly lead to specific on the ground conservation outcomes. This critical function does remain outside the purview of historic performance metrics. This necessitates both identifying what specific outcomes these cooperatives should be accountable for, as well as detailing how to track them. This talk argues for the need for new metrics based on the LCC case study and suggests that this has important implications for approaches to define and assess climate change adaptation efforts.

Future forest persistence in a changing climate: how climate drives ponderosa pine seedling emergence and establishment in the southwestern United States

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Abstract: The persistence of ponderosa pine forests in the 21st century depends on the ability of these ecosystems to regenerate following fire and other disturbance events. In many cases, forest regeneration is governed by how seedling emergence and establishment respond to driving climate and environmental variables, and even small changes in climate conditions may reduce the persistence of ponderosa pine forests. We reviewed the literature, identified 92 relevant publications, and determined that emergence and establishment for ponderosa pine is highest at intermediate temperatures (15-25ºC), and that higher precipitation and moisture availability supports higher seedling success. Yet, studies often do not replicate the types of conditions experienced by tree seedlings in the field and lack specific empirical response surfaces that describe how moisture availability influences emergence and establishment, such that existing information on regeneration is limited. It is imperative to close this knowledge gap of how climate and

environmental conditions influence ponderosa pine seedling emergence and establishment, especially in the context of 21st century climate change. We used the SOILWAT ecohydrological model to investigate how historical and future climate conditions support 18 climatic and environmental criteria for emergence and establishment in 25 ponderosa pine tree stands in the southwestern United States. Using simulations of 20th century climate, model outputs successfully identified past periods of forest regeneration. Simulations of future climate change suggest that emergence and establishment periods will become less frequent and will be shorter in duration in the coming century. Historical forest regeneration events across the southwestern US have been infrequent, and our results suggest that the probability that these climate-driven events will coincide with favorable demographic and vegetation community conditions in the future may be alarmingly small. Therefore, the regeneration and persistence of ponderosa pine forests in the 21st century may become increasingly limited by unfavorable climate conditions.

Innovative techniques for weakening cheatgrass-wildfire feedbacks in the Colorado Plateau and Great Basin

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Abstract: Millions of hectares in the western United States have been negatively impacted by cheatgrass invasion, which transforms high-functioning ecosystems providing many ecosystem services into low-functioning areas. Once invasion begins, cheatgrass litter fuels increased wildfire frequency and extent, and wildfires promote further cheatgrass invasion. A combination of fuel breaks and targeted grazing (to reduce litter and cheatgrass seed set) may be able to weaken the feedback between fire and cheatgrass invasion by reducing fire size and fire frequency, preventing the spread of cheatgrass into uninvaded areas and improving the success of restoration projects on already invaded sites. At sites in Nevada and Arizona, we are determining how best to combine greenstripping (fuel breaks composed of living plants), seed coating technologies, and targeted grazing to weaken cheatgrass-fire feedbacks, as well as determine how moderate grazing influences the effectiveness of greenstrips. In each state, we established replicated 50 acre plots that are randomly assigned to no grazing, fall grazing (fall 2015), and spring grazing (spring 2016) treatments. Within each plot we established 10-12 fuel breaks, each 0.3 acres in size. In fall 2014, experimental fuel breaks were planted with five native grass species. Fuel breaks were randomly assigned to high or low seed rate treatments. A portion of each fuel break was planted with surfactant-coated seeds to assess the potential of seed coating technologies to improve restoration success. In summer 2015 we evaluated the effects of different seeding rates, seeded species, and seed coating treatments on seedling emergence.

Mapping weeds on ancestral lands: a collaborative pilot program engaging Navajo and Hopi young adults

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Abstract: Considering the extensive open space on the Navajo Nation, early detection of new weed infestations and monitoring of known populations using GIS/GPS technology are important in controlling the spread of non-native invasive plant species. Financial and personnel resources of the Bureau of Indian Affairs (BIA) are stretched thin; meanwhile, youth residing on tribal lands often lack educational and employment opportunities. The Southwest Conservation Corps' Ancestral Lands Program partnered with the BIA to train and employ Navajo and Hopi young adults in a pilot program to conduct weeds mapping along roads, streams and washes, and range units across three chapters of the Western Navajo Agency of the Navajo Nation in northwestern Arizona. In addition to creating a current map of weed populations, the collaborative program introduced participants to technical skills useful for a career in natural resources and encouraged a deeper connection with their land. A crew leader and four-person crew were trained in botany, field identification of 50 target species, and use of tablets equipped with a mapping application (MapItFast by Agterra) and Garmin bluetooth GPS receiver. The crew inventoried assigned acreages on foot, recorded spatial information for found targeted species as points, lines, or polygons, and recorded attributes including species, area of infestation, percent cover, and phenology. Data was quality control checked in ArcGIS; as the crew demonstrated improved capacity with the technology they assumed increased responsibility for data management in ArcGIS. Results informed current year BIA weed mitigation actions. We will present 1) the results of detected populations of non-native invasive species, 2) an evaluation of the program and lessons learned, and 3) program impacts on the participants' technical capabilities, interest in natural resources careers, and connection to place.

New evidence for calendrical petroglyphs at Horseshoe Mesa (WS834), Wupatki National Monument, Arizona

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Abstract: Recent baseline documentation of Horseshoe Mesa (WS834) by Museum of Northern Arizona and Flagstaff Area National Monuments personnel has expanded our knowledge of solar observatories in Wupatki National Monument. Noted avocational archaeoastronomy researcher Robert Preston identified two possible solar calendars at Horseshoe Mesa in the 1980s, now known as Panels 50 and 52; the current project identified a third solar feature, Panel 115. Although Panel 52 is one of the larger and better known panels at the site, and shows visually interesting sun and shadow interactions, we question that it was a solar observatory. Panel 52 has been previously described as a migration scene that depicts the travels of various clan groups, an interpretation confirmed by members of the Hopi Tribe. Panel 115 also exhibits a striking sunray interaction, but only during winter months when the sun is low enough on the horizon to pass through a narrow gap between sandstone monoliths. Panel 50 has been observed on the summer solstice and on the vernal equinox, and it exhibits at least four distinct shadow and sunlight interactions with the two large elements of the panel, a group of eight pecked disks and a large spiral. The two elements unequivocally mark important solar events, although at different scales; the exact increments being measured are still being investigated. Panel 50, which we have named the Horseshoe Mesa Solar Observatory, is an equal to the well-known Fajada Butte Solar Observatory in Chaco Canyon National Historic Park, but with important differences.

Petroglyph element distribution and patterns at Horseshoe Mesa (WS834), Wupatki National Monument, Arizona

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Abstract: National Park Service, Flagstaff Area National Monuments partnered with Museum of Northern Arizona to conduct baseline documentation of Horseshoe Mesa (WS834) in the backcountry of Wupatki National Monument. WS834 is a sandstone flatiron with associated rock art and features, including habitations. The site was originally recorded during the 1983 Wupatki Archaeological Inventory Survey Project, at which time 72 petroglyph panels were identified. The current project took place in fall of 2014, with additional visits in 2015, and identified 1,130 elements on a total of 121 panels. Each panel was mapped to submeter accuracy, and the aspect of each panel was recorded. As a result, a previously unrecognized Archaic component has been identified, and the known Historic Navajo component was found to be much more extensive than previously reported. Additionally, two panels were identified as possible solar calendars. The orientation of all anthropomorph, zoomorph, plant, and selected geometric elements was graphed for cardinal direction. Some element types display a strong cardinal orientation, for example zoomorph horse elements almost always face due east, whereas others show no bearing preference.

Exposure to environmentally relevant arsenic levels affects estrogen sensitive tissues in an adult vertebrate

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Abstract: Inorganic arsenic (As) is a common environmental metalloid that can be found in many ground and surface water resources around the world. Exposure to high concentrations of As negatively impacts cardiovascular health and can lead to cancers in humans. Recent evidence shows exposure to low concentrations of As can impact endocrine physiology. In this study, we tested the hypothesis that low dose exposure to arsenic affects estrogen dependent reproductive tissues. Using adult *Xenopus tropicalis* as a model system, 60 female and 38 adult male *X. tropicalis* were exposed to 0.0, 0.1, and 1.0 uM As for 14 days, after which tissues were collected and analyzed for effects on organ mass. Although the exposure had no effect on the males, we observed significant outcomes in estrogen-sensitive tissues in exposed females. Arsenic exposure had little effect on most non-reproductive endpoints, but there was a significant decrease in both oviduct/ovary weight and oocyte diameter suggesting that environmentally relevant exposure to arsenic may affect female reproduction in adult vertebrates, possibly through disruption of estrogen signaling processes. These results suggest that arsenic, at concentrations below current EPA drinking water limits (10 ppm), may be inhibiting estrogen signaling processes.

Woodland recovery following drought-induced tree mortality across an environmental stress gradient

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Abstract: Recent droughts and increasing temperatures have resulted in extensive tree mortality across the globe. Understanding the environmental controls on tree regeneration following these drought events will allow for better predictions of how these ecosystems may shift under a warmer, drier climate. Within the widely distributed piñon-juniper woodlands of the southwestern USA, a multi-year drought in 2002-04 resulted in extensive adult piñon mortality and shifted adult woodland composition to a juniper dominated, more savannah-type ecosystem. Here, we used pre- (1998-2001) and 10-year post- (2014) drought stand structure data of individually mapped trees at 42 sites to assess the effects of this drought on tree regeneration across a gradient of environmental stress. We found declines in piñon juvenile densities since the multi-year drought due to limited new recruitment and high (>50%) juvenile mortality. This is in contrast to juniper juvenile densities, which increased over this time period. Across the landscape, piñon recruitment was positively associated with live adult piñon densities and soil available water capacity, likely due to their respective effects on seed and water availability. Juvenile piñon survival was strongly facilitated by certain types of nurse trees and shrubs. These nurse plants also moderated the effects of environmental stress on piñon survival: survival of interspace piñon juveniles was positively associated with soil available water capacity, whereas survival of nursed piñon juveniles was negatively associated with perennial grass cover. Thus, nurse plants had a greater facilitative effect on survival at sites with higher soil available water capacity and perennial grass cover. Notably, mean annual climatic water deficit and elevation were not associated with piñon recrui¬tment or survival across the landscape. Our findings revealed a clear shift in successional trajectories towards a more juniper dominated woodland and highlight the importance of incorporating biotic interactions and soil properties into species distribution modelling approaches.

Incorporating global change effects on biological soil crusts into modeling efforts

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Abstracts: Climate and land use change are predicted to have significant effects on the biota and biogeochemical cycles of dryland ecosystems, yet our understanding and predictive capacity regarding such effects on biological soil crusts (biocrusts) remains notably poor. Nevertheless, due to the global extent of biocrust communities and to their significant role in regulating the structure and function of ecosystems where they are prevalent, this lack of understanding substantially hinders our ability to forecast dryland responses and consequences at the global-scale. In particular, despite these critical roles, neither global change models used to predict future climate and ecological states, nor state-transition models used to inform management decisions currently consider the cover, structure, or function of biocrusts. Emerging data suggest that biocrust degradation may become even more widespread in the face of climate and land use change, calling into question the accuracy of these models, as well as offering exciting opportunities to include biocrusts in such modeling approaches. The research described here explores potential avenues for including biocrusts into modeling efforts and, taken together, these data support the idea that (1) biocrust communities have the potential to respond dramatically to climate change, (2) these changes will likely have marked effects on dryland biogeochemical cycling and energy balance, and (3) including biocrust responses to global change in modeling efforts is both tractable and important in effectively forecasting dryland ecosystem structure and function, as well as climate.

Synopsis of recent rock art research at Petrified Forest National Park, Arizona

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Abstract: In 2004, Congress authorized Petrified Forest National Park to more than double in size, in part to protect unique cultural resources. The park has a long history of historic preservation, beginning at the start of the 20th century. Cultural resource management, however, was not a strong focus of park policy until the last decade. Ongoing boundary expansions are adding thousands of unrecorded archaeological and historical sites to the nearly one thousand already documented in the park. Many of these additional sites are large petroglyph galleries and isolated glyph panels. These additional glyph sites add to a diverse record of hundreds of recorded glyph sites spanning thousands of years of occupation. This paper will present the ongoing results of rock art management in Petrified Forest National Park. Management challenges include field documentation, protection, and public access. These ongoing issues require innovating solutions and help from researchers, students, the public, and NPS management. In addition, this paper will present the latest update of rock art research in the park including new sites, public programs, and opportunities for future rock art research and documentation.

The role of mycorrhizae and soil organism communities in restoring a native grass, *Bouteloua gracilis,* in the face of a dynamic climates and exotic species invasion

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Abstract: On the Colorado Plateau, land use changes and prolonged drought are negatively impacting native plants. *Bouteloua gracilis* is a perennial grass that is obligate to soil organisms, such as mycorrhizal fungi. Plants and soil organisms may be locally adapted to one another, suggesting that benefits from soil organisms are site specific. In this experiment, we conducted a greenhouse study to examine whether novel soil organisms would provide equal benefits to *B. gracilis* populations as natal soil organisms. We also examined the lasting effects of exotic plant invasion on soil organism communities, and how such alterations affect native grass growth. We used soil inocula and *B. gracilis* individuals from two sites and an area invaded by *Bromus tectorum* to determine the benefits received from novel versus natal soil organisms. We found that plants grown in association with soil organisms from their natal site were the tallest ($p=0.0184$). We also found that plants grown in association with *B. tectorum*-invaded soil had the lowest establishment rates and were the smallest ($p=0.0022$). In addition, plant roots were more colonized by arbuscular mycorrhizal fungi when paired with their home team soil organisms. These data suggest the symbiosis that occurs between *B. gracilis* and its soil organisms is site specific. In addition, *B. tectorum* appears to manipulate soil organism communities in a way that inhibits establishment of *B. gracilis*. This could be due to a reduction of mycorrhizal densities, or due to an accumulation of parasitic organisms. Land managers should then be interested in preparing soil inoculum from seed collection sites to enhance performance of restoration projects in disturbed or invaded sites. In doing so, land managers should be able to enhance plant productivity and resilience in restoration and conservation projects.

Historical predator control efforts and Apache knowledge of gray wolves in Arizona

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Abstract: In 1893, the Territorial Bounty Act was passed by the Arizona–New Mexico Territorial Legislature, allowing a bounty to be paid on predators including gray wolves (*Canis lupus*). By 1963, all resident gray wolves were exterminated in Arizona. In 1995, the White Mountain and San Carlos Apache tribes were advised by the U.S. Fish and Wildlife Service of a proposal to reestablish a population of Mexican gray wolves (*C. l. bailyi*) in east-central Arizona. The White Mountain Apache and San Carlos Apache tribal councils passed resolutions officially opposing the reintroduction of the Mexican wolf. To most non-Native people, opposition to restoring a displaced species by a Native American tribe would seem inconsistent with what they have come to believe about the Indian relationship with the environment. The purpose of my research was to investigate the cultural significance and indigenous knowledge (also referred to as traditional ecological knowledge, or TEK) of the wolf within Western Apache culture. I interviewed 32 people who identified themselves as White Mountain Apache, San Carlos Apache, Cibecue Apache, or Camp Verde Apache (Yavapai-Apache) about Mexican gray wolves historically as well as the wolf reintroduction program. Results included consultants describing another subspecies of gray wolf (the "old wolf") along the Mogollon Rim and north throughout the Colorado Plateau that differed from the Mexican wolf and that wolves appeared to be a rare occurrence. The knowledge of two gray wolf subspecies historically occurring in Arizona at low abundances was supported in government reports documenting wolves killed by government paid agents, bounty hunters, and ranchers. My conclusion is that ethnography is a powerful tool and should be used to collect information about a species prior to a reintroduction program so that proper dialogue can occur between different cultures. Further, TEK and western science represent parallel, potentially complementary knowledge systems.

Responses of soil properties and mycorrhizae to 18 years of short duration high intensity grazing in an Arizona grassland

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Abstract: Little is known about belowground responses to livestock management practices. Livestock grazing may influence the susceptibility of soils to erosion and the dynamics of soil carbon stocks. Mycorrhizal fungi form beneficial symbioses with the roots of most plants, and there is evidence that these fungi play important roles in soil carbon storage and soil stability. The purpose of our study is to compare soil properties and mycorrhizae in experimental grassland plots that have received either short duration high intensity grazing (approximately 200 cattle per hectare for 24 hours) or no-grazing for 18 years. We studied replicated 1-hectare plots ($n = 6$) that were established in 1997 in a semiarid grassland approximately 24 miles southeast of Flagstaff Arizona. Measurements and samples were taken in May, July and August of 2015. We used a slake-test to measure soil stability and a penetrometer to measure soil compaction. Soil organic matter was measured by loss-on-ignition following correction for carbonates. Total soil

carbon, natural abundance 13C and carbon to nitrogen ratio were measured at the Colorado Plateau Stable Isotope Laboratory. Hyphal length density of mycorrhizal fungi was measured with a compound microscope. In May, mean gravimetric soil moisture was significantly lower in plots with high intensity grazing compared to plots excluded from grazing ($F = 7.4$, $p = 0.009$). Also, mean soil pH was significantly lower in plots managed with high intensity grazing (pH = 6.49) compared to plots in which grazing was excluded (pH = 6.60; $F=7.5$, $p = 0.009$). The responses of soil stability, organic matter, carbon and mycorrhizae will also be discussed. More carbon is stored in the soil than in the atmosphere and all living plants combined. Consequently, better understanding of belowground responses to grazing will help develop management strategies to minimize erosion and maximize soil carbon storage.

Restoring and maintaining resiliency within the fire adapted ponderosa pine ecosystem at Grand Canyon National Park

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Abstract: Fire managers at Grand Canyon National Park are committed to restoring and maintaining fire resiliency within the fire adapted ponderosa pine ecosystem. Since 1980, 104,418 acres of the ponderosa pine at Grand Canyon has experienced a wildland fire disturbance. Restoration efforts have occurred through the utilization of both planned and unplanned ignitions (prescribed fire and wildfire events). Fire managers are observing the direct effects of resiliency being created and maintained within the ponderosa pine ecosystem. Current and predicted fire behavior estimations are more in line with historical accounts. Surface fuel loadings are moving towards desired conditions and understory densities of pole-sized trees have decreased resulting in less potential for passive and active crown fire events. Key ecosystem components are being protected and maintained during the peak of the defined fire season at Grand Canyon; wildfires are not creating undesirable post burn fire effects within the ecosystem at the landscape scale. Low intensity surface fires are occurring where restoration activities have occurred and firefighter and public safety concerns have decreased. Restoration with fire can be successful and will aid in maintaining resiliency within the ponderosa pine ecosystem in the face of future climate change.

Effects of climate variability and accelerated forest thinning on watershed-scale runoff in southwestern USA ponderosa pine forests

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Abstract: The recent mortality of up to 20% of forests and woodlands in the southwestern United States, along with declining stream flows and projected future water shortages, heightens the need to understand how management practices can enhance forest resilience and functioning under unprecedented scales of drought and wildfire. To address this challenge, a combination of mechanical thinning and fire treatments are planned for 238,000 hectares (588,000 acres) of ponderosa pine (*Pinus ponderosa*) forests across central Arizona, USA. Mechanical thinning can increase runoff at fine scales, as well as reduce fire risk and tree water stress during drought, but the effects of this practice have not been studied at scales commensurate with recent forest disturbances or under a highly variable climate. Modifying a historical runoff model, we constructed scenarios to estimate increases in runoff from thinning ponderosa pine at the landscape and watershed scales based on driving variables: pace, extent, and intensity of forest treatments and variability in winter precipitation. We found that runoff on thinned forests was about 20% greater than unthinned forests, regardless of whether treatments occurred in a drought or pluvial period. The magnitude of this increase is similar to observed declines in snowpack for the region, suggesting that accelerated thinning may lessen runoff losses due to warming effects. Gains in runoff were temporary (six years after treatment) and modest when compared to mean annual runoff from the study watersheds (0–3%). Nonetheless, gains observed during drought periods could play a role in augmenting river flows on a seasonal basis, improving conditions for water-dependent natural resources, as well as benefit water supplies for downstream communities. Results of this study and others suggest that accelerated forest thinning at large scales could improve the water balance and resilience of forests and sustain the ecosystem services they provide.

Partnering to preserve history: a collaborative approach to administrative histories

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Abstract: An administrative history is a written account of the origin and evolution of each unit of the National Park System. Preparing an administrative history is a major undertaking; it requires a highly skilled, experienced historian paired with quality historical data, including oral histories and interviews with current and former employees. Grand Canyon National Park has taken a novel approach to updating an existing administrative history by partnering with the History Department at Northern Arizona University. By partnering with a graduate student, park staff, retired employees, and the Grand Canyon Association, we were able to create a mutu-

ally beneficial product meeting the intent and spirit of the Cooperative Ecosystem Studies Units. This 1999-2014 update is critical for a park unit as large and complex as Grand Canyon; a park administrative history explains how the park was conceived and established and how it has been administered up to the present. The primary audience for park administrative histories is current and future park managers and staff. Given the sometimes ephemeral, digital nature of current park management, maintaining an up-to-date history helps managers understand how past events influence today's issues and provides opportunities to learn from the past.

Management of a tailwater trout fishery downstream of Glen Canyon Dam

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Abstract: The 15.5-mile stretch of the Colorado River within Glen Canyon National Recreation Area is commonly referred to as Lees Ferry. Since 1964, with the completion of Glen Canyon Dam, this tailwater has hosted a recreational trout fishery. This blue ribbon fishery has become a financial and economic mainstay for the small community of Marble Canyon and for Coconino County. Lees Ferry is upstream of Grand Canyon National Park where fisheries are managed for native species including the endangered humpback chub (*Gila cypha*). Management of non-native sport fisheries in systems that are also managed for native fish has a troubled history nationwide. However, the Colorado River below Glen Canyon Dam is one of the locations where a non-native sport fishery and native fish conservation can coexist. Humpback chub and other native fish have been doing well over recent years, and knowledge gained through flow experiments and long-term monitoring in the Glen and Grand Canyons has led to potential management tools that may allow managers to better manage both the trout fishery and native fish. Periodic high densities of rainbow trout at Lees Ferry are detrimental to the blue ribbon trout fishery and may increase emigration of rainbow trout out of the Lees Ferry reach to downstream areas where they may interact with native fish species. Experimental flows as a result of dam releases may allow managers to control trout recruitment and densities at Lees Ferry. The limited fish food base (aquatic invertebrates) impacts both native and non-native fish species throughout Glen, Marble, and Grand Canyons. Experimental flows may enhance the food base downstream of Glen Canyon Dam. Temperatures within the main channel Colorado River likely have the greatest impact on fish energetics, survival, and species composition within Glen and Grand Canyons. Manipulation of temperatures will likely be key to long-term management of fish species downstream of Glen Canyon Dam.

Nutrient addition change nitrogen fixation rates of Colorado Plateau soil crust

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Abstract: Nitrogen (N) deposition is a documented and ongoing ecological problem in the southwestern United States. Though not a densely populated region, the Colorado Plateau is an area of particular concern due to the potential high vulnerability of its biota, and drastically increased oil and gas development occurring on and around the Plateau. Previous research indicates that increased levels of anthropogenic N may lead to vegetation and mycorrhizal community change, haze, and water pollution. The effect of anthropogenic deposition on N_2 fixing biological soil crusts, however, is poorly documented. We hypothesized that with increased added N, N_2 fixation rates in native lichens would be suppressed. Using the acetylene reduction assay, we estimated the N_2 fixation rates of *Collema tenax* and *C. coccophorum* at increasing rates of N fertilization. Some N treatments were coupled with phosphorous (P) additions, another markedly limiting nutrient in desert soils. We found that N fertilization dramatically suppressed N_2 fixation even at relatively low rates of N addition. In contrast, P drastically stimulated N_2 fixation rates. Our findings suggest that the biological soil crusts studied here could reduce their N_2 fixation in the face of increasing anthropogenic N inputs, which would result in less overall N enrichment of the ecosystem. Over the long term, N deposition could result in N_2-fixing biocrust members becoming less competitive within crust assemblages. Taken together, our and others' studies suggest that biocrust activity is very sensitive to the availability of nitrogen and phosphorous, and that these nutrients are key in understanding coupled biogeochemical dynamics in crusted ecosystems.

The effects of microbial legacies on plant response to extreme climate events

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Abstract: Ecosystem resilience in a changing world depends on interactions between soil microbes and their plant hosts. Microbial communities are responsive to abiotic stress, including increased salinity and prolonged drought, and shifts in microbial assembly feed back to plant performance through alterations to symbiotic interactions. This phenomenon has not yet been explored in the context of climactic extremes, which are expected to increase in frequency and severity in a warming world. We explored the legacy effects of a simulated heat wave on microbe-mediated plant performance. Three patterns emerged. 1. Growing plants with viable field inoculum increased plant height by 14%, leaf number by 27%, and chlorophyll content by 30% in a C4 grass species (*Bouteloua gracilis*) in comparison with a sterile control. 2. On the other hand, viable inoculum decreased plant height by 30%, leaf number by

32%, and chlorophyll content by 39% in a C3 grass species (*Festuca arizonica*) 3. Heat waves reduced plant height by 50% and leaf number by 18% in the C4 grass but had no impact on C3 grass growth in comparison to the viable field inoculum treatment. These results suggest that root mutualists dominate the C4 grass rhizosphere and root antagonists dominate the C3 grass rhizosphere. Species level differences in plant-microbe symbioses are revealed in the presence of environmental extremes, providing a useful tool for influencing plant trajectories. Future directions include characterization of bacterial communities using 16S rRNA gene sequencing, measurements of arbuscular mycorrhizal colonization, and exposing a subset of grasses to a field-imposed heat wave to monitor whether soil acclimation to heat waves influences plant survivorship.

Integrating multiple stakeholders and jurisdictions into the Greater Grand Canyon Landscape Assessment

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Abstract: The immense topographical and elevational diversity of the Grand Canyon region produces enormous ecological diversity as well as powerful cultural significance. These resources face uncertain futures as climate warms, regional development increases, and stressors such as resource extraction, groundwater withdrawal, and recreational user impacts escalate. Potential impacts extend beyond the borders of the national park itself to the broader landscape of the region. We are working with Grand Canyon National Park and other regional stakeholders to assess the condition of key resources in the region through the Greater Grand Canyon Landscape Assessment (GGCLA). The analysis, encompassing 5 million acres, includes the jurisdictions surrounding the national park. We worked with stakeholders to identify key resources and stressors in the region, and are using spatial tools to assess condition and trend of those elements across the landscape. Stakeholder groups further assisted this effort by supplying a value-weighted framework to the assessment, enabling us to spatially identify regions of particular ecological and/or cultural value as well as vulnerability. This effort builds off of the National Park Service's Natural Resources Condition Assessment (NRCA) process being implemented across the National Park system. The GGCLA moves beyond the NRCA structure by including cultural as well as natural resources, increasing the study area to an inter-jurisdictional watershed scale, and engaging stakeholders in a collaborative planning effort. By evaluating the Grand Canyon in its broader landscape and involving stakeholders in the spatial assessment process, we have implemented an interdisciplinary approach to landscape-scale conservation assessment and planning.

Seasonal precipitation and warming effects on the native grass, *Pleuraphis jamesii*, on the Colorado Plateau

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Abstract: *Pleuraphis jamesii*, or James' galleta, is a native, shallow-rooted, C_4 grass found across the Colorado Plateau and prominent throughout southwestern USA. As a dominant grass in rangelands, *P. jamesii* is a valuable economic and ecosystem resource in drylands where vascular plant cover is low. The Colorado Plateau, a cool desert with winter/spring precipitation and summer monsoons, is projected to experience rising temperatures and altered rainfall regimes due to climate change, but little is known about the long-term climate effects on native grasses. To explore the potential for climate change impacts, we compared seasonal *P. jamesii* biomass and photosynthesis (A_{net}) measurements with inter- and intra-annual precipitation patterns using a field climate manipulation experiment that included ambient and infrared warming plots (+4°C above ambient) from 2010-2014. In 2010 and 2014, the Colorado Plateau experienced high winter/spring precipitation (146 mm and 103 mm) and showed massive differences in spring versus monsoonal *P. jamesii* growth in control and warmed plots, respectively (740±313%, 570±261% in 2010; 107±44%, 207±70% in 2014). Spring and fall *P. jamesii* biomass growth in 2010 (control: 0.5±0.1g, 1.8±0.5g; warmed: 0.40±0.1g, 1.2±0.3g) was higher compared to 2014 (control: 0.36±0.08g, 0.8±0.2g; warmed: 0.35±0.09g, 0.96±0.30g), possibly due to high June rainfall in 2010. Photosynthesis rates in control and warmed plots in fall of 2014 (37±7.3, 34±11 $\mu molm^{-2}s^{-1}$) were much larger than a normal spring precipitation year of 2011 (28±4.2, 21±3.2 $\mu mol\ m^{-2}\ s^{-1}$), and far surpassed the drought year of 2012 (5.6±0.88, 2.7±0.66 $\mu mol\ m^{-2}\ s^{-1}$). The largest monsoons occurred in 2014, but 2010 had more fall biomass, proposing that winter/spring and, specifically, June precipitation has a greater effect on fall production. Similar spring/fall dynamics of *P. jamesii* were found in both treatments, suggesting that warming did not have a large effect on seasonal biomass production or photosynthesis between 2010 and 2014.

HRV in a changing world: Is the concept of historical range and variation still relevant?

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Abstract: Many feel that the concept of HRV (historical range and variation) may no longer be viable for managing lands in the future because expected climate warming and increasing human activities will create landscapes dramatically different from the past. The continued spread of exotic plants, diseases, and other organisms will also permanently alter ecosystems. Climate warming is forecast to trigger major changes in disturbances, plant and animal species dynamics, and hydrological responses to create new plant communities and altered landscapes that may be quite different from historical analogs. At first glance, it may seem obvious that using historical references may no longer be reasonable in this rapidly changing world. However, a critical evaluation of possible alternatives may indicate that HRV, with all its faults and limitations, might, in fact, be the most viable approach for the near-term because it has the least amount of uncertainty. Predicting future climates, then simulating changes and interactions of this climate change on flora and fauna, and then modeling the impact of current and future management actions on plants and animals may result in such great compounding uncertainty that HRV might be a better approach. Given the huge uncertainties in predicting climatic responses to increasing CO_2 and the ecological effects of this response on ecosystem and landscape dynamics, HRV time series derived from the past may have significantly lower uncertainty than any simulated predictions for the future. This presentation examines the past, present, and future use of HRV in land management. Possible modifications in HRV theory and application are proposed, and it may be that climate change adaption actions may incorporate HRV concepts in their design to define resistance and resilience.

Fine-scale forest patterns and landscape ecology of Powell Plateau, Grand Canyon National Park

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Abstract: Frequent low-intensity surface fires and topography in ponderosa pine (*Pinus ponderosa*) forests create fine-scale mosaics with varying forest structure and composition. Increasing evidence suggests that these mosaics affect many ecological processes, including the movement and persistence of particular species, the susceptibility and spread of disturbances such as fires or pest outbreaks, and the redistribution of biomass and nutrients. Due to increased occurrence of catastrophic wildfire, land managers increasingly direct forest treatment efforts at manipulating the forest structure at meso- and landscape-scales with the aim of restoring ecosystem function and creating highly heterogeneous landscapes. We studied the effects of varying environmental and vegetation conditions in the ponderosa pine forest of Powell Plateau, a 1,000 ha relict landscape within Grand Canyon National Park, on fine-scale (0.1-10 ha) tree spatial patterns and landscape-scale (up to 1,000 ha) patterns. We present comprehensive site-specific information (measured with airborne LiDAR data and 0.1 ha permanent plots) on individual tree and tree-group spatial patterns, structure (size and age), and landscape attributes (e.g., canopy cover, patch distribution, contagion) and suggest how this information might be used by management or as comparison for similar ("different place, same time"; *sensu* White and Walker 1997) ponderosa pine forests of the Colorado Plateau. While it is likely that the historical forest condition and fine-scale spatial heterogeneity vary among frequent-fire ecosystems, managers may use this information to generally inform the restoration of other departed frequent-fire ecosystems. Particularly, the results of this study provide unique insights into the landscape ecology of a functioning relict forest, where a fine-scale forest mosaic made of many small openings and patches still dominates the landscape.

Bats as drivers of bacterial biodiversity across multiple trophic levels of subterranean biomes

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Abstract: Subterranean ecosystems, such as caves and abandoned mines, are numerous (100,000+ exist in the western U.S. alone), yet understudied. In these environments, bats, through their nutrient-rich guano, have long been known as a foundation species, supporting a diverse food web including bacteria and arthropods that use guano as a food source, as well as predators that consume them. While bats are clearly important to this ecosystem, the degree to which their presence, species composition, and gut microbiota drive the diversity and stability of subterranean bacterial communities, and what happens when bat assemblages are significantly disrupted, is not known. We have used a variety of barcoding and shotgun metagenome sequencing techniques to explore bacterial communities across multiple trophic levels (bat guano, associated arthropods) in bat-occupied subterranean sites (abandoned mines) within USA's four corner states (Arizona, New Mexico, Utah, Colorado). Our results to date support the hypothesis that bats, and their gut/guano microbiota, drive the bacterial biodiversity and composition of their immediate subterranean ecosystem. In particular, we have observed bat guano pile microbiota affecting arthropod gut bacterial composition, with detritivorous insect gut communities most closely mimicking the microbiota of guano from which it was isolated. Shotgun metagenomic sequencing revealed a number of bacterial taxa persisting across the guano pile and arthropod gut niches. Finally, we observed bat species composition across different sites closely correlating with guano pile microbiome compositions. Exploration of subterranean biomes is particularly relevant given that biodiversity within these ecosystems is threatened from a variety of sources, including invasive species, hu-

man activities, and disruptions to bat assemblages due to extinction, disease, habitat loss, and climate change. Bats themselves are increasingly recognized as an important reservoir for a number of human- and livestock- affecting bacterial zoonotic diseases, further highlighting the need to understand how their gut microbiota propagate through the environment.

Remote sensing applications at NAU with UAV imagery

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Abstracts: Many remote sensing applications require high resolution imagery for detailed analysis of soils and vegetation. While satellite images are commonly used for such analysis, they often do not provide the spatial and temporal resolution necessary. UAV platforms are an effective alternative, when equipped with sensors in varying spectral bands. Northern Arizona University's Remote Sensing and Geoinformatics (RSG) Lab recently purchased two UAV platforms: a fixed-wing UAV equipped with a near-infrared sensor and a multispectral sensor, and an octocopter equipped with a lidar scanner and a hyperspectral sensor. We are using both platforms and all sensors in various remote sensing applications. The lidar scanner provides a 3-dimensional, high resolution imagery of the Earth surface and vegetation height. The multispectral and hyperspectral sensors image the land surface in many spectral bands beyond the visible range. Using the lidar scanner, we are measuring the volume and distribution of sand dunes on the Paria Plateau in northern Arizona as potential sources of sediment in the Colorado River and Grand Canyon. We can then scale up the 3D data to a larger spatial extent across the plateau using high-resolution satellite data such as WorldView. Similarly, we are using the lidar scanner in examining forest restoration treatments in northern Arizona and their effects on snow distribution and accumulation. We measure snow depth using snow-on and snow-off lidar images and relate the snow depth to soil moisture and groundwater recharge in different treatments. In southern Arizona, we are using the hyperspectral data to detect and monitor an invasive plant species known as buffelgrass. By identifying the current spatial distribution and habitat range, we can determine where this invasive species can spread to in the future under changing climate. We can also inform satellite image-based invasive species detection using the hyperspectral data. The UAV technologies have provided many unique research opportunities at NAU. The cutting-edge sensors and platforms position NAU at the forefront of UAV research.

Assessing climate change impacts to cultural resources in a geomorphically diverse environment in Petrified Forest National Park

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Abstract: Petrified Forest National Park contains a diversity of cultural resources located over an extensive and geomorphically diverse landscape. Cultural resources include over 1,300 recorded archaeological sites, including prehistoric sites such as artifact scatters, pithouse villages, and multi-room pueblos, as well as historic sites and structures. These are located in a geomorphically diverse environment of washes and floodplains, sand dunes and blowouts, mesa tops and slopes, alluvial fans, ridges, and badlands. The authorized park boundary has over 218,000 acres of land, and the park continues to expand within the authorized boundary. This presents a wide range of microenvironments across a very broad area with diverse landform positions. The park has partnered with meteorological researchers at Arizona State University to collect microclimate data at discrete locations throughout the park, including placing new stations as the park continues to increase in size. These climate stations are focusing on collecting data near sensitive archaeological sites and within a variety of geomorphic positions. This will assist in understanding microclimate variation across the landscape, and in assessing how sites in different areas of the park may be differentially impacted by climate. However, detailed data on climate change effects have been limited due to a lack of a formal, in-park, NPS climate monitoring program to understand effects of changing climates on cultural resources in the park. This, combined with a lack of consistent funding for the cultural resource management in the park, has resulted in only minimal collection of standardized data on climate impacts at the archaeological site level.

Sagebrush decline on the Colorado Plateau: a look at sagebrush and soils

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Abstract: Sagebrush (*Artemisia tridentata*) ecosystems are important habitat for mule deer, greater sage grouse, and many other charismatic fauna. They are also important rangeland for the western livestock industry, and considered by many to be vital recreation areas. However, these ecosystems are also in decline. Growing concern for this problem has led to a great many studies on the dynamics of sagebrush ecosystems, particularly in the Great Basin, but very little is known about how sagebrush responds on the Colorado Plateau which has drier and monsoonal climatic conditions as well as different soils and vegetation. This is problematic because there is little to suggest that restoration successes in well studied areas will be successful on the Colorado Plateau. In Beef Basin, an area of southern Utah known for recreation, cattle grazing, and deer hunting, sagebrush habitat has degraded to such an extent that it is more accurately described as grassland. Sampling sites were randomly selected across two neighboring basins based on the three dominant soil types and four vegetation classes. These classes were assigned based on September NDVI values. Line-

point-intercept, shrub density, and soils data are used to determine which soil characteristics influence the presence of sagebrush on the landscape. Non-ephemeral sagebrush leaves provide nitrogen content and hydration measures, which are used to explain the variation of sagebrush health. Our findings allow land managers to direct conservation efforts by predicting which areas can be successfully restored as well as those which may face further loss of sagebrush and sagebrush ecosystems.

Multiscaled approaches to southwestern arid lands vegetation monitoring, modeling, and management

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Abstract: Arid land vegetation composition and structure vary substantially at multiple spatial and temporal scales. This presents a challenge for determining large-scale changes moderated by inter-annual to decadal precipitation cycles and temperature regimes. We present lessons learned from three ongoing studies in the Sonoran Desert focused on estimating native and non-native plant distributions, fine fuels, and other vegetation parameters associated with disturbance and climate change. Over 4,000 vegetation plots were established across a 103,500 km^2 area within multiple land jurisdictions between 2011 and 2014. Plots were specifically designed for integration with multiple satellite remote sensing platforms. Field plots targeted specific non-native invasive plants *Brassica tournefortii, Schismus* spp*., Erogrostis lehmanianna*, *Cenchrus ciliaris*, *Bromus madritensis*, and *Eruca vesicaria sativa* using species distribution models and areas of high habitat suitability. Spatial models developed from plots and remotely sensed data (i.e., MODIS, SPOT, Landsat, and Worldview 2) focused on predicting herbaceous plant biomass, canopy cover, invasive plant distribution, and probability of occurrence. Google Earth Engine applications are being developed to automate time series satellite image-based models to predict landscape to region-scale plant and fine fuel parameters, useful for estimating potential fire behavior, hazard, and risk. Our findings suggest that large-scale, multi-temporal, and multi-jurisdictional sampling efforts can provide substantial gains in estimating arid-land vegetation conditions and change important to land planning and management activities.

Linking theory and practice while navigating ecosystem change in the Southwest

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Abstract: Worldwide, changing climate, species extirpations, biological invasions, and other forms of global change are transforming not only the physical landscape, but also the diversity of life it can support and the human communities that depend upon it. As evidenced by the talks in this symposium, a common result is the formation of novel ecosystems with unprecedented species assemblages and functional properties. While the assembly of novel communities and their impact on ecosystem function is fraught with uncertainty and largely unpredictable at present, several common threads can be woven into a preliminary approach to both research and management. This talk will synthesize messages from the symposium and offer insights relevant to land and resource management on the Colorado Plateau. In bringing to the fore the ecological and evolutionary implications of novel ecosystems, I will link the social and environmental dimensions of change, and provide a thought model for how decision makers might integrate the scientific insights regarding novel ecosystems into a management perspective that acknowledges uncertainty, yet moves boldly toward actions that will build greater resilience into human communities, economies, and management systems. By addressing environmental and social challenges in tandem, we will be better positioned to unprecedented change and the emergence of novel environmental conditions that will transform ecosystems and how we manage them in the 21st century.

Assessing ungulates' role in riparian hummocking on three national forests in southern Utah

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Abstract: Very little research has been conducted on the role of ungulates in the development of hummocked topography in wetlands. Hummocks can channelize water in riparian areas, favor less productive plant species, and allow higher utilization of wetland species by ungulates by decreasing the distance between the plants and an ungulate's mouth. This survey evaluates 22 hummocked wet meadows and riparian areas on the Dixie, Fishlake, and Manti-La Sal National Forests in southern Utah. It explores the variability in location and morphology of hummocked areas in order to better understand the mechanisms of formation at play. The study explores evidence for ungulate grazing as a factor in hummock formation and/or exacerbation in order to better direct federal land managers' approach to wetland protection and mitigation. Hummock oblateness (the ratio of hummock length to width) may be an important indicator of ungulate interaction with hummocked wetlands. However, the lack of suitable ungrazed reference areas compounds the difficulty of determining ungulate impact. It appears that hummocked areas exhibiting elongated hummocks with

sheared sides and bare interspaces are less likely to be formed naturally. Two locations with exclosures or lighter grazing regimes present different hummock morphology. In these two paired sites, the areas of heavier grazing exhibited an average of 15% taller hummocks, 17.5% greater oblateness, and 35% higher density.

Developing landscape change scenarios from long-term monitoring databases

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Abstract: Long-term monitoring datasets inform our understanding of how past climate and land uses drive vegetation changes and distributions. This information can be used to model potential future scenarios of vegetation response to intensified land use and climate change. Using established climate-vegetation relationships from plot-based measurements, satellite-based measurement of vegetation change, and historical land-use patterns, we developed a suite of land change scenario models in the Southwest US. These models are capable of assessing the impacts of drought, climate change, invasive species spread, and land-use intensification at local and regional scales. Multiple future scenarios were developed with input from land managers and stakeholders, and based upon a wide range of assumptions of how climate and land-use may change in the near future. We will discuss examples of this work at two scales: watershed-scale modeling of land and groundwater water use linked to riparian vegetation change, and regional modeling of potential future xeroriparian change based on climate-driven vegetation change. Modeled changes can be used to better evaluate potential consequences to vegetation resources and to explore the effectiveness of potential mitigation actions.

Use of passive integrated transponder technology in recovery of endangered fish in the upper Colorado and San Juan River basins

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Abstract: In recent years, use of passive integrated transponder (PIT) technology in the Upper Colorado and San Juan river basins has evolved from the use of PIT tags to identify individual fish in active mark/recapture investigations to use of stationary passive interrogation arrays (PIAs) and other types of antenna technology for a variety of monitoring purposes. To date, about 18 PIAs or temporary flat plate antenna installations been deployed in the two river basins to answer a variety of research and monitoring questions related to recovery of endangered fish and/or ecology of non-listed native fish. Most of these systems were installed in the last four years (2012-2015) and have already collected a considerable amount of endangered fish PIT data. Of the 18 applications, eight (44%) were intended to document fish use of tributaries, three (17%) to document entrainment in canals, three (17%) to document fish use of restored off-channel habitats, two (11%) to document fish use of passage structures, and two (11%) to collect ancillary tag data and/or document spawning activity. Other innovative approaches, which have yielded some success as data collection tools, include floating PIT surveys and use of portable, submersible antennas. While PIA systems and other PIT technology collectively result in collection of large amounts of individual tagged fish data, questions remain as to integration of data from these systems with other data types as a means to improve population and survival estimation, uncertainties about sampling efficiency, the role(s) of such technologies in future recovery or conservation efforts, ability of programs to cover operation and maintenance costs, and data acquisition and stewardship.

Bat occupancy in a patchy post-wildfire landscape

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Abstract: Frequency and size of wildfires have dramatically increased in southwestern ponderosa pine (*Pinus ponderosa*) forests in the U.S. These changes result from an increase in tree density since EuroAmerican settlement because of fire suppression efforts and increased livestock grazing. How change in vegetation post-wildfire affects habitat use by bats is poorly known. We hypothesized that burn severity would affect bat occupancy and would vary based on wing morphology; species with long, narrow wings would have higher occupancy in high burn severity sites, and species with short, broad wings would have higher occupancy in low burn severity sites. We used the 2011 Wallow Fire (217,721 ha) in eastern Arizona as our study area. At 21 randomly selected sites within the fire boundary, we monitored echolocation calls in each of four burn severity classes (0%–25%, 26%–50%, 51%–75%, and 76%–100% basal area [BA] loss) using acoustic detectors (n=84 locations). We sampled each location twice in 2014, during the dry (June-July) and wet (July-August) season. We used SonoBat 3.0 to classify calls to species, determining detection history for each species. We grouped *Myotis* species because they could not always be identified to species; other species were examined separately. The *Myotis* group and big brown bats (*Eptesicus fuscus*) used low burn severity (0-50% BA loss) areas, but silver-haired (*Lasionycteris noctivagans*) and Mexican free-tailed bats (*Tadarida brasiliensis*) used high burn severity (>50% BA loss) areas. The *Myotis* group (short, broad wings)

and Mexican free-tailed bat (long, narrow wings) followed our hypotheses; however, silver-haired and big brown bats (short, narrow wings) responded differently than expected. These responses might be due to other factors such as diet or roost selection. Immediately post-wildfire, the patchy forest landscape created by the Wallow Fire provided habitat for a diverse bat assemblage.

Stasis and change in Holocene small mammal diversity during a period of aridification in southeastern Utah

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Abstract: Biodiversity conservation relies on accurately understanding past environmental conditions. However, the environment fluctuates over decades, centuries, and millennia, so disentangling natural variation from unusual and potentially detrimental change requires long-term records. For mammals, we know little about the magnitude of "normal" ecological fluctuations in the absence of anthropogenic impacts on the Colorado Plateau and how they have responded to past climate change. To better understand the local pre-industrial fluctuation in species diversity, I excavated two fossil-bearing alcoves in San Juan County, UT—East Canyon Rims 2 and Rone Bailey Alcove—and quantified small mammal abundance change. 33 AMS radiocarbon dates indicate that these sites span ~4,400 cal ybp to the present, and they provide new, fine-resolution information on faunal dynamics in the region over the course of environmental change, most notably aridification. I measured diversity through time using relative and rank-order abundance, guild abundance, and three indices of diversity and evenness: Shannon, Simpson, and Hurlbert's PIE. There were no correlations between these measures of diversity and independent proxies for climate, including reconstructed tree ring width, PDSI, and reconstructed mean July temperature anomaly. However, evenness was significantly lower from 3,500-2,700 cal ybp, and again from 650-500 cal ybp. Nonmetric multidimensional scaling reveals that certain groups of species have similar diversity trends through time, like kangaroo rats and pocket gophers or woodrats, voles, sciurids, and deer mice. Identifying what environmental factors drive these cross-taxa abundance patterns will be important for predicting future biotic changes. The small mammal community of this region maintained the same overall structure for several thousand years of climatic change. The metrics assessed here can be monitored in modern faunas; if the community is significantly different today or in the future from what is seen in the fossil record, it indicates anthropogenic influences outside the range of natural variability.

Hot droughts and lessons for the new era of forest management

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Abstract: Recent examples of forest dieback induced by hot droughts likely foreshadow even greater changes to come, and sharply highlight our entry into a new era of forest management – an era in which we cannot automatically use past forest conditions as management targets for the future. In strategically-chosen areas, management efforts will likely focus on avoiding the sudden loss of forest cover, while actively trying to ease the transition to new forest types that are better adapted to an array of probable future conditions. In areas that do experience sudden forest dieback, efforts may focus on avoiding loss of biological potential (e.g., by avoiding extensive topsoil loss to erosion) and on re-establishing a vegetation cover better adapted to future conditions. In both cases, we will likely strive to maintain regional native biodiversity and key ecosystem functions, while abandoning attempts to maintain "natural" communities (combinations of species). Some broad classes of management strategies worth considering include "the four Rs": restraint, resilience, and realignment.

A functional trait-based model predicts different rates of germination and establishment among grass species under experimentally-controlled light and soil conditions

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Abstract: Trait-based approaches in ecology have been lauded for their potential to achieve predictive generality. In this study, we test whether the CATS (community assembly by trait selection) model, when calibrated with data from natural plant communities, can predict differential rates of germination and establishment among five dominant grass species in an experiment that manipulates light and soil properties. Generalized additive models (GAMs) were used to model community-weighted mean (CWM) seed mass, mean Julian flowering date, and specific root length (SRL) as non-linear functions of two environmental variables (soil pH and pine basal area) in natural vegetation. The model-fitted CWM traits were then used as constraints in the CATS model to predict the relative abundance of five grass species (*Bouteloua gracilis, Elymus elymoides, Festuca arizonica, Muhlenbergia montana,* and *Poa*

fendleriana) that were equally seeded into a 2×2 factorial experiment with soil parent material and light level as crossed factors. Main effects of light and soil parent material explained a significant amount of variation in overall seedling community composition, though the effects of light were strongest. *Bouteloua gracilis,* a C_4 species, was consistently more abundant in the full sun treatment, whereas the C_3 species, *E. elymoides, F. arizonica,* and *P. fendleriana*, dominated in shade treatments. The model-predicted relative abundances were significantly correlated with the observed relative abundances (r=0.53, P=0.01). *Poa fendleriana* was accurately predicted to be the most abundant species in the shade treatments, and *B. gracilis* was accurately predicted to be the most abundant species in the sun-limestone treatment. Our results provide strong evidence that trait-based models can be used to predict the outcome of the early stages of community assembly under experimental conditions. We discuss how managers can apply these models to define targets and predict understory plant community response to forest restoration treatments.

Reducing wilderness search and rescue operations through direct and indirect visitor contact within the Kachina Peaks Wilderness, Flagstaff, Arizona

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Abstract: Being prepared to hike in backcountry and wilderness is crucial for the safety and enjoyment of wilderness visitors. Many lack basic knowledge about high elevation environments and the importance of having sufficient resources to enjoy their experience and avoid illness and injury. This is particularly true for Kachina Peaks Wilderness located near Flagstaff, Arizona, home to the highest peak in Arizona, Humphreys Peak at 12,635 feet. Coconino County Sheriff's Department conducts numerous search and rescue (SAR) operations on the peaks every year to rescue and possibly save the lives of visitors who overlooked the importance of being prepared. In the summer of 2015, the U.S. Forest Service and a team of dedicated volunteers created an innovative preventive search and rescue (PSAR) program aimed specifically at reducing the number of SAR operations within the wilderness. Grand Canyon and Yosemite National Parks have documented the benefits of similar programs, reporting financial savings due to decreases in the number of backcountry SAR operations after implementation of a PSAR program. The Kachina Peaks Wilderness PSAR program includes indirect visitor education through visual signage and displays located at the Wilderness trailhead that discuss the essentials needed for wilderness hiking and altitude awareness and weather information. The PSAR program also utilizes trained volunteers who interact with visitors at the wilderness trailhead and on-trail to provide additional information and suggestions to help improve visitor experiences, and better prepare them for wilderness hiking, even suggesting alternative hikes for those unaware and unprepared to hike in a wilderness. Through these efforts, we hope to reduce the number of SAR incidents in the wilderness. While we cannot definitively attribute reduced numbers of operations directly to the introduction of the PSAR program, continuation of this program and collection of SAR data will provide a more definitive answer.

Vegetation structure conditions across the Colorado Plateau departed from reference conditions: a LANDFIRE enabled assessment

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Abstract: Assessing ecosystem conditions across large areas is a vexing but important problem that is greatly aided by spatial data and models provided by the LANDFIRE program. For example, LANDFIRE provides reference condition models that describe presettlement structure and composition for the ecosystems of the United States. We compared reference conditions to current vegetation structural data to calculate a metric called Vegetation Departure for all 74 mapped ecosystems of the Ecomap Colorado Plateau Semi-Desert Province 313 (Cleland et al. 2007). We found substantial structural changes in most ecosystems. For example, within the Ponderosa Pine Woodland ecosystem, we found that the open canopy large tree succession class was greatly underrepresented (up to 54%) and the closed canopy large tree succession class overrepresented (up to 49%) compared to reference conditions across the plateau. Overall Vegetation Departure was ~49% (low = 0, high =100). Similarly the Ponderosa Pine Savanna had an even higher overall departure level of 59%, mostly driven by underrepresentation of the open canopy succession classes. Rocky Mountain Montane Riparian Systems had high levels (~30%) of "Uncharacteristic Native" vegetation, where canopy cover and/or height did not match reference conditions (e.g., uncharacteristically low canopy cover). On the other hand, the Pinyon-Juniper Woodland had a relatively low overall vegetation departure value of 25%. In the Mixed Salt Desert Scrub ecosystem, LANDFIRE mapped over 17% as being "Uncharacteristic Native, but otherwise the ecosystem had relatively low Vegetation Departure (17%). While reference conditions do not always represent so called "Desired Future Conditions", comparing them to current conditions provides important planning context, can represent potential climate change vulnerabilities and provides a monitoring metric that can be applied across large areas. The reference conditions are under review currently and we encourage you participate in this effort.

The Lower Colorado River Multi-Species Conservation Program: successes and challenges after ten years of implementation

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Abstract: The Lower Colorado River Multi-Species Conservation Program (LCR MSCP) is a multi-stakeholder, federal and non-federal partnership responding to the need to balance the use of lower Colorado River water resources with the conservation of native species and their habitats in compliance with the Endangered Species Act (ESA). The LCR MSCP is a 50 year program to conserve at least 26 species, including seven currently listed as threatened or endangered under ESA, through the implementation of a Habitat Conservation Plan. The program area extends over 400 miles along the lower Colorado River from Lake Mead to the Southerly International Boundary with Mexico. The LCR MSCP provides ESA compliance for the delivery of 9 million acre-feet (maf) of water, power production from six dams, change in point of diversion of up to 1.574 maf of water, and routine operations and maintenance activities associated with management of the lower Colorado River. The program began implementation in 2005. Major components include augmenting native fish populations by raising and stocking over 1.2 million native fish into the lower Colorado River, conducting research on species and habitat, monitoring species populations and habitats throughout the program area, creating and managing at least 8,132 acres of new habitat, protecting existing habitat, and using adaptive management principals to ensure effective conservation. Through 2015, approximately 343,000 native fish have been raised and stocked by the LCR MSCP to meet augmentation goals and to maintain the genetic diversity of the Lake Mohave brood stock. Eleven conservation areas have been created, encompassing over 4,600 acres of riparian, marsh, and backwater habitats.

Development of transboundary land use and cover models to inform conservation planning efforts in the Southwest

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Abstract: To evaluate the effects of ongoing climate and land use changes, particularly for understanding regional ecological flows and connectivity, we are developing a consistent, trans-boundary datasets on land use and land cover for the Sky Islands/Madrean Archipelago (southwestern US and northern Mexico). I will discuss the challenges and opportunities of developing transboundary products, emphasizing the role that new geospatial tools like Google Earth Engine, as well as describe a new collaborative science platform for conducting comprehensive and transparent landscape conservation analysis and design.

High frequency vegetation monitoring for dynamic times in semiarid rangelands

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Abstract: Semiarid vegetation of the Colorado Plateau provides important wildlife habitat and livestock forage but is undergoing large changes induced by land use and climate. Remote sensing has unique advantages for monitoring broad spatial scales at high temporal frequency that can help assess vegetation response. We use the normalized difference vegetation index (NDVI) as an indicator of vegetation condition to improve understanding of vegetation response to climate under currently grazed and ungrazed conditions. We built monthly growing season vegetation response models by considering different durations of antecedent climate and water balance conditions preceding each NDVI measurement across an 11-year period. We found that 9 to 12 month durations of antecedent soil moisture were the best predictors of early and late growing season NDVI, but 0 to 3 month durations of evapotranspiration or water deficit were important predictors of mid-season NDVI. We found differences in vegetation response models that were linked to differences in plant community assemblage and historic grazing practices. We also found evidence of climate-legacy effects. We demonstrate the utility of our methods as a near-term management tool by forecasting monthly NDVI for 3 hold-out years with reasonably good accuracy. Understanding the relationships between climate/water balance and vegetation can create new opportunities to inform near-term management of semiarid rangelands that can help achieve long-term goals.

Informing renewable energy development decisions with landscape biodiversity measures

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Abstract: Renewable energy development is expanding in southwestern deserts, including Arizona. Energy developers look to resource management agencies to provide siting guidance on public lands. Agency siting guidance may incorporate information on potential development-wildlife conflicts for species of conservation concern and economic importance but information on comprehensive vertebrate biodiversity has been hard to incorporate. The National Gap Analysis program has developed watershed level mapping of vertebrate species habitat that supports inclusion of biodiversity richness information in siting guidance.. We obtained 511 National Gap vertebrate models representing native terrestrial vertebrate species identified by the Arizona Game and Fish Department (AGFD) as occurring in Arizona. Using these models in ArcMap (ESRI, 10.2) we calculated total biodiversity richness for groups of vertebrate models: 1) all species, 2) by four lifeform groups (amphibians, reptiles, birds, and mammals), and 3) by three sensitive guilds (bats, raptors, and migratory land birds) across Arizona. The mean and standard deviation of richness were calculated for all GIS raster cells (30m) for each of these groups and the richness value for each cell in a group raster was assigned a value representing how many standard deviations it varied from the group mean. Using these data, we generated maps showing the distribution in Arizona of above average richness by standard deviation category for each group. The Arizona Species and Habitat Conservation Guide (SHCG), developed by the AGFD, provides renewable energy development guidance that ranks habitat priority within Arizona, using parameters for some but not all native vertebrate species. We identified locations in Arizona that could pose development-wildlife conflicts using a GIS overlay of SHCG categories of lowest priority habitat with our rasters of above average richness. This approach can be applied across the western United States to provide additional input toward renewable energy development siting decisions.

Tumbleweeds and sand on the southeast Colorado Plateau: Does invasive *Salsola* increase dune mobility?

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Abstract: Vegetation is important in mitigating sand dune mobility, especially in areas with frequent winds and plentiful sand supply. On the southeastern Colorado Plateau, dune fields are common on public and tribal lands. Non-native forbs of the genus *Salsola* are increasingly invading the grasslands and steppe plant communities that stabilize these aeolian sand deposits. The impacts of *Salsola* on native vegetation, especially during periods of prolonged drought, are largely unknown. We are studying the relationship of *Salsola* to native vegetation composition and cover and to sediment movement on four different dune-grassland systems at Petrified Forest National Park and the Navajo Nation. In the spring of 2015, we established experimental plots (12-18 1-m^2 quadrats) at each site to be observed for four years. We are measuring the rate and intensity of *Salsola* invasion and the response of native plants to either the presence of invading *Salsola* or absence of *Salsola*, either through lack of invasion or removal by clipping or pulling. We hypothesize that the sedimentation and erosion measured at each plot will be a function of seasonal wind energy and the vegetation cover, particularly during periods of high wind speed. Further, native perennial grasses and shrubs can be reduced or replaced through competition with *Salsola*. While cover of *Salsola* infestations can be quite high in the summer and early fall, the species identified in northeast Arizona (*S. gobicola*, *S. paulsenii*, and *S. tragus*) are annuals. Where *Salsola* has replaced native vegetation, cover of dune substrates may be substantially reduced during the winter and spring seasons when higher winds are expected. Our poster presents preliminary results from the first year of observations. This project is part of the larger study 'Hydrologic Extremes and Aeolian Thresholds on southwestern tribal lands'.

Building advocates for the Colorado Plateau through collaborative, hands-on service learning projects

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Abstract: The mission of the Grand Canyon Trust is to protect and restore the Colorado Plateau - its spectacular landscapes, flowing rivers, clean air, diversity of plants and animals, and areas of beauty and solitude. To achieve our mission, we work collaboratively with federal and state agencies, tribes, and other environmental organizations. Equally as important, we need effective citizen advocates for our public and tribal lands. The Trust's Volunteer Program aims to connect residents and visitors to the unique landscapes of the Plateau through hands-on conservation work, forming life-long stewards and advocates for these special places. Our volunteers spend up to a week living on the land and working on conservation projects such as wildlife habitat or springs restoration, assessing grazing impacts, or supporting sustainable economic development on tribal lands. Volunteers engage in discussions about threats to

the region and learn about sustainable solutions, as well as learn tools for creating positive social change. The Volunteer Program is keenly interested in building the next generation of conservation leaders, and through our Youth Leadership Initiative we are providing young adults ages 14-25 entry points into conservation with volunteer service learning trips, conservation internships, and other opportunities to plug into this important work. Without youth involvement, conservation itself is unsustainable.

Soil water availability across an elevation gradient: a proxy study of climate change in the Southwest

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Abstract: Soil water availability (SWA) greatly affects the health and productivity of vegetation in dryland ecosystems and particularly in the arid Southwest. Forecasts for climate change in the Southwest include enhanced drought severity and frequency, highlighting the need to understand the impact of water limitation on plants and ecosystems. The initiation of the Southwest Experimental Garden Array (SEGA) project in 2012 provided a platform to start a long-term elevation gradient precipitation manipulation study. Five sites (three within the SEGA study area), with elevations ranging from 1,566 to 2,591 meters, near Flagstaff, AZ were selected based on plant community compositions that represent those found on the Colorado Plateau of the Southwestern United States. Treatments at each site will include: ambient (control), rainout shelters with 50% removal of precipitation, and water addition. Experimentally manipulating the soil moisture at these sites will inform scientists, land managers, and the general public on how shifts in SWA affects plant populations present at these elevations as well as the larger communities within the region. Repeat measurements of plant structure, demography, phenology, and net primary productivity, in tandem with soil moisture and weather conditions at each site over the long-term, will provide information on how plant populations and communities may react to the warmer, drier conditions predicted for the region.

Analysis of sub-hourly weather data for a *Pinus ponderosa* site at the northwest edge of the North American monsoon system

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Abstract: False rings in tree-ring chronologies throughout the American Southwest have been used by dendrochronologists to interpret past magnitudes of summertime monsoonal precipitation. However, the mechanisms that drive the formation of false tree rings are unclear. We are studying *Pinus ponderosa* radial growth at a state-of-the-art NevCAN (Nevada Climate-ecohydrological Assessment Network) site in the Sheep Range, Nevada, USA. The Sheep Range is located in the Great Basin at the northwest edge of the region influenced by the North American monsoon (NAM), and *P. ponderosa* is particularly sensitive to monsoonal precipitation. We aim to investigate the influence of the NAM and alternative precipitation events at this site using a combination of dendrochronological techniques including wood anatomy and stable isotope analysis. We present here a detailed analysis of the sub-hourly weather data that have been collected over the past three years, and we show how monsoonal climate is realized at this high-elevation site.

An Upward Shift of Engelmann Spruce in Sparse Old-Growth Forests on the Pinaleño Mountains in the American Southwest

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Abstract: Spruce-fir forests in the American Southwest are located at the uppermost elevation of isolated desert mountain ranges consisting of species once found at lower elevations during the Last Glacial Maximum. These species have gained less attention than other more widespread forest species in the region, even though the available climate space for these species to migrate upwards has become drastically limited. We analyzed the coexistence of Engelmann spruce (*Picea engelmannii*) and corkbark fir (*Abies lasiocarpa* var. *arizonica*) on the Pinaleño Mountains, Arizona, USA, from ca. 1,300 cal yr BP years ago projected to 2099 through the combination of a meadow sediment core, tree-ring chronologies, plot demographics, and ecological niche models. We particularly

examined the influence of warm-season vapor-pressure deficit, cold-season minimum temperature, cold-season precipitation, and monsoon-season precipitation with the growth-climate relationship for Engelmann spruce and corkbark fir on an elevation gradient (32.7 ºN, 2800–3270 m). Results indicate that Engelmann spruce declined within the Transition Forest (2930–3100 m) on the Pinaleño Mountains from 1988 to 2012, while corkbark fir, Douglas-fir (*Pseudotsuga menzessi*) and quaking aspen (*Populus tremuloides*) have maintained similar densities. However, ecological niche models projected to 2099 with dynamically down-scaled (15 km) general circulation models trained on these same climatic variables project a decrease in probability of occurrence for Engelmann spruce, subalpine fir (*Abies lasiocarpa*), and quaking aspen for the Rocky Mountain region influenced by the North American Monsoon System.

Comparing metabolic rates of native chubs species and non-native fish species of Arizona

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Abstract: Arizona's water bodies have a variety of native and non-native fish species. Most native fish species are threatened or endangered, and non-native fishes have replaced native species across much of the state. The ecological ramifications of these community changes are not clear. While energetic requirements can help describe ecological differences between native and non-native fish species, little is known about metabolic rates in native chub and non-native fish species. Here, we use metabolic rates in still and flowing water to describe the energetic requirements of native and non-native fish species. Fish metabolism was measured using a custom-built flow chamber and integrated dissolved oxygen meter. Oxygen consumption of three native fish (roundtail chub, *Gila robusta*; bonytail, *G. elegans*; humpback chub, *G. cypha*) and three non-native fish species (largemouth bass, *Micropterus salmoides*; koi, *Cyprinus carpio*; goldfish, *Carassius auratus*) found in Arizona was measured. Bonytail were the most efficient swimmers, using the least amount of oxygen per body length/second and able to swim at the highest water velocities. Roundtail chub and largemouth bass used similar amounts of oxygen per body length/second, while koi were able to swim at high velocities but were the least efficient swimmers at high speeds. These differences in swimming efficiency could influence the ability of each species to maintain position in desert streams that experience floods and fast flowing water. The greater swimming efficiency of native fish species may explain why large flood events seem to temporarily restore native fish communities.

Truth and Consequences of the 1968 Central Arizona Project Act

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Abstract: In 1968, after over 40 years of anticipation, a Supreme Court battle, and hardball politics, Arizona finally won Congressional approval to build its Central Arizona Project (CAP). To obtain California's approval, Arizona agreed to a critical condition that CAP would be junior to California's water rights. The agreement set in place the 'structural deficit' that now threatens Lake Mead, and the water users who rely on the Lake for reliable deliveries, hydropower and recreation. This talk covers the history before the passage of the act, the politics that lead to the agreement, and what has happened since. It discusses one of the most important battles in the history of the environmental movement, the debate over whether to build dams in the Grand Canyon to support the project financially. Colorado's Wayne Aspinall, Secretary of the Interior Stewart Udall, Arizona's Carl Hayden and Morris Udall, and the Sierra Club's David Brower all played starring roles in this major event in western water development. The consequences of this act remain with us today.

Habitat use by bats at and near uranium mines within the Grand Canyon National Park region

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Abstract: Uranium mining near Grand Canyon National Park is in a variety of stages of construction and closure. It is important to understand the possible impacts of contaminants to surrounding ecosystems from these mines. As part of a multi-disciplinary study, the USGS-Fort Collins Science Center, Arid Lands Field Station has participated in providing insight on habitat use by bats at these mines and surrounding areas. Bats serve as a model taxonomic group for studying contaminants from uranium mining because they are long-lived (e.g., 25+ years) and over time can allow for the detection of contaminants from low-dose exposure. Some possible contaminant exposure may come directly from consumption of water related to mining efforts, such as the water detention ponds within mining facilities. In addition to direct consumption of water from the uranium mine detention ponds, visiting bats to the site can also consume emerging aquatic insects that also use the detention pond. Despite these direct means of possible contamination, it is important to understand the long-term habitat use and frequency of occurrence of bats at these pre- and post-developed mining sites and adjacent areas that are not exposed to mining. In order to examine these patterns of habitat use, frequency of occurrence, and diet, I conducted acoustic monitoring, captured bats with mist nets, and collected feces (guano) from individuals to determine dietary preferences of bats using the habitats at three mines.

Benefits and risks of temperature modification at Glen Canyon Dam to fishes of the Colorado River through the Grand Canyon

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Abstract: Cold hypolimnetic water released from Glen Canyon Dam limits reproduction of native warm-water fishes of the Colorado River through lower Glen, Marble, and Grand Canyons. A temperature control device (TCD) has been proposed to warm dam releases by modifying the penstocks and allowing warmer water to be withdrawn from the near-surface of Lake Powell. The effect on temperature from modifying the penstocks was evaluated with a 1-D Generalized Environmental Modeling System (GEMSS) for high reservoir elevations (1990–2003). Modifying 0, 2, 4, or all 8 penstocks (i.e., units) results in annual temperature degree-days (TDDs, base temperature ≥10ºC) of dam releases equivalent to 8%, 53%, 82%, and 88%, respectively, of pre-dam conditions (i.e., 1959). However, only 17% of cumulative TDDs occur before July 1 for these modifications (maximum TDDs in August and September), compared to 48% for pre-dam conditions (maximum TDDs in June and July). Thermal requirements of 24 fish species show that a 2-unit TCD has little effect on most fish species, and TDDs continue to favor cold-water species such as rainbow trout (*Oncorhynchus mykiss*) and brown trout (*Salmo trutta*), and provide suitable conditions for reproduction and growth of walleye (*Sander vitreus*) and smallmouth bass (*Micropterus dolomieu*) that are currently rare in the system. The 4- and 8-unit TCDs have similar benefit to warm-water native and nonnative species, but suitable conditions for spring spawners do not occur until late summer. Native species most likely to benefit include humpback chub (*Gila cypha*), flannelmouth sucker (*Catostomus latipinnis*), bluehead sucker (*C. discobolus*), razorback sucker (*Xyrauchen texanus*), and roundtail chub (*G. robusta*); whereas nonnative competitors and predators would also benefit, including red shiner (*Cyprinella lutrensis*), fathead minnow (*Pimephales promelas*), common carp (*Cyprinus carpio*), channel catfish (*Ictalurus punctatus*), and largemouth bass (*Micropterus salmoides*).

Does prescribed fire promote forest resistance to drought?

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Abstract: Prescribed fire is a primary tool used to restore western forests following more than a century of fire exclusion. Prescribed fire reduces fire risk partly by removing small trees and shrubs; it is assumed that there is less competition for resources among remaining trees following prescribed fire so that they are more resistant (more likely to survive) in the face of additional stressors, such as drought. Yet this proposition remains largely untested, so that managers do not have the basic information to evaluate if prescribed fire may help forests adapt to a future of more frequent drought. Following two years of drought, we surveyed 5,981 trees in 28 burned and 13 unburned ponderosa pine/mixed conifer plots in 2014 at Sequoia, Kings Canyon, and Yosemite National Parks. Fire had occurred in the burned plots from 6 to 27 years before our survey. After accounting for differences in individual tree diameter, trees found in the burned plots had significantly reduced mortality probabilities. Ponderosa pine had higher overall mortality probabilities compared to other co-occurring species, but its proportional reduction in mortality in burned stands was comparable to that of the other species. Stand density (number of stems per hectare) was significantly lower in burned versus unburned sites, supporting the idea that reduced competition may be responsible for the differential drought mortality response. At the time of writing, we are not sure if burned stands will maintain lower tree mortality probabilities in the face of the continued, severe drought of 2015. Future work should aim to better identify drought response mechanisms and how this may vary across other forest types and regions, particularly in other areas experiencing severe drought in the Sierra Nevada and on the Colorado Plateau.

Influences of the tamarisk leaf beetle (*Diorhabda carinulata*) on birds along the Dolores River in southwest Colorado

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Abstract: Biological control, or the introduction of host-specific natural enemies to control exotic pests, is potentially a sustainable and relatively inexpensive option for the management of invasive species. However, there are questions associated with this approach as it calls for the introduction of additional non-native organisms and can contribute to changes in the existing structure of native plant and animal communities. From 2008-2014 we examined the effects of a biological control agent, the tamarisk leaf beetle (*Diorhabda carinulata*), on the diet of 25 bird species over the Colorado Plateau in southwestern Colorado. We documented tamarisk phenology, avian foraging behavior, characterized the arthropod community, sampled bird diets, and undertook an experiment to determine whether tamarisk leaf beetles are palatable to birds. Our goal was to determine the degree to which birds eat tamarisk leaf beetles. We observed that tamarisk leaf beetles compose up to 24% (95% CI; 19.9-27.4 percent) of arthropod abundance and 35.4%

(95% CI; 32.4-45.1 percent) of biomass within our mixed-tamarisk habitat within our Dolores River study area. However, we found that only 11 of 188 birds of four species ate tamarisk leaf beetles, despite a superabundance of *D. carinulata* in the environment. The frequency of occurrence of tamarisk leaf beetles in bird diets was 2.1% (95% CI; 1.3- 2.9 percent) by abundance and 3.4% (95% CI; 2.6-4.2 percent) by biomass averaged across all species. Although most avian foraging occurred within tamarisk habitat, the largest portion of the diet was native insects. We conclude that tamarisk leaf beetles probably do not contribute significantly to the diets of birds in areas where biological control of tamarisk is being applied, which highlights the importance of restoration efforts that will help support bird populations as tamarisk stands are reduced along riparian corridors.

The Glen Canyon Dam Adaptive Management Program 20 years after the 1st EIS on GCD operations: an overview

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Abstract: The Glen Canyon Dam Adaptive Management Program was established in 1997 to provide for long-term research and monitoring of the effects of Glen Canyon Dam and its operations on downstream resources. The scientific information obtained under the Adaptive Management Program is used as the basis for recommendations for dam operations and management actions. The Program's Adaptive Management Work Group is a federal advisory committee comprised of 25 stakeholder groups that advises the Secretary of Interior on the effects of dam operations and related management actions on Colorado River resources in Glen and Grand Canyons. Key resources include native and nonnative fishes, the aquatic food base, riparian vegetation, sediment, cultural resources, and recreational opportunities. The program is managed by the Bureau of Reclamation, with research and monitoring efforts overseen by the U.S. Geological Survey's Grand Canyon Monitoring and Research Center. Focal areas include fishes like humpback chub, *Gila cypha*, an endangered species, and nonnative rainbow trout, *Oncochynchus mykiss*, which provide a popular sport fishery, as well as sediment transport, storage, and dynamics with particular emphasis on the effects of implementation of the High Flow Experiment protocol beginning in 2012. Information on resources of interest is collected, analyzed, and provided to managers and stakeholders in support of the ongoing adaptive management process, which is designed to protect and benefit downstream resources by improving Glen Canyon Dam operations.

Key factors controlling the growth of biological soil crusts: towards a protocol to produce biocrusts in greenhouse facilities

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Abstract: Biological soil crusts (biocrusts) are topsoil communities comprised of, but not limited to, cyanobacteria, algae, lichens, and mosses that grow intimately associated with soil particles in drylands. Biocrusts have central ecological roles in these areas as sources of carbon and nutrients, and efficiently retain water and prevent soil erosion, which improves soil structure and promotes soil fertility. However, human activities, such as cattle grazing, hiking, or military training, are rapidly striking biocrusts. Although it is well known that the inoculation with cyanobacteria or lichens can enhance the recovery of biocrusts in degraded soils, little is known about the factors that control their growth rates. Using soil and inocula from four different sites located in one cold desert (Utah) and in one hot desert (New Mexico), we performed a fractional factorial experiment involving seven factors (water, light, P, N, calcium carbonate, trace metals, and type of inoculum) to screen their effects on the growth of biocrusts. After four months, we measured the concentration of chlorophyll *a*, and we discovered that water, light and P, N, or P+N were the most important factors controlling the growth of biocrusts. In the experimental treatments involving these three factors, we measured a similar concentration of chlorophyll *a* (or even higher) to this found in the field locations. Amplification of the 16S rRNA gene segment using universal bacteria primers revealed a microbial community composition in the biocrusts grown that closely corresponds to initial measurements made on inocula. In summary, based on our success in obtaining biocrust biomass from natural communities in greenhouse facilities, without significantly changing its community composition at the phylum and cyanobacterial level, we are paving the road to propose a protocol to produce a high quality-nursed inoculum aiming to assist restoration of arid and semi-arid ecosystems affected by large-scale disturbances.

Carbon dioxide regulation and power plants on the plateau: Arizona's response to the Environmental Protection Agency's Clean Power Plan

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Abstract: The United States Environmental Protection Agency (EPA), in summer 2014, released a draft rule for carbon dioxide emissions reductions from existing electricity generating units (power plants), commonly referred to as the Clean Power Plan. Arizona faces the second-strictest emissions reduction requirements under the plan, at a 52% reduction from an average emissions rate of 1,350 lbs./MWH of CO_2 in 2005 to 702 lbs./MWH in 2030. The EPA proposed four 'building blocks' for meeting the target, including increasing power plant efficiency, implementing energy efficiency, development of renewable energy sources, and replacement of coal power plants with natural gas. The Arizona Department of Environmental Quality, charged with developing Arizona's implementation plan for the rule, is leading a stakeholder process to involve major power user groups, electric utilities and coops, environmental groups, energy and fossil fuel suppliers, and other interested parties in the planning process. Arizona's likely response to the rule will necessarily involve the shutdown of part or all of some of the state's coal plants, including the Cholla Power Plant, Navajo Generating Station, and Springerville Generating Station, where utility owners have recently announced plans for unit retirement. Coal plant shutdown or replacement will have positive environmental consequences for the region beyond reductions in CO_2 emissions, but could have negative economic consequences for electricity rate-payers and providers of coal, including the Navajo Nation and Hopi Tribe. Additionally, increased reliance on natural gas creates a risk of price volatility for electricity consumers, while increasing use of renewables poses other operational challenges for electric utilities. Our analysis of Arizona's options and likely implementation strategies highlights the challenges and benefits of various courses of action that Arizona can take in its final plan, to be submitted in summer 2016.

Increasing values in conservation work: the Escalante River Watershed Project as a conservation laboratory

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Abstract: Join Kris Waggoner, the Project Coordinator for the Escalante River Watershed Partnership (ERWP) as she discusses the challenges and rewards of using four conservation corps programs in one watershed, and the value of the conservation corps program in meeting multiple goals for a variety of funders. Kris will discuss the goals of the ERWP funders and how using conservation corps program meets both the conservation targets of the partnership and the social values the funders are seeking while providing jobs and training for youth. She will also discuss the watershed wide approach that the ERWP has taken in implementing their restoration tactics and how that has increased capacity for fund raising.

Species from feces: a tool for genetically identifying bats

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Abstract: Bat guano is a relatively untapped reservoir of information, having great utility as a DNA source because it is abundant in caves and mines even when bats are not present, and is stationary and easy to collect. Three technologies have come of age that together enable species identity from guano: reliable DNA typing from feces, DNA barcoding (species-specific genetic identifiers), and bioinformatic analysis. Taking advantage of these advances, we used 1.6 million sequences to develop a DNA mini-barcode assay that targets a segment of mitochondrial gene Cytochrome c oxidase I that we have found to be highly discriminatory among Chiroptera globally, readily accommodates fecal DNA, and selectively targets bat but not prey DNA. Our assay has high resolution (93%) for barcoded bat species; we have successfully validated it from feces of 25 bat species (primarily from the U.S. southwest), with aged fecal pellets (up to 3 months old), and with individual and pooled guano pellets, such that questions can target individuals (using specific fecal pellets) or populations and communities (long-term roost sites). Other benefits of our Species from Feces tool is in confirming field identification, especially of morphologically similar species. In several instances our genetic approach revealed misidentification of mist-netted species. We have developed searchable website (http://nau.edu/batdna) that allows users to determine the discriminatory power of our markers for bat species that interest them. Our Species from Feces tool has immediate application in the U.S. southwest, where abandoned mines are plentiful and used by bats as roost sites, and in central and eastern U.S. and Canada, where bats are under threat from White-Nose Syndrome. It is also a potentially powerful application worldwide for assessing presence of bat species that are vulnerable or facing extinction.

Mapping invasive buffelgrass in southern Arizona using the temporal dynamics of landscape greenness response to precipitation

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Abstract: The detection and eradication of buffelgrass (*Pennisetum ciliare*) is a high priority for land managers in Saguaro National Park (SNP) in southern Arizona, where the invasive perennial grass out-competes native vegetation for scarce resources and fosters devastating wildfires. Our research leveraged the rapid green-up response of buffelgrass after precipitation inputs to map plant locations across SNP. We used four primary sources of data: field observations of buffelgrass growth, precipitation timing and amount, satellite imagery measures of greenness (i.e., normalized difference vegetation index [NDVI]), and aerial surveys of buffelgrass presence in SNP. We first established the relationship of buffelgrass greenness to precipitation timing and NDVI response by linking weekly National Phenology Network (NPN) field observations of plant growth in Tucson, AZ to rainfall data and composited 250 m moderate resolution imaging spectroradiometer (MODIS) imagery from 2010 to 2013. We compiled plant phenology and precipitation data into 8-day periods to correspond with the MODIS composite interval. Correlation analyses revealed that field observations of greenness were most highly correlated with precipitation accumulated over the previous four composite periods (r=0.78) and with coincident MODIS NDVI measures. We extrapolated these findings to the analysis of precipitation and NDVI correlations across SNP on the basis of rasterized maps of buffelgrass presence and density derived from a 2012 helicopter survey. In a time series of MODIS data from 2011 to 2013, pixels that contained higher percentages of buffelgrass displayed uniformly higher correlations of NDVI with precipitation. Moreover, the correlations of pixels with any identified amount of buffelgrass peaked at fewer accumulated periods of moisture. Maps of the correlation coefficients of NDVI and precipitation across SNP showed strong spatial association with verified buffelgrass locations, confirming the promise of this approach for identifying buffelgrass presence across regional extents.

Mercury and selenium accumulation in the Colorado River food web, Grand Canyon, USA

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Abstract: Mercury (Hg) and selenium (Se) biomagnify in aquatic food webs and are toxic to fish and wildlife. We measured Hg and Se in organic matter, invertebrates, and fishes in the Colorado River food web at sites spanning 387 river km downstream of Glen Canyon Dam. Concentrations were relatively high among sites compared to other large rivers (mean wet weight for six fishes was 0.17-1.59 $\mu g\ g^{-1}$ Hg and 1.35-2.65 $\mu g\ g^{-1}$ Se), but consistent longitudinal patterns in Hg or Se concentrations relative to the dam were lacking. Mercury increased (slope = 0.147) with $\delta^{15}N$, a metric of trophic position, indicating biomagnification similar to that observed in other freshwater systems. Organisms regularly exceeded exposure risk thresholds for wildlife and humans (6-100% and 56-100% of samples for Hg and Se, respectfully, among risk thresholds). In the Colorado River, Grand Canyon, Hg and Se concentrations pose exposure risks for fish, wildlife, and humans and our findings add to a growing body of evidence that remote ecosystems are vulnerable to long range transport and subsequent bioaccumulation of contaminants. Managing exposure risks in Grand Canyon will remain a challenge, as sources and transport mechanisms of Hg and Se extend far beyond park boundaries.

Variation in surface gamma radiation around breccia-pipe uranium deposits before, during, and after mining in the Grand Canyon, Arizona region

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Abstract: In 2012, the Secretary of the Department of Interior issued a record of decision withdrawing about 1 million acres of federal land from mining in the Grand Canyon region for 20 years, subject to valid existing claims. Uncertainties about potential effects to biota and water resources from mining breccia-pipe uranium deposits are primary reasons for the withdrawal. Radiation associated with uranium deposits and mines has potential to affect the health of biota. In order to better understand the effects of uranium mining on surface radiation, gamma-radiation surveys were conducted at three different breccia-pipe uranium deposits to represent conditions before (Canyon Mine), during (Pinenut Mine), and after (Arizona 1 Mine) mining, but before mine reclamation. Surface radiation at the Canyon Mine was concentrated directly over the buried ore deposit and varied up to about 3-4 times background measured around the mine. Because the ore deposit is about 300 meters below the surface, radiation may be from remnant explora-

tion drill cuttings. During mining, a broad radiation halo existed around the Pinenut Mine with up to about 15-20 times background measured at the mine boundary, decreasing with distance away from the mine. This radiation halo is related to the storage of ore at the surface before transport to the mill. After mining, a small radiation anomaly (about 150 m square) of about 3-5 times background existed north of the Arizona 1 Mine boundary. In addition, a broader, relatively weak anomaly of about 2 times background existed around the mine perimeter, and north of the mine, following surface drainage. These patterns were likely caused by distribution of dust during mining operations as the dominant wind direction is to the north. These results can be used to help quantify risk to biota during and after mining, and also could help guide reclamation planning.

Overgrazing by bison destabilizes soil and diminishes plant growth in Grand Canyon National Park

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Abstract: Intensive grazing by the overpopulated bison in the Grand Canyon National Park presents a threat to devastate the productivity and biodiversity of the landscape. To understand the impact of bison on soil stability and vegetation, we established 133 transects in high and low bison use meadows on the Kaibab Plateau in Fall of 2014. Bison scat was counted along each transect and was used as a proxy for use intensity. We sampled soil and tested for soil stability using the slake method. We measured plant height and percentage grass cover at each transect. Soil stability, plant height, and percentage grass cover were significantly higher in low use meadows than high use meadows. Across all sites, we found a significant negative relationship between bison scat count and soil stability. We also found that bison scat count was associated with reduced plant height across all sites. This study provides preliminary evidence of potential negative impact of bison in the national park. Our results suggest the urgency of bison population management for conserving valuable natural resources and ecological integrity of the landscape.

Consequences of an altered thermal regime for Colorado River native fishes in Grand Canyon

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Abstract: Throughout the Southwestern United States, native fish populations continue to decline with decreases largely attributed to predation and competition by introduced warm water fishes. In the Colorado River in Grand Canyon a few species of native fish, including humpback chub (*Gila Cypha*), flannelmouth sucker (*Catostomus latipinnis*), and bluehead sucker (*Catostomus discobolus*), have managed to persist and in recent years even expand in numbers despite overall declining trends for most other native fishes in the desert southwest. One reason for this unique increase may be the altered thermal regime of the Colorado River in Grand Canyon caused by Glen Canyon Dam. Although stenothermic cold water releases typically less than 10°C are detrimental to native Colorado River fishes, they have been effective at keeping invasive warm water species out of the Little Colorado River, an important tributary for native fish spawning and recruitment. Adaptations that allowed native fish to persist in the historically unregulated Colorado River may also facilitate persistence under current cold-water conditions and allow native fish to take advantage of recent warming events caused by drought conditions at Lake Powell.

An evaluation of two new tools for removal of quagga mussels (*Dreissena bugensis*) from water conveyance systems

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Abstract: It is well documented that quagga mussels, *Dreissena bugensis*, create numerous long lasting and detrimental impacts to water conveyance systems and plumbing infrastructure. Their prolific breeding and quick colonization makes controlling populations and preventing future spread difficult. Chlorine products are currently used to remove quagga mussels from infrastructure, but chlorine is extremely toxic to non-target organisms and corrosive to equipment. In a controlled laboratory setting, we evaluated two new treatments for suppression or eradication of adult quagga mussels. Treatments for evaluation were chosen based on their suitability for application in fish hatcheries and large water delivery or hydroelectric infrastructures, where having minimal effects on non-target organisms are desirable. Treatments of liquid ammonia (29%) and salt (NaCl), were applied for 1-3 days at varying concentrations. Ammonia is a byproduct of fish metabolism, which natural bacteria in the environment detoxify, and salt up to 6 ppt has been demonstrated to be non-lethal to most freshwater fish. We found that 0.5 ml of ammonia (29%) per liter of water and 6 ppt salt concentration applied for a minimum of three days resulted in less than one percent survival of adult quagga mussels.

Genetic variation in adaptive traits of southwestern white pine: early results

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Abstract: Southwestern white pine (*Pinus strobiformis;* SWWP) is a high-elevation five-needle white pine found in the southwestern United States and Mexico that is susceptible to dieback and mortality from white pine blister rust, a non-native disease caused by the fungal pathogen, *Cronartium ribicola*. Additionally, the future sustainability of SWWP could be compromised by rapidly changing climate conditions across its range. There is a need to understand how adaptive traits vary across the range of SWWP and in conjunction with genetic resistance to white pine blister rust for sustainable management of SWWP. In 2013, we began a series of common garden studies of SWWP to investigate genetic variation in adaptive traits. The common gardens included a greenhouse study in which a drought treatment was applied to half of the 420 seedlings from 44 families representing 16 seed source populations from Arizona and New Mexico. The number of days to mortality was recorded for all drought-treated seedlings. Traits associated with drought adaptation (wood density, tracheid diameter, tracheid wall thickness, specific leaf area, stomata density, shoot-root ratio) are being measured on each population and related to mortality. A common garden located outside in Flagstaff, AZ contains 165 families from Arizona and New Mexico, for which we are recording adaptive traits related to growth and survival. To study the effects of epigenetics, developing seeds are being warmed and traits compared with control lots following sowing in the greenhouse. We will use results on from our trials to determine where adaptive traits may overlap in populations and families and across the landscape. We will also link our results to results from disease resistance trials occurring in Oregon. Results from epigenetics research will provide information about how similar trees might respond to warming climatic conditions.

Limestone springs provide a possible refuge for native species from non-native crayfish

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Abstract: Introduced non-native species have played a large role in the decline of fish, amphibians, and other aquatic species in much of western North America. Introduced crayfish have few effective predators in much of this region, their populations may reach extraordinarily high densities, and they may decimate aquatic vegetation and aquatic animals. Even for large-bodied animal species, crayfish predation on eggs, larvae, and juvenile stages may lead to serious declines and local extirpation. Introduced crayfish have been shown to kill young Sonora mud turtles (*Kinosternon sonoriense*) in the Southwest, and size/age structure of mud turtles at some sites with high crayfish numbers is shifted strongly toward large, old individuals, suggesting failure of effective recruitment of young turtles into the population. Lack of recruitment, in turn, signals the potential for an impending crash in the turtle populations in these areas. In contrast, pools, streams, and other surface waters fed by large limestone springs in the Colorado Plateau region have high levels of carbonates and carbon dioxide, which severely limit crayfish and other gill-breathing species. In these areas, Sonora mud turtles show a normal, "healthy" size structure, balanced between juveniles, young, and mature adults. We studied the specific relationship between water chemistry, crayfish numbers, and Sonora mud turtle populations at two sites in central Arizona, Montezuma Well and adjacent Beaver Creek and Fossil Creek. Our observations at these study sites suggest that large carbonate-rich spring systems may provide a local (albeit limited) refuge for mud turtles and other native aquatic species.

How can experimental gardens improve conservation knowledge and practice?

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Abstract: Common gardens and provenance trials have long served as important tools in evolutionary ecology, agriculture, and forestry. With species and ecosystems facing the threats from climate change and invasive species, experimental plantings that partition genetic and environmental sources of variation are increasingly important to refine empirical model predicting future species distributions and to determining whether mitigation of climate impacts is possible. The Southwest Experimental Garden Array provides an experimental facility and framework that allows multiple research groups to test performance genetically different sources of plant species from grasses to trees and from foundation species to the critically endangered. In collaboration with government agencies and land owners, we are establishing ten experimental garden sites across a range of temperatures, enabling researcher to address the effects of changing temperature experimentally. In particular, these experiments address how

genetic variation within species can help mitigate climate change impacts. Examples from projects on grasses, trees, and rare plants illustrate how the results from common garden experiments can influence conservation actions in the face of a changing climate and invasive species spread. The results can guide what sources of seed should be used for plantings and how interacting mutualists, competitors, pathogens, and herbivores can affect outcomes. Common gardens across a range of temperatures can play an important role in conservation in a changing world.

Restoring Heiser Spring at Wupatki National Monument

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Abstract: Heiser Spring is fed via a local perched aquifer in the Moenkopi Formation, and is among the few sources of reliable surface water within Wupatki National Monument. Prior to Anglo settlement, the spring was utilized by Native Americans. Beginning in the early 20th century, Heiser Spring was sequentially relied upon as the primary water supply for a ranching homestead, an early archeological field camp, and a Depression era labor camp. The National Park Service (NPS) purchased the homestead tract in 1950, and developed it into an operations facility and employee housing area. As a cumulative result of post-Anglo settlement use and development, Heiser Spring is among the most severely degraded natural features within the national monument. Between 1990 and 2002, the NPS phased out operations near the spring and removed most structures. The 2002 General Management Plan proposed formally abandoning operations area and restoring the springs to a more natural condition. Restoration planning was completed between 2007 and 2009, and restoration tasks were implemented during 2009 and 2010 by the NPS and partners under cooperative agreements. The total project area is 12 acres, and notable accomplishments include: removal of 2¼ tons of abandoned infrastructure and debris, demolition and removal of the four primary water diversion structures, closure of ⅓ mile of access road, herbicide treatment of 2½ acres of invasive camelthorn plants (*Alhagi maurorum* Medik.), and "dry-land" revegetation treatments on 1.35 acres. Follow-up actions since 2010 include: continued herbicide treatment of invasive camelthorn, continuous water table monitoring, and qualitative monitoring with repeat photographs and field observations. An overview will be presented on Heiser Spring and the restoration effort, including hydrogeology, history, reference conditions, restoration objectives, regulatory compliance, implementation, monitoring, and recovery of the area since 2010.

Conservation consequences of rapid community evolution in response to climate change and invasive species

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Abstract: Climate change and invasive species have the potential to be agents of natural selection on foundation plant species, which in turn affect whole communities of organisms ranging from microbes to vertebrates. Thus, climate change, invasive species and other global challenges are not just ecological events, but evolutionary events as well. This has important basic and applied implications, as anthropogenic effects are changing the very fabric of communities by selecting for novel communities, ecosystems, and interactions, which in turn result in new evolutionary trajectories. Although this evolutionary process may compensate, in part, for global change, there are definite limits especially in regions such as the American Southwest. In this region climate and other global changes are among the greatest in North America and can exceed the ability of foundation plants to either adapt or migrate to new environments where they can still survive. We develop examples with climate change on pinyon woodlands, invasive tamarisk on riparian communities, and introduced elk on understory goldenrod communities. This "new global change reality" is likely to destabilize communities and result in biodiversity loss. Importantly, the change in selection regimes with global change will further complicate land management goals of restoring for unattainable past conditions. Key to quantifying and mitigating these ecological and evolutionary effects is the use of experimental forests/common gardens arrayed across temperature, moisture, disturbance, and other gradients that allow researchers/managers to identify those genotypes and populations best suited to projected future environments. The NSF/NAU supported Southwest Experimental Garden Array (SEGA; http://www.sega.nau.edu) embedded in lands of diverse GO and NGOs is an essential tool open to all users to quantify the genetic components of community structure, which in turn can be used in restoration to optimize biodiversity, ecosystem processes, and other management goals.

Using the Southwest Experimental Garden Array (SEGA) to identify plant genotypes and populations that can survive future climates

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Abstract: Climate change is a grave risk for the ecosystems of the world; with rapid climate change, plants that are locally adapted today are likely to become locally maladapted to tomorrow's environments. In regions with especially rapid change such as the American Southwest, local populations are unlikely to possess sufficient genetic variation to adapt to these new environments. Similarly, with rapid change and a fragmented landscape, many species cannot migrate fast enough to reach favorable environments. Ignoring this climate change reality will contribute to restoration failure, high biodiversity loss, and the loss of restoration funding. With foundation species that support 1,000s of other species (e.g., Fremont cottonwood, pinyon pine), their loss will have cascading impacts on whole communities. Thus, it is crucial to identify the individual plant genotypes and populations that can survive future conditions. To achieve this goal, the National Science Foundation, Northern Arizona University, and land managers, including the U.S. Forest Service, Bureau of Land Management, Bureau of Reclamation, Grand Canyon Trust, National Park Service, Arizona Game and Fish Department, Babbitt Ranches, The Nature Conservancy, and The Arboretum at Flagstaff have collaborated to establish the Southwest Experimental Garden Array (SEGA; http://www.sega.nau.edu). This array is composed of 10+ experimental forests/common gardens distributed along an elevation gradient from desert to mixed conifer forests. Combining experimental water treatments and using elevation as a surrogate for temperature and moisture, scientists and managers can identify the genotypes, populations, and beneficial interactions among species that are best suited for a range of future conditions that support high biodiversity and minimize risk of restoration failure. This experimental approach is currently being used in reforestation in Canada and other regions of the world. SEGA is open to all with the goal of using the power of genetics to promote best restoration practices for future environmental conditions.

The San Juan River recovery management and planning

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Abstract: The San Juan River Recovery Implementation Program (Program) was initiated in 1992 as a result of an Endangered Species Act section 7 consultation on the Animas-La Plate Water Project in southwestern Colorado. The Program's two primary goals are recovering the endangered Colorado pikeminnow and razorback sucker in the San Juan River Basin and allowing water development to proceed in compliance with applicable federal and state laws. The Program's activities and actions serve as the "reasonable and prudent alternative" for water projects in the basin and help ensure those projects will not jeopardize the continued existence of the two endangered fish. An underlying premise of the Program is that recovery will be accomplished within the context of conservation and management of the entire native fish assemblage and in a manner that does not compromise the persistence of unprotected native fishes. One of the Program's primary guiding documents is its Long Range Plan (LRP) that identifies activities believed necessary to recover the listed species in the San Juan Basin. The LRP describes what actions will be implemented, who will implement them, when they will be implemented, and why. Details of how actions will be carried out are described in supporting documents and plans such as genetics management plans, augmentation plans, monitoring plans, and annual work plans. The LRP functions under the principles of adaptive management where annual updates and periodic revisions are necessary to ensure the best use of available scientific information in modifying or eliminating existing activities and formulating future Program activities. The Program has made great strides toward recovering the Colorado pikeminnow and razorback sucker in the San Juan Basin, but more work is needed to achieve downlisting and delisting. Adaptive management changes and challenges for long range planning will be discussed.

Is the recent southwestern US drought a megadrought?

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Abstract: Persistent, and at times severe, reductions to water supply for humans and ecosystems in western North America have recently reached levels potentially unprecedented in recorded human history. Tree-rings, however, indicate that the Medieval

period, from approximately AD 800 to 1300, was punctuated by several prolonged drought events. Until recently, these events appeared longer and more severe than any events in the observed record, providing disturbing insights into what may still be the full range of natural hydroclimate variability in the West. These prolonged drought events, many lasting more than a decade, have been termed "megadroughts." A question that has emerged recently is: has drought recently reached megadrought levels in any of the West? We address this question with up-to-date calculations of the self-calibrated Palmer Drought Severity Index (scPDSI), which consider a physically based representation of atmospheric demand, and updated versions of the widely used North American Drought Atlas (NADA), a tree-ring derived reconstruction of scPDSI gridded at 0.5 degree resolution and extending back beyond AD 800 for most of the West. Considering all periods of ≥10 years, we determine how time averaged drought areas throughout the West during the observed record compare to reconstructed drought areas over equal durations during the past 1200 years. This analysis highlights AD 2000-2015 as the period with the most extensive drought area in the observed record, on par with some of the most extensive 16-year drought areas in the tree-ring record. The Southwest is the region with the most persistent post-1900s drought. We determine how the recent and possibly ongoing drought event in the Southwest, and areas within, compares to reconstructed megadroughts derived from the NADA. We test robustness of the conclusions by repeating the NADA reconstructions using various realizations of the scPDSI calculated from alternate climate datasets.

Leaf litter morphology influences moisture dynamics and predator abundance: implications for decomposition and fire

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Abstract: Leaf litter plays a major role in ecosystem function, community organization, and influences the intensity of some disturbances such as fire. Although the ecological consequences of litter chemistry and quantity have been extensively studied, we know little about the ecological effects of litter morphology. We used a *Populus* (cottonwood) experimental garden, natural plant populations, and a greenhouse experiment to examine interspecific and intraspecific effects on the morphological trait of litter curling, the impacts of litter curling on spider abundance, and the effects of flat and curled litter on soil and litter layer moisture dynamics. We report three major findings. 1) There was significant interspecific and intraspecific variation in the degree of litter curling, and the intraspecific effect rivaled, and sometimes exceeded, the effect of species. 2) Litter layers consisting of curled litter was associated with ~2.5 times the number of agelenid spider webs compared to litter layers consisting of relatively flat litter. 3) After an 8 week drying experiment using litter from two tree species differing in litter morphology (flat vs. curled litter) and litter whose shape was experimentally manipulated (to control for other species effects), the litter layers consisting of flat litter contained 1.4 times more moisture than litter layers consisting of curled litter, and this response extended to at least 20 cm into the soil. Our results indicate there is a lot of natural variation in litter morphology, and this variation is probably ecologically important. Because litter morphology influences litter-dwelling fauna and regulates litter layer and soil moisture dynamics, it is likely that this trait indirectly influences decomposition rates and plays an important role in litter layer flammability, which may be particularly important in moisture-limited ecosystems like those found in the Colorado Plateau region.

Use-inspired hydroclimatic research in the upper Colorado River basin

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Abstract: Although there is a move to increase the relevance and usefulness of research to decision makers, research projects are commonly developed within academic or governmental research communities, without input from intended users. The Department of the Interior Climate Science Centers (CSCs) are designed to encourage research in support of the needs of decision makers in resource management agencies. The Southwest CSC provided us with the opportunity to develop a collaborative research project that involved water resource manager from the onset to develop research objects that met the needs of water managers who utilize the resources of the upper Colorado River basin. This interdisciplinary research project has partnered with seven water resource agencies to investigate the roles of temperature and soil moisture on water year flow at Lees Ferry on the Colorado River. Initial result indicate the importance of spring and early summer temperatures in conditioning the impact of both wet and dry winters on water year flows. The role of prior fall soil moisture is less clear, but potentially important in some years as well. At the end of our first year of the two-year project, we have progressed towards our research objectives, providing results on a project web site, and through presentations at both professional conferences and informal working group meetings. Although past experience clearly indicates the importance of two-way and iterative communication, in practice, this has proven challenging, given the number and range of water resource partners, remote nature of communications, and demands on both researcher and resource managers' time.

Fire burn severity mapping on the San Carlos Apache Reservation

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Abstract: On the San Carlos Apache Reservation in east-central Arizona, fire suppression and other factors have led to overstocked forests and woodlands, and woodland encroachment into grasslands. Restoring the historic fire return interval in forests and woodlands with the current unnaturally high fuel loads in times of prolonged drought is a challenge in the Southwest US. Landsat 8 and WorldView-2 satellites were used to estimate fire burn severity of the Creek Fire on the San Carlos Apache Reservation. Canopy loss mapping from WorldView-2 and spectral index differencing from Landsat 8 agreed well with the field-based burn severity measurements and are both effective for vegetation burn severity mapping. Canopy loss maps created with WorldView-2 imagery add to a short list of accurate vegetation burn severity mapping techniques that can help guide effective management of forest resources on the San Carlos Apache Reservation, and the broader fire-prone regions of the Southwest.

A national Biomass Essential Climate Variable (ECV): are we there yet?

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Abstract: Large uncertainties of large scale biomass estimates contribute to uncertainties in carbon stocks assessments, ecosystem process and climate modeling. An operational biomass essential climate variable (ECV) can reduce these uncertainties by using structural information extracted from active remote sensing and spectral information obtained from passive remote sensing. In the context of a potential operational Biomass ECV product, we evaluated the effectiveness of airborne lidar data at various densities to estimate aboveground biomass for forests and woodlands, in comparison with Landsat 8. Airborne lidar data, characterized by a mean density of 12 points/m2 were randomly decimated to produce datasets with lower densities ranging from 8 to 1 point(s)/m2. The errors associated with aboveground biomass estimates decreases as lidar point density increases, and tend to level off at 8 points/m2. Landsat 8 based aboveground biomass estimates roughly equaled to those derived from ≤ 1 point/m2 lidar data. Based on the operational 3D Elevation Program (3DEP) estimates of lidar acquisition cost at various quality levels (QL)/densities, the aboveground biomass estimate efficiency (error per unit cost) increases as the point density increases. Thus, a national Biomass ECV with optimal accuracy can potentially be achieved at the 8 points/m2 (3DEP QL2) with Landsat 8 providing additional spatial coverage where lidar is unavailable.

Characterizing remote sensing shrubland components in the Mojave Desert

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Abstract: Accurate and consistent estimates of shrubland ecosystem components are crucial to a better understanding of ecosystem conditions in arid and semiarid lands. We developed an innovative approach by integrating multiple sources of information to quantify shrubland components as continuous field products within the National Land Cover Database (NLCD). The approach consists of several procedures including field sample collections, high-resolution mapping of shrubland components using WorldView-2 imagery and regression tree models, Landsat 8 radiometric balancing and phenological mosaicking, medium resolution estimates of shrubland components using Landsat 8 phenological mosaics and regression tree models, and product validation. We estimate the fractional cover of nine shrubland components including annual herbaceous, bare ground, big sagebrush, herbaceous, litter, sagebrush, shrub, sagebrush height, and shrub height for the Mojave Desert in the southwestern United States. Results, representing spatial distributions and cover intensities of these components in 2014, show that most components have relatively significant correlations with validation data, have small normalized root mean square errors, and correspond well with expected ecological gradients. The model formulated in this study provides a cross-validated, unbiased, and cost effective approach to quantify shrubland components at a regional scale and advances knowledge of horizontal and vertical variability of these components in Mojave Desert.

Population dynamics of humpback chub that spawn in the Little Colorado River: drivers and their implications for management

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Abstract: Since 2009, GCMRC biologists and their collaborators have regularly sampled a fixed reference reach in the Colorado River just below its confluence with the Little Colorado River. Mark-recapture data from this reach have dramatically improved our un-

derstanding of humpback chub survival and growth in the mainstem Colorado River, particularly with respect to juvenile fish. When these data are analyzed together with long-term system wide sampling in the Little Colorado River led by USFWS, a holistic understanding of humpback chub population dynamics emerges. Recent data suggests a stable adult population; however, because of long time lags this stability could be misleading. Understanding juvenile recruitment in the Little Colorado River, outmigration, and survival provides a leading indicator of future change. Many factors likely contribute to variation in juvenile survival including the size of juveniles and the abundance of rainbow trout. Growth allows chub to quickly move through vulnerable life stages and appears to be strongly driven by water temperature. The size structure of juveniles in the mainstem is affected by preceding conditions in the Little Colorado River as the amount of outmigrants and their size structure varies annually. Turbidity also likely plays a role in both juvenile survival and growth. Here I discuss the evidence for the importance of different drivers of humpback chub population dynamics and the implications of the relative roles of these drivers for management options, including different methods of limiting trout numbers near the confluence of the Colorado River with the Little Colorado River.

Integrating studies of dam operations and flow influences on the Glen Canyon trout tailwater fishery

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Abstract: As part of Grand Canyon Monitoring and Research Center's ongoing monitoring and research, information about how low-flow dam releases and low-angle nearshore areas influence fish are being studied by biologists and physical scientists. Preliminary data presented here include detailed Glen Canyon hydraulic characteristics from a 2-D flow model in development, examples of sidescan sonar imagery, recently acquired multibeam bathymetry, and digitally-derived particle size distributions (PSD) of low-flow gravel/cobble bars. These data are being evaluated as part of a unique collaboration between fishery researchers and geomorphologists relative to channel features where rainbow and brown trout (*Oncorhynchus mykiss* and *Salmo trutta*) are frequently sampled. Recent PSD collected at Glen Canyon tailwater bars were extracted from digital photos taken October 31, 2013, during 2013 minimum modified low fluctuating flow (MLFF) dam releases (~185-227 m^3/s) using methods developed by Buscombe (2013). Low-angle nearshore bars (e.g., Four-Mile bar) have been identified as important rearing areas for early life-stage survival of juvenile rainbow trout after fry emerge from redds. At higher flows (>227 m^3/s), cobble bars are also known to be areas of aquatic food production for fish. In combination with historical low-flow aerial imagery of the river, these PSD are being compared with earlier PSD collected in 1984 and 2003, to detect any change over time. Patterns of PSD are also being compared with available spawning and age-0 recruitment of rainbow trout. Channel topography, bed substrate imagery, and PSDs are also intended to improve the 2-D flow model currently being developed. Flow model results are anticipated to inform trout responses to normally scheduled and experimental dam operations in the Glen Canyon tailwater.

Recent innovations in monitoring rainbow trout (*Oncorhynchus mykiss*) below Glen Canyon Dam in Glen and Marble Canyons

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Abstract: The Colorado River is logistically a very difficult ecosystem to study, owing to the navigational hazards and extreme environmental conditions encountered in the field, particularly when conducting large-scale mark recapture studies. Dispersal of rainbow trout from Glen Canyon can have negative effects on native fish, like the endangered humpback chub (*Gila cypha*), that reside near the confluence of the Little Colorado River (LCR). A primary goal of our study was to determine the contribution of rainbow trout emigrants from Glen and Marble Canyons to the trends in trout abundance into the downstream reaches. Herein we describe the sampling approach employed that allowed us to more efficiently capture, using nighttime boat electrofishing and new methods for processing and data acquisition, more than 190,000 rainbow trout over 16 trips between November 2011 and September 2014, and PIT-tag 70,660 individuals. We used a modified version of an open population Jolly-Seber model implemented in a robust design framework to estimate abundance, recruitment, survival, and capture probability of rainbow trout ≥75 mm in each reach through time. Our study area extends from Glen Canyon Dam (river kilometer (rkm) 0) to 5 km below the LCR (rkm 130, Fig. 1). We sampled five reaches in this area: I) rkm 16.3-21.7, II) rkm 52.8-58.3, III) rkm 86.6-91.9, IVa) rkm 122.0-123.6, and IVb) rkm 127.1-129.6. All data for each processed fish were electronically recorded using custom software that included the capability to capture the PIT tag ID from the scanner, eliminating potential transcription errors. The overall sampling framework has revolutionized the quantity of data collected, processed, and analyzed, and has effectively reduced post processing error and increased the rate at which trout status and trends can be reported to managers following a trip.

Movement, abundance, survival, and growth of rainbow trout (*Oncorhynchus mykiss*) in the Colorado River in Grand Canyon

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Abstract: Rainbow trout (*Oncorhynchus mykiss*) have been intentionally introduced as sport fish world-wide, with unforeseen consequences on native fishes. We describe how trout movement, abundance, survival, and growth could be influencing trout population dynamics throughout Glen, Marble, and Grand Canyons. This study describes these dynamics based on a large-scale mark-recapture program in the Colorado River below Glen Canyon Dam over a 130-km study area during a 3-year period (2012-2014) where we captured more than 190,000 rainbow trout, and PIT-tagged 70,660 individuals, from which trout growth in length and weight was determined for 7,951 and 7,004 across trips recaptures, respectively. There was a steep decrease in trout abundance with increasing distance from Glen Canyon Dam, with densities ranging from 10,000-25,000 fish/km near the dam to 200-800 fish/km 125 km downstream. Trout populations in upstream reaches declined over the study period, while populations grew in reaches near the Little Colorado River (LCR), where native fish like the endangered humpback chub (*Gila cypha*) rear. The extent of rainbow trout movement was limited, with less than 1% of over 8,000 recaptures making movements greater than 20 km. Although the proportion of fish emigrating from upstream reaches was very small, these upstream populations were large relative to downstream populations such that trout recruitment to reaches near the LCR could be explained entirely by immigration from upstream sources. There were strong temporal and spatial variations in growth in both length and weight. These patterns were consistent with variation in invertebrate drift and effects of turbidity on foraging efficiency. Highest growth rates and relative condition occurred in downstream reaches with lower trout densities. These findings indicate that a reduction in trout abundance and increased condition in Glen Canyon will likely increase trout size in the tailwater fishery and may help reduce downstream dispersal into Grand Canyon.

Using biological soil crust for soil stabilization and restoration

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Abstract: Areas around the American southwest are experiencing large amounts of soil erosion as a combined result of land use practices and climate change. Indeed, within our study area, Bandelier National Monument, NM, some areas are projected to experience wholesale loss of topsoil in the next 200 years without management intervention. Recent advances in cultivating ecologically relevant biological soil crust (biocrust) communities suggest that biocrust restoration may be an effective intervention technique. Biocrusts provide valuable ecosystem services, such as soil aggregate stability, nitrogen and carbon cycling, and can promote higher amounts of water infiltration, all of which may contribute to reducing erosion. To test our hypothesis that biocrusts can reduce soil loss and aid ecosystem restoration, we are applying greenhouse grown biocrust inoculum experimentally to actively eroding plots in Bandelier NM. Using a full factorial design, we are adding small diameter slash pieces and *Bouteloua gracilis* seeds, and hydrologically isolating the hillside within 40x35 cm split plots with and without added inoculum. By measuring soil stability, biocrust and vegetation cover, and nutrient cycling within the split plots, we hope to elucidate combinations that best stabilize soil. In addition, we are examining how the previous restoration technique of placing slash pieces over areas of bare ground, administered by the Park Service, influences the presence of biocrust by measuring crust cover and nutrient cycling adjacent to and away from placed slash pieces in 10x10m plots. While still early in our experiment, biocrust additions may be a promising tool for stabilizing and restoring ecosystem functions to a degraded landscape.

Estimating prescribed fire effects on semidesert vegetation composition and structure using a 30-year Landsat derived fire history data

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Abstract: Prescribed fire plays a vital role in restoring vegetation and fuel bed conditions characteristic of frequent fire regimes in southwestern semidesert grasslands. However, current fire management activities implemented at the local-to landscape-scales must be compatible with specific habitat requirements for threatened and endangered birds. The Buenos Aires National Wildlife Refuge (BANWR) in southern Arizona was established in 1985 to provide habitat for threatened and endangered plant and animal species, with primary emphasis on the critically endangered masked bobwhite quail (*Colinus virginanus ridgwayi*). Masked bobwhite are known to occupy semidesert grassland sites of moderate elevation (240-760m) with abundant grass cover and seed producing plants, a high diversity of forbs, and interspersed woody plant cover. We used BANWR fire perimeters to examine the effect of fire frequency over the last 3 decades on vegetation characteristics. Multivariate analyses indicate that semidesert vegetation composition on plots (n=116 plots) is significantly (A=0.04, p<0.001) different among fire frequency strata. Locations with high fire frequency were strongly correlated with high fine-fuel biomass dominance by *Eragrostis lehmanniana*, an invasive perennial bunch grass introduced from South Africa in the 1930s. Locations of low to moderate fire frequency may favor a greater abundance of native plants or lack site conditions suitable for *E. lehmannian*. Further analyses are aimed at determining soil conditions and fire management activities most conducive to developing habitat preferred by the masked bobwhite on BANWR.