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Abstracts

Abstracts are ordered alphabetically by presenting author, whose name is indicated in bold type.

The future is now: impacts to our most valued western cultural heritage from changing environmental conditions

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ABSTRACT: Land managers in the National Park Service and elsewhere have long been concerned by the effects of a rapidly changing environment on the natural resources protected by our public lands. However, only in the past decade has it become clear that federally protected cultural resources are at risk as well. The resulting lack of research on the potential effects of climate change on cultural resources presents a major challenge to current resource managers when it comes to planning and prioritizing documentation, treatment, and monitoring of the cultural sites under their care. While the available research has increased exponentially since 2012, most of the resources that have been studied through the lens of changing environmental conditions are located in coastal and arctic areas of the US, focusing on the associated risks of sea level rise, increased frequency and intensity of hurricanes and tropical storms, and the melting of tundra and permafrost. Cultural resources in the desert southwest are underrepresented in the current research, but face unique challenges that will need to be addressed if there is any hope of preserving the area's cultural heritage in an uncertain environmental future. Drought, increased frequency and intensity of wildfire, and increased intensity of precipitation events are all conditions that have been associated with a changing climate in the West. In addition, architectural materials that are common in this geographic region, such as adobe and other forms of earthen architecture, face unique risks that have not been dealt with in other areas of the country. The National Park Service is working to expand the body of research related to how these materials respond to the specific changing environmental conditions they currently face, and are expected to face in the future.

Genetic investigation of *Bouteloua gracilis* on the Colorado Plateau: implications for restoration using wild and cultivated varieties

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ABSTRACT: As large-scale restoration efforts on the Colorado Plateau become increasingly important, the need to understand the adaptive genetic structure of natural plant populations and their relation to heavily-utilized cultivars is critical. Here, we investigate how genetic variation is partitioned in the widespread perennial grass, *Bouteloua gracilis* (blue grama), and the degree to which this

variation is shaped by environmental variation in natural populations and cultivated varieties. Consisting of several cytotypes (2n=2x-6x) blue grama has a widespread distribution in western North America and is regularly used in restoration treatments. Using AFLP (Amplified Fragment Length Polymorphism) and cpDNA (chloroplast DNA) analyses, we assessed the genetic variability and adaptive genetic structure of blue grama within and among 44 sampling sites that are representative of the species' environmental and habitat diversity in the southwestern U.S., specifically on the Colorado Plateau and adjacent regions. Five cultivars were also included to investigate genetic diversity and differentiation in natural versus cultivated populations. Three main findings resulted from this study: 1) Ninety-four polymorphic AFLP markers distinguished two population clusters defined largely by samples on and off the Colorado Plateau; 2) Substructure of samples on the Colorado Plateau was indicated by genetic divergence between boundary and interior regions, and was supported by cytotype distribution and cpDNA analysis; 3) Six AFLP markers were identified as "outliers," consistent with being under selection and were significantly correlated to several environmental variables in natural populations, but not in cultivated samples. Marker x environment relationships were found to be influenced by cytotype and cultivar development. Our results demonstrate that blue grama is genetically variable and broadly structured across the Colorado Plateau and is responsive to environmental variation. Our study enables the selection of seed source populations for commercial development and conservation management of *B. gracilis,* and potentially other native grasses, on the Colorado Plateau.

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 our respective Cooperative Ecosystem Studies Units (CESUs), followed by an overview of recent developments (e.g., new partners) and examples of new research, education and technical assistance activity. We will also discuss best practices for managing our CESUs and ongoing challenges, such as ensuring adequate reporting by all partners, the lack of effective interaction with some technical representatives, 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.

Monitoring uranium and trace elements associated with breccia pipe uranium deposits in the Colorado River and main tributaries of Grand Canyon, northern Arizona

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ABSTRACT: The Colorado River, which carved Grand Canyon over the last 6 million years, is one of the most important water sources in the western U.S., serving the needs of more than 38 million people in the U.S. and Mexico. The Grand Canyon region also hosts some of the highest-grade uranium deposits in the U.S. and has subsequently experienced varying levels of uranium mining activity since the 1950s. The U.S. Geological Survey has monitored major surface waters in Grand Canyon for elements associated with mineralized uranium deposits in the area since late 2015. Dissolved constituents in the Colorado River are monitored upstream (Lees Ferry), near the middle (Phantom Ranch), and downstream (above Diamond Creek) of Grand Canyon National Park. Observed uranium concentrations in water at these sites are 2.5 to 4 µg/L, substantially less than the 30 µg/L USEPA maximum contaminant level, with little change observed over time or with changes in streamflow. Additionally, dissolved and sediment bound constituents are monitored at the mouths of the Little Colorado River (LCR), Kanab Creek, and Havasu Creek tributaries, whose watersheds have experienced different levels of uranium mining activities over time. Difficult sampling conditions exist at these remote tributary monitoring sites, including limited access and extremely variable flow from baseflow to flood runoff conditions. Dissolved uranium concentrations sampled across a range of flow at the tributary sites were ~1–17 µg/L at LCR, ~1–9 µg/L at Kanab Creek, and ~1–4 µg/L at Havasu Creek. Concentration of uranium in suspended sediment samples were ~2–5 µg/g at LCR, ~2–3 µg/g at Kanab Creek, and ~2–3 µg/g at Havasu Creek, all well below a published sediment quality guideline of 104.4 µg/g. Continued monitoring at these and additional tributary sites will provide a robust dataset with which to compare potential future changes.

Assessing the magnitude of compositional change in two arid ecosystems over 80 years

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Abstract: The capacity to quantify changes in plant communities in response to shifting environmental conditions is crucial to predicting future composition and restoring resilient communities. In the arid Southwest, the effects of climate change are already being felt as annual mean temperatures increase and annual precipitation levels decrease. Utilizing permanent 1-m^2 quadrats put in place over a century ago, we analyzed rates of change of understory species at two sites at two elevations in Northern Arizona to ask two questions. 1) Does the magnitude of change in community composition differ between the two sites? And, 2) Are there changes in species richness at the two sites, and do patterns of change differ? Plant cover by species was mapped on 1-m^2 quadrats at two study locations, the Sierra Ancha Experimental Forest (1450 m ASL), and the "Hill and Wild Bill" plots surrounding Flagstaff, Arizona (2200 m ASL); cover data was then digitized using ArcMap. The data for this study were collected over 82 years (1935 to 2017) at Sierra Ancha, and 92 years at the Hill and Wild Bill plots (1933 to 2017). Magnitude of change in understory communities was quantified using Bray-Curtis dissimilarity and ANOVA; change in species richness were also assessed using ANOVA. Preliminary results indicate a significant change in community composition and increase in species richness at both locations. While species richness has increased, a difference in magnitude of change between sites suggests that both environment and land management decisions may be responsible. Determining drivers of these community-level shifts is essential for developing management practices that will promote resilience in the coming decades.

Sustainability planning for an uncertain future

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ABSTRACT: Communities are being forced to make long term planning decisions in a rapidly changing world. Despite the known and projected impacts of the social, environmental, and financial impacts of climate change, communities must begin to broaden planning and decision-making processes to incorporate future impacts, risks and opportunities. Planning for an uncertain future necessitates a shift in perspective. A shift that anticipates, adapts to, and learns from change in both the present and the future. With the climate emergency growing more dire, planning must address multiple needs, emphasizing the value of diverse perspectives and the balance of human, natural, and financial needs. Planning must emerge as a tool for collective "embetterment" to strengthen community, demonstrate what works and accept what does not, adapt to the changing world, share knowledge, replicate action, reevaluate continuously, and collaborate.

Minimal impact of modeled drought on natural dust emission in the Southwest United States

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ABSTRACT: The assumption that the emission of fine mineral dust particles increases during drought in the Southwest United States is common, and is the basis of the expectation that future drought will exacerbate regional dustiness with impacts on snowmelt and health. However, recent studies suggest that dust deposition did not increase during past megadroughts. To investigate the hypothesis that drought is the major natural driver of the dust cycle in the Southwest, we examine an 11-member single model ensemble, the Last Millennium Experiment (LME) output from Community Earth System Model (CESM). First, the role of potential drivers of dust emission, including soil moisture, wind speed and bare ground exposure were investigated through multiple linear regression. Second, dust emissions during identified megadroughts were compared to years without drought. Contrary to expectations, the fraction of bare ground with the potential to erode, controlled by vegetation cover, is the main driver of simulated dust emissions in the Southwest in the LME. Although soil moisture and dust emissions correlate moderately in time, megadroughts do not show increased dust emissions like in the paleo-records. In conclusion, hydroclimate had a minimal direct impact on emissions and an indirect impact on vegetation cover. Since simulated vegetation exerts a large influence on emissions and thus predicted changes, our findings highlight the importance of incorporating dynamical vegetation and in reducing the uncertainties in ecological processes included in the models.

Improving adaptive management outcomes through engaged scholarship

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ABSTRACT: Since emerging four decades ago as a tool to improve natural resource management practices despite dynamic and incomplete knowledge of complex systems, adaptive management has come to emphasize learning through monitoring and managing by incremental adjustments. Stakeholder engagement processes lie close to the core of adaptive management, but some argue that in practice it often fails to increase public understanding of ecosystems or help stakeholders "make useful, broadly supported recommendations regarding … long-term management." Through a case study of the Taylor Park Adaptive Management Group, we argue for "engaged scholarship" as a mechanism to cultivate a culture of learning among diverse actors working within an adaptive management framework. In 2018, Gunnison National Forest and Western Colorado University began a public engagement and adaptive management process around a large-scale vegetation and timber project. The agency identified a goal to create a working group of stakeholders not only for the project at hand, but for future community relationships. Accordingly, the group cohered around three key principles, explored in this presentation. 1) *Applying principles of engaged scholarship* to produce scholarly work and social action. One such reciprocal commitment is the support of graduate students working in both public engagement and science. 2) *Studying progressive approaches to public engagement*, with the goal of improved stakeholder impacts on the project. For example, we are researching how record-keeping builds trust and fosters stakeholder ownership of decisions and actions. 3) *Engaging scientists, including students, in both research and science communication.* Beyond traditional on-the-ground resource monitoring, the science team is also studying how the adaptive management group influences local views of Forest Service actions, transparency and responsiveness. Preliminary findings of the science team will be presented. This project demonstrates measurable benefits from engaged scholarship, where scientists, policymakers, and public each "become a student of the other's culture."

Multi-stakeholder governance in the Upper Madeira River Basin (Bolivia and Brazil): the case of the "Comité Binacional por la Vida y la Amazonia en la Cuenca del Rio Madera" (Binational Committee for the Amazonia Life in the Madera River Basin)

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ABSTRACT: The Amazon Dams Network has built a relationship with the U. S. Geological Survey to share lessons learned regarding river resource management and the governance of impacts wrought by construction of hydroelectric dams. This poster presents study results of the multi-stakeholder governance in the Upper Madeira River Basin (Bolivia and Brazil), through the case of the "Comité Binacional por la Vida Amazónica en la Cuenca del Rio Madera" (Binational Committee for the Amazonia Life in the Madera River Basin). The Upper Madeira Basin is already experiencing transboundary impacts from the Santo Antônio and Jirau dams on the Brazil side of the Madeira River. Moreover, it is facing further impacts from the planned binational Riberão and Cachuela Esperanza dams along the Beni River in Bolivia. The main objective of the Binational Committee is to strengthen alliances and articulation of communities in Bolivia and Brazil, as well as, to avoid the construction of mega-dams, preserving life and promoting sustainable development in the Madera River Basin. This study uses participatory methods to understand the infrastructure governance issues in the communities living in the area, as well as participatory mapping conducted with small groups of community members followed by semi-structured interviews on the communities. This research provides a better understanding of environmental governance processes in dam-impacted communities and communities to be impacted by future dams' construction in the area. This study demonstrates that communities that have been affected by dam construction are still trying to cope with the adverse effects. However, the ineffective governance, translating into a missing link between local, regional, and national government, makes the coping process more complicated for local communities. Moreover, the study also shows how the binational governance is weak in this area since Brazil takes most of the decisions regarding dams' construction in the Bolivian territory.

Patterns and ecological impacts of human migration in response to climate change on the Colorado Plateau

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ABSTRACT: Although the impact of climate change on range shifts of animals and plants is often discussed, human movement in response to climate change is less explored. As temperatures rise, movement of people to higher and cooler geographies is becoming evident. Such movement can be temporary (i.e., "escaping the heat") or permanent, as resource availability and amenities become scarce in hotter and lower communities. Human movement in response to climate change can take the form of amenity migration by individuals with the economic capacity to move to more comfortable climates, or it can be a matter of necessity, wherein movement is required for health or employment. Surrounded by low-lying, large-population urban areas subject to alarming heat projections (e.g., Phoenix, Las Vegas, Salt Lake City), the Colorado Plateau is an increasingly attractive destination for people moving in response to climate change. A rapid growth in human population carries significant implications for ecosystems of the Colorado Plateau. Increased activity in recreation areas will increase the frequency and duration of disturbances, in many cases favoring non-native species and impacting vulnerable native ecosystems such as fragile riparian areas. Increased human populations within fire-prone ecosystems will increase fire ignition rates and alter fire frequency in locations near population centers. Areas of high human activity can disrupt habitat connectivity for sensitive wildlife species, whereas other species are more robust to human disturbance and may therefore become competitively dominant. A primary projected effect of climate change is altered precipitation patterns, and surface waters such as lakes, streams, and springs are likely to experience water quantity fluctuations as a result. Increased human activity also may impact water quality, affecting aquatic and riparian species. In this talk and this session, we will explore the coupled social-ecological effects of ongoing human migration in response to climate change on the Colorado Plateau.

Science at the nexus of diversity and history: research on the North Rim Ranches

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ABSTRACT: The Landscape Conservation Initiative has acted as a science provider for the Grand Canyon Trust since the acquisition of the North Rim Ranches. Together, the Kane and Two Mile Ranches encompass an area of immense topographical and ecological diversity, spanning high sagebrush desert to cool mixed conifer forest. The region is host to sensitive, endangered, and endemic species. A long history of ranching, hunting, and timber harvest has now segued into a period of intense recreational use, making the region a center for social-ecological feedbacks and interactions. The Grand Canyon Trust's stewardship of this landscape carries an important opportunity for solutions-oriented research to be conducted hand-in-hand with decision-makers, so that evidence-based practices can be implemented in order to manage the land for sustainability and biodiversity in the face of environmental change. Our scientific studies on the North Rim Ranches, performed in collaboration with Grand Canyon Trust, have provided insights into ecological community assembly and persistence, ecological disturbance and resilience, fire recovery, invasive species management, endangered species population dynamics, and other conservation-relevant foci. Major challenges to this work include the need for and scarcity of monitoring resources, funding and resource needs inherent in long-term studies, shifting management priorities, and external pressures and constraints. A critical component of successful science in this context has been the mutually committed and trusting relationship between scientists and managers on the North Rim Ranches: a deep confidence that both sides are committed to the sustainable management of these lands and their ecology has been essential to maintaining a productive and effective collaboration.

Monitoring bighorn sheep habitat by assessing vegetation, topography, and soil moisture

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ABSTRACT: Bighorn sheep (*Ovis canadensis*) are a charismatic desert species that have enormous ecological and cultural significance to the Mojave Desert region. After overcoming large population losses in the late 1900s, further habitat degradation and fragmentation has continued to affect the livelihood of remaining bighorn sheep herds. Past studies have shown that the habitat selection of remaining metapopulations is extremely selective, requiring very specific forage and topographic conditions. In partnership with the National Park Service, the California Department of Fish and Wildlife, Oregon State University, and the Sierra Nevada Bighorn Sheep Foundation, we utilized data from various NASA Earth Observations, including Soil Moisture Active Passive (SMAP), Terra Moderate Resolution Imaging Spectroradiometer (MODIS), Terra Advanced Spaceborne Thermal Emission and Reflection (ASTER), Global Digital Elevation Map (GDEM), along with National Agriculture Imagery Program (NAIP) aerial imagery to further evaluate the spatiotemporal vegetation characteristics in relation to bighorn sheep habitat. The Software for Assisted Habitat Modeling (SAHM) processed soil moisture, Normalized Difference Vegetation Index (NDVI), topography, and vegetation presence classification in Random Forest and Maximum-Entropy (MAXENT) models. Time series of soil moisture and NDVI indicated that green up events are immensely variable in the Mojave Desert. This could be attributed to the fact that highly variable precipitation has a greater effect on NDVI and soil moisture values, regardless of the season. Random Forest and MAXENT

results suggest bighorn sheep habitat selection favors higher elevation, which was shown to have a higher NDVI and vegetation cover but still varies significantly due to a variety of factors such as predation risk and lambing season.

Manager-scientist relationships and the Four Forest Restoration Initiative

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ABSTRACT: At over 2.4 million acres, the Four Forest Restoration Initiative (4FRI) is the largest of the Collaborative Forest Landscape Restoration Program projects. From its inception, the 4FRI has been encouraged to innovate and find new ways of doing business in the planning process as well as during implementation. Some of these shifts may benefit from unique approaches from managers as well as researchers. As landscape-scale restoration projects become more common and the size of these initiatives shifts from tens of thousands of acres to a million or more, there may be value for scientists to engaging individual project managers to determine project-specific research needs and approaches to analysis. Currently, the United States Forest Service is proposing a new rule to the National Environmental Policy Act to define and explicitly allow for "condition-based management." This new concept may require the development of new tools that improve efficiency in environmental analysis while maintaining or improving public support for restoration projects. Validation of implementation advances such as digital boundaries and tablet marking would improve confidence in these techniques and the most appropriate place for their use. The 4FRI has benefitted greatly from timely research due to the high-profile nature of the project and location near a forest research hub. Expanding these benefits to other large restoration projects could improve the pace and scale of restoration activities nationally.

Effects of herbicide treatments on Mojave Desert biological soil crust

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ABSTRACT: Incorporating biological soil crusts (biocrusts; the community of mosses, lichens, and cyanobacteria that cover the soil surface in arid landscapes and provide vital ecosystem functions) into conventional restoration practices will often expose them to herbicides used in invasive plant management, with unknown implications on biocrust health. We are testing the effect of four common herbicides and blue marker dye crossed with non-ionic surfactant on Mojave Desert biocrusts in a greenhouse experiment. Biocrusts were salvaged from a construction area in Jean, NV; small 'cookies' were cut of the three main functional groups in this system (moss, squamulose lichen, jelly lichen), then placed into units of sterile sand and watered from below to ensure crusts were active. Matching the concentrations used by land managers, we mixed the four most commonly used herbicides in the Mojave (Imazapic, Glyphosate, Aminopyralid, 2,4-D) as well as blue marker dye (used to track application during spraying) and a control treatment of water, all with or without non-ionic surfactant (used to penetrate plant cuticles). Each unit was sprayed with approximately 20 ml of mix to achieve saturation, and each of the 12 treatments had 6 replicates. We are photo monitoring bi-weekly. Preliminary visual evaluations of crust health after two months suggest that mosses are more susceptible to herbicide, while the N-fixing jelly lichen genus *Collema* is moderately resistant. The inclusion of surfactant in herbicide mix does not appear to increase the effects on biocrusts, though surfactant alone does seem to reduce vigor. Furthermore, greatest decline in biocrust vigor was seen in units treated with Glyphosate, the most commonly used herbicide in the USA. Final results from this study could be used to guide selection of more biocrust compatible herbicides mixes for use in restoration areas.

Drought and hydropower impacts on electrical system production costs in the Southwest United States

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ABSTRACT: The Colorado River is an important natural resource for the Southwestern United States. Predicted climate change impacts include increased temperature, decreased rainfall and increased probability of drought in this region. Given the large amount of hydropower on the Colorado River and its importance to the bulk electricity system, the purpose of this study was to quantify the value of hydropower in operating the electrical system, and examine changes in hydropower value and electricity costs under different possible future drought conditions and regional generation scenarios. The goal was to better understand how these scenarios affect operating costs of the bulk electrical system, as well as the value of the hydropower produced, and proposed a method for doing so. The calculated value of the hydroelectric power was nearly double the mean locational marginal price in the study area, about $73 to

$75 for most scenarios, demonstrating a high value of the hydropower. In general, it was found that reduced water availability increased operating costs and increased the value of the hydropower. A calculated value factor showed that when less hydroelectric power is available, the hydropower is more valuable. Furthermore, the value factor showed that the value of hydro increases with the addition of solar or the retirement of thermal generating resources.

Dispatching hydropower to reduce the social cost of electricity sector emissions

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ABSTRACT: Evaluating tradeoffs between hydropower development and ecosystem services is a constant challenge in environmental management and economic development. However, there are limited inquiries into the role of existing hydropower facilities in minimizing social and environmental costs in regulated river management. Structural changes in the electricity sector are presenting opportunities for hydropower to play an important role in electricity sector emissions mitigation, reducing total social costs of energy generation. This not only reduces social costs associated within the electricity sector, but restructures costs associated with restoration and maintenance of ecosystem function and services in regulated rivers. This is of increasing importance as regulated rivers are managed with designer flows to achieve environmental and social goals. Here, we demonstrate an opportunity for hydropower to mitigate electricity sector emissions in the Western Interconnect by reoperation of a large hydropower facility along the Colorado River in the Southwest United States. This example illustrates the importance of incorporating external social costs in environmental decision making and considering the technical characteristics of future power system expansion when managing regulated rivers. This broad view of the electricity sector and regulated rivers as interconnected systems provides insights into the utilization of hydropower to minimize environmental and social costs.

Environmental filtering acts on plant traits to influence survival and community composition across RestoreNet plantings

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ABSTRACT: We present survival results from the first year of RestoreNet's Biodiversity-Ecosystem Functioning experiment. In summer of 2018, we planted perennial species with a wide range of functional traits along an environmental gradient to decipher patterns of plant establishment. We focused on dryland sites within Arizona and Utah where differences in temperature and precipitation may drive complex patterns in plant community assembly. Baseline functional trait data include both above- and belowground measurements from each species grown in a greenhouse setting. After the first year of establishment, we compared the traits of all planted species to the traits of surviving species to determine if the environment is "filtering" out sub-optimal trait values in a predictable way across the region. Our results demonstrate that optimal trait values for a given set of environmental conditions are reflected in survival rates of planted species; additionally, we found that variation in many traits is restricted to a greater extent in resource limited environments. These results shed light on the ways traits can be matched to optimal environmental conditions to promote plant establishment, especially in post-disturbance early successional communities where restoration action is needed.

Using Meteor Crater, Arizona, to understand impact craters throughout the solar system

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ABSTRACT: Meteor Crater is the best-preserved and first confirmed impact crater on the Earth and was one of the sites used to train the Apollo astronauts on how to explore and sample impact craters on the Moon. It is the premier location to conduct in-situ investigations of the characteristics of small, simple craters which dominate on solid-surfaced bodies throughout the solar system.

Using time-series satellite vegetation indices to assess fractional plant cover changes and ecological recovery for riparian restoration sites on the Colorado Plateau

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ABSTRACT: Many places on the Colorado Plateau have undergone environmental changes that have led to myriad restoration techniques and a plethora of effort over the last two decades in an effort to restore riparian vegetation across this dryland ecosystem. Investigation into the initial start year and the type of restoration method used in over 400 ground plots has been compiled and meticulously updated with site validation. We investigate the use of remote sensing for assessing how well these restoration plots, with their vegetation cover, type and structure, can be scaled to Landsat resolution (30 m) using time-series data from Landsat 5 (2000 -2011) and Landsat OLI (2012 – 2018). We also investigate the use of coarser resolution imagery, from MODIS (250 m), to determine if this fast acquisition method proves useful for acquiring vegetation status for these vast and often inaccessible regions. In plant communities dominated by *Tamarix* spp. (saltcedar) active restoration efforts have been employed and have been successful in the establishment of native vegetation. With the arrival of *Diorhabda* spp. (tamarisk beetle) at various times between 2001 and present at these selected ground plots, we want to be able to track before and after changes in fractional canopy cover within the plots, tracking greenness through the use of vegetation indices (VIs) and identifying any shifts in phenology which could be related to changes in plant type during and after the restoration activity. The goal of this study was to investigate the use of remote sensing to provide a rapid assessment for the state of restoration plots on the Colorado Plateau that have been tracked and validated over time with ground truthing. A selection of the total number of sites is being used to test this remote sensing method on sites where *Tamarix* previously existed but has since been impacted by *Diorhabda* biocontrol or mechanically removed, sites where *Tamarix* previously existed but native riparian species have since been planted following tamarisk removal, and control sites, those presently dominated by *Tamarix* without any habitat manipulation and not yet impacted by *Diorhabda*. We estimated both the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI) I and II from both MODIS and Landsat from 2000 to 2018 to analyze the plant community response through measuring greenness and determine the feasibility of using this resolution of imagery to detect changes in vegetation cover and shifts in phenology depicted in time-series data.

Partnering with the Vanishing Treasures Program: five case studies

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ABSTRACT: Cornerstones Community Partnerships is a not for profit corporation located in Santa Fe, New Mexico with a mission to work in partnership with communities to restore historic structures, encourage traditional building practices and affirm cultural values. Our first CESU project was with a Vanishing Treasures park, Arches, in 2011, where we conducted workshops to stabilize Stone Cabin and the Wolfe Ranch. Our model was to use the project as a training ground for "hands on" experience in applied historic preservation. Interns, volunteers, students and park employees were involved at varying experience levels. The idea of tactile experience of "hands on" learning connects individuals to the resource beyond data and theory. For example, the Death Valley Cow Creek Walls involved AmeriCorps youth restoring CCC walls thereby connecting cultural heritage. At Glen Canyon, we stabilized the French's Cabin with local volunteers, experts and park staff. The lime kiln at Capitol Reef required reconstruction with an expert stone mason, three trainees and one NPS staff person. The stabilization of Geer Cabin in Mojave National Preserve stimulated locals to join and keep going beyond the workshop. Recently, we conducted stone work training with the Southwest Conservation Corps Native Lands Program at JO Ranch in Wyoming. An expert stone mason trained five youth, one BLM staff person and one volunteer in stone work skills. These workshops bring locals and others into the process, have at least one expert to lead, prioritize safety, stimulate and allow experiential learning to occur, and work collaboratively with park staff to achieve a desired result in which all parties benefit.

Public lands and community connections

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ABSTRACT: Cornerstones Community Partnerships is a not-for-profit corporation located in Santa Fe, New Mexico, with a mission to work in partnership with communities to restore historic structures, encourage traditional building practices, and affirm cultural

values. Our first involvement with a federal cooperative agreement, which led to joining the Desert Southwest Cooperative Ecosystem Studies (DSCESU), was in 2009 when we assisted Fort Union National Monument with the construction of interpretive waysides about the Old Santa Fe Trail. We recognized the context as important to northern New Mexico and our communities that exist along the corridor of the trail. This led to a partnership with the University of Arizona and a project at Organ Pipe National Monument and subsequently to applying for membership to the DSCESU in 2011. Since then, we have completed 19 task agreements accomplishing $800,000 of work and currently have 16 active projects. All projects follow the same formula: the projects are organized as training workshops with applicability from basic to advanced levels. The emphasis is on experiential learning through "hands-on" work. All workshops are led by at least one subject matter expert. The key to a successful project is the involvement on both sides of the agreement, active participation on the part of park resource professionals, and public participation. A primary goal of our projects is to provide the venue for participants to appreciate the cultural values and heritage embodied in the architecture of the resource.

The Escalante River Watershed Partnership: supporting Grand Staircase-Escalante National Monument in difficult times

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ABSTRACT: The Grand Staircase-Escalante National Monument was designated in 1996 by President Clinton. It is situated in one of the most remote parts of the lower 48, truly a gorgeous nowhere. Grand Escalante Staircase Partners (GSEP) was founded in 1996 to assist the Bureau of Land Management (BLM) in the management of the monument and in "preserving and protecting the vast landscape of Grand Staircase-Escalante National Monument for the use and enjoyment of present and future generations." For much of its 23-year history, GSEP was a small organization assisting in education, stewarding volunteers, and offering educational trips and experiences to help visitors better understand this landscape. Ten years ago GSEP became a large part of the Escalante River Watershed Partnership (ERWP), serving as the fiscal agent for much of the funds and coordination the Conservation Corps Crews that conducted the restoration work ERWP was created to do. Then in 2017 the monument was reduced by 47%. That same day, Grand Staircase Escalante Partners and two other plaintiffs filed a lawsuit challenging that reduction. The subsequent lawsuit elevated GSEP into a national spotlight and created a new slate of challenges in the partnership and restoration efforts. However, amidst this time of controversy, litigation and challenge, GSEP has endured in its mission to support the Monument, continued to play that same role in the ERWP, and maintained its efforts coordinating the Conservation Corps crews, never missing a day of work. No small feat in what is arguably the most divisive public lands debate in the country.

Developing pollinator-dependent plant materials for use in a growing restoration economy

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ABSTRACT: There is a growing need for the development of pollinator-dependent plant materials for use in the rapidly growing "restoration economy," where agencies, nonprofits, and businesses collaborate to restore degraded ecosystems to promote agriculture, tourism, conservation, fire resilience, multi-use landscapes, and more. We are addressing critical knowledge gaps in this effort in a largescale provenance trial in the arid western US, including nearly 30,000 plants of 17 native forb species, to develop seed zone guidelines and predict plant-pollinator response to climate change. We are also initiating a regional seed production trial of over 100,000 plants to spearhead a farm-based seed development program for pollinator plants across three states. In this talk we will present the array of gardens along with their design and how we intend to mine the richness of this garden array for data. We will discuss some potentially exciting datasets that a project of this scale will bring, as well as potential pitfalls.

Informing planning and management through assessment of ecological conditions and visitor experiences in Grand Staircase-Escalante National Monument

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ABSTRACT: Policies mandate that managers at Grand Staircase-Escalante National Monument must balance recreational opportunities with a variety of resource management and utilization activities across a vast and diverse landscape containing numerous Wilderness Study Areas and other lands containing spectacular resources. This balancing act is stressed by increasing levels of use and recent changes in management direction and policy. An understanding of visitor preferences and current ecological and social conditions is an essential component of recreation management; however, scant social science data exist for the Monument. This study used semi-structured qualitative interviews to describe Monument visitors' motivations, experiences, and perceptions to determine existing social conditions. Researchers paired interview data with direct measurement of resource conditions from a long-term monitoring program to inform management. Results help inform possible indicators of quality that can be used for long-term monitoring and adaptive management of the Monument's unique wilderness resource.

Phenology of *Diorhabda carinulata*, a biocontrol agent for *Tamarix* spp., along the lower Colorado River's Cibola and Imperial National Wildlife Refuges

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ABSTRACT: Introduced populations of the northern tamarisk beetle, *Diorhabda carinulata*, originated in Central Asia where photoperiodic and thermal environmental cues allowed for 2-3 generations per season. Following release of *D. carinulata* into North America in 2001, to control exotic shrubs in the genus *Tamarix*, beetles were restricted to more northern locations, generally north of the 38th parallel. Rapid evolution of phenology cues, primarily the use of photoperiod to signal overwinter dormancy (diapause) has enabled beetles to move southward into the lower Colorado River Basin. We have previously shown that the critical day length (CDL) for diapause induction in *D. carinulata* populations has shifted dramatically, decreasing by an hour or more in southward moving populations. The impact of this shift on the timing of diapause induction prior to overwintering, as well as on the number of generations achieved seasonally (voltinism) has been modeled, taking into account both temperature dependent developmental rate and naturally occurring photoperiods encountered at a given location. In this presentation we focus on *D. carinulata* populations as they move southward into Cibola and Imperial National Wildlife Refuges. We found that beetles are reproductive at much shorter day lengths than those previously observed, and that this has resulted in rapid southward movement and major defoliation events in both refuges during the spring and summer of 2019. We compare *D. carinulata* phenology on the lower Colorado River with model predictions and discuss the continued rapid evolution of phenology cues.

Relationships between ticks, desert tortoises and tick-borne relapsing fever

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ABSTRACT: Soft-ticks in the genus *Ornithodoros* (*O. parkeri* and *O. turicata*) occur throughout the Mojave Desert and have been documented to frequently parasitize Mojave desert tortoises. However, ticks often are not identified to species nor life stage when collected. These tick species carry the pathogen *Borrelia*, which is responsible for tick-borne relapsing fever (TBRF) in people. The relationship between ticks and their common host, the desert tortoise, has not been well studied. We aim to identify ticks to species found in Mojave desert tortoise habitat and attached to desert tortoises to determine the pathogen prevalence in ticks collected in the Mojave desert. We identified 245 ticks collected from desert tortoises using microscopy and morphological characteristics. Out of the 245, 60% were identified as *O. parkeri*, 17% were *O. turicata* and the remaining 23% were not identifiable. Of the 245 ticks collected from tortoises, a subset of 224 were and analyzed for *Borrelia,* 223 tested negative while only 1 tested positive for the pathogen. Further, two biologists tested positive for *Borrelia* infection and were diagnosed with TBRF after exposure to ticks in desert tortoise habitat. Future plans for this research include further research into a possible *Borreliacidal* effect of an enzyme found in tortoise blood (similar to that found in western fence lizard blood). A species distribution model of ticks will be created and pathogen dynamics of *Borrelia* will be modeled in relation to potential *Borreliacidal* factors in the desert tortoise. Continued research will contribute to the large gap of knowledge in relation to ticks and desert tortoises in the desert southwest and how conservation of this iconic animal may lead to better public health.

An index for measuring community resilience to energy development boom and bust cycles on Colorado Plateau

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ABSTRACT: The boom and bust cycles that often occur due to energy development can have both positive and negative effects on communities; however, we are currently without a reliable method for predicting how a given community might respond to the stresses associated with energy expansion. This lack of understanding is particularly troubling in the arid mountain west, where the race to tap vast energy resources is often at competition with the recreational and scenic opportunities that have supported communities for generations. Additionally, these conflicts could potentially further destabilize vulnerable populations in the region. Therefore, our overarching goal is to develop a new high-level index using secondary data to measure and spatialize community resilience to energy development booms. Using Utah as a case study, we identified 20 potential effects of energy booms on communities from the literature and selected 44 indicator variables from freely available sources (e.g., census) that represent these possible effects. We used Principal Components Analysis (PCA) to reduce these variables into measurable components at both state and local levels. We refined the index by removing variable redundancies to test sensitivity. We then applied an additive model to the components to finalize the index at the census block group level. Our results suggest that a community's resilience to stresses brought on by energy development is highly associated with its existing social and economic wellbeing. Additionally, health and education are important factors. This work provides us with a broad understanding of community resilience to energy booms and allows us to identify potential "at risk" communities that are candidates for more targeted assessments.

Remote sensing of tamarisk beetle (*Diorhabda carinulata*) impacts along 412 km of the Colorado River in the Grand Canyon, Arizona, USA

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ABSTRACT: Tamarisk (*Tamarix* spp.) is an invasive plant species that is rapidly expanding along arid and semi-arid rivers in the western United States. A biocontrol agent, tamarisk beetle (*Diorhabda carinulata*), was released in 2001 in California, Colorado, Utah, and Texas. In 2009, the tamarisk beetle was found further south than anticipated in the Colorado River ecosystem within the Grand Canyon National Park and Glen Canyon National Recreation Area. Our objectives were to classify tamarisk stands along 412 km of the Colorado River from the Glen Canyon Dam through the Grand Canyon National Park using 2009 aerial, high spatial resolution multispectral imagery, and then quantify tamarisk beetle impacts by comparing the pre-beetle images from 2009 with 2013 post-beetle images. We classified tamarisk presence in 2009 using the Mahalanobis Distance method with a total of 2500 training samples and assessed the classification accuracy with an independent set of 7858 samples across 49 image quads. A total of 214 ha of tamarisk were detected in 2009 along the Colorado River, where each image quad, on average, included an 8.4 km segment of the river. Tamarisk detection accuracies varied across the 49 image quads, but the combined overall accuracy across the entire study region was 74%. Using the Normalized Difference Vegetation Index (NDVI) from 2009 and 2013 with a region-specific ratio of >1.5 decline between the two image dates (2009NDVI/2013NDVI), we detected tamarisk defoliation due to beetle herbivory. The total beetle-impacted tamarisk area was 32 ha across the study region, where tamarisk defoliation ranged 1–86% at the local levels. Our tamarisk classification can aid long-term efforts to monitor the spread and impact of the beetle along the river and the eventual mortality of tamarisk due to beetle impacts. Identifying areas of tamarisk defoliation is a useful ecological indicator for managers to plan restoration and tamarisk removal efforts.

The trophic ecology of a desert river fish assemblage: influence of season and hydrologic variability

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ABSTRACT: In the remaining undammed rivers of the arid southwestern United States, it is thought that plasticity in feeding behavior allows native fishes to thrive in the context of natural fluctuations in temperature, sediment, and resource availability

associated with extreme swings in season and flow. There have been few evaluations of this hypothesis, in part owing to the rarity of rivers that retain their natural environmental dynamics and native species composition. We investigated the feeding ecology of the fish assemblage of one such river, the Little Colorado River, Arizona, focusing on four native species: bluehead sucker (*Catostomus discobolus*), flannelmouth sucker (*Catostomus latipinnis*), speckled dace (*Rhinichthys osculus*), and endangered humpback chub (*Gila cypha*). Over two years, we sampled fish diets in July, September, January, March, and June, encompassing turbid and clear-water conditions across seasons. We quantified food resource contributions to fish diets in fish-centered food webs, comparing diversity of trophic linkages and linkage-strength distribution across time. We observed a high diversity of dietary items (as absolute numbers and consumer–resource ratios) within a fish assemblage that was apparently resistant to extreme and recurrent environmental variability. Fish diet diversity was high with as many as 69 different diet items in a single season, and over 50% of fish-resource linkages were weak (< 1% of species' diet). Native fishes consumed a mix of terrestrial and aquatic resources. Notably, the water column-feeding humpback chub consumed the largest percentage of terrestrially derived food items and appeared to capitalize on food resources made available by a summer flash flood, consuming twice as much during this flood than during other seasons (based on gut fullness, corrected by estimates of food quality). Such opportunist/generalist strategies, coupled with diverse food resources, may be important to the persistence of these and other native fishes in dynamic environments.

Thirty years of connectivity conservation plans: an assessment of factors influencing implementation of plans

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ABSTRACT: To identify attributes of connectivity conservation plans (CCPs) that correlated with conservation action, we gathered 263 CCPs from around the world, asked authors to characterize attributes of 109 plans, and interviewed authors and implementers of 77 CCPs to learn more about how the plans were produced and implemented. Production of CCPs started about 1990 and increased markedly on all continents. Europe, the United States and the Republic of South Africa were leaders in CCP production. Most plans were followed by implementation actions such as highway crossing structures, ecological restoration, land purchases or easements, or recognition of corridors through zoning or government designation. Broad-brush vision plans were useful decision-support tools for transportation and land-planning agencies. Interviewees highlighted the need for transportation, land-use planning, or regulatory agencies to request development of a CCP. Stakeholder involvement was also important late in CCP development, but not during the intermediate phases. Types of data and models used to develop the CCP were unimportant as long as procedures were transparent and repeatable. Other factors favoring plan implementation were leadership continuity, providing specific recommendations for implementation, and the existence of enabling legislation and policy.

Geochemical characterization of groundwater south of Grand Canyon, Arizona

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ABSTRACT: Better characterization of the geochemical evolution of groundwater south of Grand Canyon is needed to understand natural conditions and assess potential effects from breccia pipe uranium mining in the region. For this study, geochemical signatures of groundwater at 28 sampling locations south of Grand Canyon were evaluated, baseline concentrations for select trace elements (As, B, Ba, Cr, Li, Mo, Rb, Se, Sr, Th, Tl, U, V) were established, and anomalous groundwater chemistries were identified. Groundwater at five sites (Red Canyon, Miners, JT, Havasu, and Warm Springs) exceeded the USEPA drinking water standard for As (10 ug/L). Salt Creek Spring exceeded the USEPA drinking water standard for U (30 ug/L). Four springs from the study area that are located near major geologic structural features (Blue, Havasu, Fern, and Warm Springs) had unique chemistries which may indicate deep flowpaths or potential contribution of fluids from lower in the crust. The other groundwater sites in the study area were distinguished by major anion water type; sulfate, bicarbonate, and a mixture of sulfate and bicarbonate. Water type distinctions were somewhat spatially segregated with sulfate type groundwater present on the western side of the study area, bicarbonate type groundwater on the eastern side of the study area, and a mixture of the two interspersed between the endmember sites. Location of spring groundwater sample collection within drainages of the Grand Canyon is important because changes in chemistry may occur as groundwater discharges from bedrock and flows through alluvial material. Geochemical analysis of groundwater in the Grand Canyon indicates the importance of continued monitoring over time and better understanding of short-term chemical fluctuations.

Why to, and how can, biocrusts be managed in grazed dryland ecosystems

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ABSTRACT: Biological soil crusts (biocrusts) are a critical part of dryland ecosystems. In many places, they are the dominant living cover. Where they occur, they increase soil fertility and stability in otherwise infertile, highly erodible soils; influence local to regional hydrologic cycles; and can be a major contributor to site biodiversity. Therefore, there are many compelling reasons why biocrusts should be managed in a sustainable manner. Compressional forces associated with grazing and other common uses of dryland regions, such as recreation and energy production, present a special challenge in terms of biocrust conservation. In order to manage biocrusts sustainably, specific management goals need to be set, as each biocrust component can play a very different role in a given system, composition can differ among microsites, and thus management techniques often vary. For instance, certain lichen species can be a main source of nitrogen in some environmental settings and if so, then actions to conserve these specific species will be important. Many lichen, moss and cyanobacterial species provide carbon and stability to soils, and thus for these services, management actions can be less species-specific. There are times of use that are more, and less, optimal, and this varies by soil type and climate regime. There are also places and times that grazing and biocrusts cannot peacefully co-exist. We will discuss all the ins and outs of biocrust management for the Colorado Plateau and both wetter and drier regions, for comparative purposes.

An educational partnership for ecological restoration in forests and woodlands on the Navajo Nation

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ABSTRACT: The Navajo Nation is the largest land-based Native American reservation in the USA, encompassing 27,413 square miles and occupying three states and seven counties. Therefore, there are many social/governmental, environmental and economic challenges and opportunities when dealing with natural resources. We initiated a partnership between the Land Grant Office of Diné College and the School of Forestry at Northern Arizona University. The long-term goal is to assess evidence of ecological restoration of native vegetation after implementing ecological restoration thinning prescriptions in dense pinyon and ponderosa pine forests on the Navajo Nation. The objectives are to increase the capacity of staff, faculty and students to participate in applied research, and to strengthen collaborations with research institutions to improve technical support systems to implement research. To date, students from both institutions participated in reciprocal visits and installed a set of permanent plots in pinyon forest on the Diné College campus. Research results will be shared with the Navajo Nation Forestry Department, Navajo communities, grazing officials, Bureau of Indian Affairs Natural Resources, and land users (grazing permittees). This presentation describes the design and initial steps of a multi-year Tribal College-University partnership.

The Escalante River Watershed Partnership: the Ancestral Lands Navajo program involvement

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ABSTRACT: The Ancestral Lands Navajo program has been involved in several ongoing restoration projects since conception in 2012. Amongst these projects, in partnership with the Escalante River Watershed Partnership (ERWP), and Glen Canyon NRA, Ancestral Lands, along with other conservation corps of the southwest region, has been involved with the rehabilitation of the Escalante River from encroachment of the woody Invasive, Russian Olive, improving the riparian health of the river. The Ancestral Lands Navajo program is one of five place-based conservation corps running strong for over 10 year with Conservation Legacy's Southwest Conservation Corps. Since 2008, the nonprofit has been engaging Indigenous youth and young adults through conservation and restoration services in local and national communities. The conservation corps model began its roots at Pueblo of Acoma and has since expanded into five place-based programs: La Placita, Acoma, Zuni, Hopi, and Navajo. The unique program is not only committed to rehabilitating the natural environment but hopes through incorporating "cultural" sensitivity and "traditional" lifeways, it will allow for a realignment of identity as being Indigenous to North America. Ancestral Lands crews' have been working on projects from historical preservation, traditional agriculture and food sovereignty, hiking clubs, fencing, trail construction, land/stream restoration and more. Thanks to partners like ERWP, Ancestral Lands has continued to connect with community, and continue with partnership development.

Erasing lines: working across disciplines to address potential climate change impacts and data gaps

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ABSTRACT: Climate change represents one of the most significant threats to the natural and cultural resources preserved by the National Park Service (NPS). Specific to parks in the southwestern US are expected conditions of increasing temperatures and aridity, punctuated with extreme precipitation events. These environmental conditions are already impacting and will continue to present extreme challenges to the management of both natural and cultural resources. Traditional resource management within the NPS has been to address the resource threats and management needs of natural and cultural resources in a separate and stove-piped manner. However, the conditions and impacts being created by climatic shifts necessitates our need to think in a more integrated fashion. This paper will provide an overview of two case studies that highlight NPS projects that have been designed to provide management benefits to both natural and cultural resources under the effects of climate change: (1) Developing baseline data on geomorphological dynamics to aide in addressing cultural resource vulnerabilities and disturbed lands restoration at Wupatki National Monument (WUPA), and (2) Use of drone collected high resolution orthoimagery to assess priority archaeological sites and to develop soil erosion baselines at Petrified Forest National Park (PEFO).

Pastoral and civilized: water, land, and tribes in the Colorado River Basin

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ABSTRACT: “Indians are still kicking around the Colorado River Basin in the twenty-first century,” explains Bernhardt, despite “the dim prognosis of the ‘vanishing Indian’ myth and considerable extermination and assimilation efforts.” Animating these efforts has been a deep-rooted Euro-American bias for “pastoral and civilized” land, water, and people. It is a bias evident in John Wesley Powell’s historical writings about Native Americans. And it is also a bias enshrined within U.S. law. Ironically, as held by Powell and his contemporaries, this “pastoral and civilized” bias has yielded unintentional gifts to tribes in modern times—gifts involving tribal sovereignty, solidarity, and water rights. These gifts are critical assets given a new Manifest Destiny mindset pervading the Colorado River Basin and outlying areas in the early twenty-first century. To avoid repeating mistakes associated with earlier versions of this mindset, a host of cultural, ethical, legal, and policy changes are in order. Acknowledgement of basin tribes’ permanence should dovetail with embrace of their knowledge and wisdom.

Landscape-scale wildfire has minimal impact on streamflow in the Lower Colorado River Basin

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ABSTRACT: Forested mountain watersheds are impacted by landscape-scale wildfires of increasing frequency and magnitude, with uncertain water resource impacts. While research shows short-term increases in peak flow and erosion during intense summer storms, an outstanding question is whether to expect meaningful long-term changes in water supply. Here, we quantify annual streamflow following two of the largest wildfires in the modern history of the western continental U.S., the Rodeo-Chediski Fire (2002) and Wallow Fire (2011). We focus in detail on nine gaged watersheds with long-term records (>50 years) within the Salt River Basin, the primary surface water source within the state of Arizona. These nested watersheds facilitate evaluation of fire impacts over ranges of elevation, climate, vegetation, and fire extent. Our analysis was challenged by the warmer, drier hydroclimate of the 21st-Century. Therefore, change detection required special consideration when applying methods of pre- and post-fire streamflow comparison. We employed four alternative empirical methods: (1) double-mass comparison between burned and control watersheds, (2) runoff-ratio comparison pre- and post-fire, (3) multiple linear regression with climate variables and satellite-based fire metrics, and (4) time-trend analysis using climate-driven linear models. We found that wildfires had mostly negative or undetectable impacts on annual streamflow. High-severity burned area, which was highly correlated with total burned area at the watershed scale, made little improvement to streamflow prediction. The entire Salt River Basin, which was ~10% burned by each of two major fires in 2002 and 2011, showed declines of 20 – 30% in annual streamflow by runoff-ratio and time-trend methods, though only the latter was statistically significant. Summer streamflow increased in the most heavily burned watersheds, but winter flows, which dominate the annual streamflow in this snowmelt-dominated basin, declined or remained unchanged. While an overall lack of increased streamflow

challenges long-held assumptions, these results support an emerging understanding that in semiarid regions, forest disturbance may not enhance water supplies, especially under the drier conditions of the early 21st century.

Rainfall manipulation quantifies ecosystem sensitivity to hydroclimatic change in Mongolian steppes and Arizona rangelands

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ABSTRACT: Semiarid ecosystems are vulnerable to changing amount and timing of water availability. Climate change effects on precipitation include altered annual totals, seasonal shifts (e.g., reduced winter rainfall) and temporal repackaging into fewer, larger storms. Because semiarid ecosystem carbon cycling depends primarily on water, precipitation changes may alter rangeland productivity and the role of semiarid regions in the global carbon cycle. First, we present results of rainfall manipulation in semiarid steppe of Inner Mongolia, China. These multi-year experiments show that 1) repackaging precipitation into fewer, larger storms negatively affected CO_2 uptake and aboveground net primary productivity (ANPP), 2) mixed grass/shrub communities were more resistant to extreme-duration drought than either grass-only or shrub-only communities, 3) with shrub encroachment into grasslands, total soil respiration was less, resulting in greater C retention in soils under extreme-duration drought, 4) drought timing within the growing season can significantly alter the severity of drought impacts, and grazing management mediates the sensitivity, 5) co-occurring heat wave and drought significantly reduced below-ground grass productivity (root production) and net CO_2 uptake, but not ANPP. We have constructed a new rainfall manipulation facility in a semiarid savanna at the Santa Rita Experimental Range in Southeast Arizona. This facility builds upon the results above and related experiments in the US Southwest. The first experiment is a factorial design including altered amounts of winter precipitation crossed with temporal repackaging of summer monsoon precipitation. Response variables include soil hydrology, ecosystem structure, productivity, and gas exchange of CO_2 and water vapor at the leaf- and plot-levels. This facility is also a test bed for development of sensors and methods to remotely sense ecosystem function under variable climate conditions, especially drought, including NDVI, EVI, PRI, thermal, and sun-induced fluorescence (SiF). We welcome those interested in participating.

Using adaptive management to address species-specific habitat requirements of the Lower Colorado River Multi-Species Conservation Program

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ABSTRACT: The term adaptive management is frequently referred to as “learning by doing” or “plan, act, evaluate.” These catch phrases are often accompanied by flowcharts and diagrams used to portray the broader context of adaptive management to a diverse audience – from policy makers to the public. These representations of adaptive management have assisted in the popularity of this conservation planning concept; however, there are, unfortunately, only a few cases of adaptive management being effectively implemented. Shrinking budgets are often to blame for the lack of success stories. As a result, there is a deficiency of scientific rigor necessary to address complex ecosystems, and resource managers and scientists need to rely on intuition or best professional judgment rather than the best science available. The Lower Colorado River Multi-Species Conservation Program (LCR MSCP) developed the Habitat Conservation Plan (HCP), which contains conservation measures to meet the biological needs of 27 covered species and to benefit 5 evaluation species. The HCP contains habitat creation conservation measures for 21 of the 27 species, which specify patches of created land cover types that will be designed and managed for more than one covered species, and it includes habitat elements for each species. To implement these conservation measures and overlapping species habitat requirements, the LCR MSCP recognizes the importance of developing a framework that is based on a structured decision-making process that will produce a science-driven adaptive management program. The development of adaptive management plans and species-specific conceptual ecological models will help integrate and organize the existing species knowledge alongside the impacts of management actions on the habitat created under the LCR MSCP. These are just a few of the many tools that will assist the LCR MSCP in creating effective resource management actions that will guide the adaptive management process.

Current distribution and potential impacts of tamarisk beetle (*Diorhabda* spp.) across the Colorado River Basin

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ABSTRACT: The tamarisk beetle (*Diorhabda* spp.), a biological control agent introduced for *Tamarix* (tamarisk, saltcedar) control, has been spreading across the Colorado River Basin (CRB) for more than a decade. Due to environmental cues constraining the beetles in their place of origin, the species released in the upper CRB was originally expected to cease southward progress at or near the 37th parallel, roughly the Utah/Arizona border. However, the large beetle population sizes resulting from the massive tamarisk stands along the Colorado River allowed for selection on the beetle's limitations of distribution. The result being continued expansion of the beetle into Arizona. This presentation will discuss the current distribution and extent of beetle populations within the CRB, including movements this season which may see the beetles reach Mexico and the Colorado River Delta. Observed and expected impacts to tamarisk throughout the CRB will also be discussed, as will potential restoration efforts to provide a live vegetation canopy in tamarisk-dominated systems affected by the beetle.

Leveraging low-cost side scan sonar to map in-stream habitat features in Florida rivers at a landscape scale

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ABSTRACT: The Florida Fish and Wildlife Conservation Commission (FWC) has been leveraging an efficient, low-cost approach for mapping habitat features in navigable rivers and streams using recreation-grade side scan sonar (SSS) fish finders at an unprecedented scale. This approach provides a means to create high resolution, spatially detailed maps of in-stream habitat across broad aquatic landscapes. Recreation-grade SSS (Humminbird® models 1198, 1199, and Helix G2n) are bow-deployed from a Jon boat (or similar) in relatively shallow (> 1 m) water to collect swaths (up to 90 m) of side scan imagery. River sections larger than 90 m are imaged using multiple overlapping passes. Sonar recordings are processed using SonarTRX to create georeferenced images which are then mosaicked in ArcGIS. Habitat features of interest are identified and mapped through heads-up digitization. This effort results in a continuous map of habitat types following a hierarchical classification scheme. Quantifying in-stream habitat metrics provides FWC managers and biologists with a means of monitoring habitat change over time, substantiating river prioritization efforts, as well as evaluating effectiveness of restoration efforts.

Population-level genetics influences *Populus fremontii* success more than antecedent climate regime at Rio Mesa research garden

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ABSTRACT: Riparian plants of the southwestern U.S. are accustomed to episodic disturbance events, such as flooding. However, it is unclear how rapid shifts in climate will affect native riparian plant species. Evidence suggests intraspecific variation may play a role in riparian plant success. For example, the range of populations that have evolved in warmer, drier climates may expand with rising air temperature and increased prevalence of drought. We seek to understand the relative role of population-level genetics and antecedent climate regime on the survivorship and growth of native *Populus fremontii* (Fremont cottonwood) cuttings established in a research garden at the Bonderman Field Station at Rio Mesa (BFSRM) in southwestern Utah. This garden, established in 2014, was planted with 1,024 *P. fremontii* trees sourced from 16 populations in Arizona with locations varying in mean annual temperature and precipitation due to differences in elevation. Each source population is represented in the garden by 16 unique genotypes replicated across four study blocks. As of fall 2018, 54.6% of trees planted in 2014 still survived. Survivorship and growth (measured as diameter at root crown) varied by provenance site, but not the climate regime where source populations are located. Growth, but not survivorship, also varied by study block. We found no evidence for differences in watering regime, soil chemistry, or soil chemistry to explain variation in tree growth by study block. Our preliminary results suggest differences in population-level genetics control

survivorship and growth in the BFSRM research garden more than the antecedent climate regime under which individual genotypes evolved.

A biocrust inoculum industry: what could/should it look like?

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ABSTRACT: Biocrust rehabilitation is being pursued and tested around the world. A core step is production, on demand or in advance, of sufficient quantities of biocrust inoculum to add to degraded ecosystems. Biocrust inocula range from cyanobacterial isolates in liquid media to mosses or lichens on solid media (e.g., soils). If and when we begin to see consistent successful application in field settings, we will need to envision the ideal model for a biocrust inoculum production industry. For a given application site, how do we select the origin of materials? Should they be strictly local or can we source from other areas? Which approach will allow sufficient material to be on the market at a given moment? Will inocula be produced only by specialized labs, or should the technology be transferrable to biocrust "seed" farmers? There are other models to learn from such as commercial mycorrhizal and *Rhizobium* inocula industries, and the native plant seed industry. In determining an ideal model or set of models, we must consider practicality, and possible risks (e.g., spread of pathogens or invasives) and benefits (climate-smart restoration, pre-storation, assisted migration) of the use of not-strictly local materials. I propose that there are at least eight alternative models, some clearly bad, some impractical, and multiple viable: 1. One source/mix fits all, 2. Multiple limited sources with known traits, 3. Strict local sourcing, 4. Closest geographic match from many sources (MS), 5. Closest genetic match from many sources, 6. Closest *current* environmental match from MS, 7. Closest *future* environmental match from MS, 8. Shotgun (MS, environment selects). Combinations are also possible. Our research community would benefit from open discussion of these ideas, and collaborative research to fill data gaps. We could benefit from the experience of others with relevant experience such as native seed developers and producers.

Effect of soil and soil biota on successful deployment of native plant materials: what are we missing?

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ABSTRACT: Practitioners know that maladaptation of native plant materials to the climate of the application site may decrease success in ecological restoration. There is less appreciation of the role of the "hidden half" of the plant environment: the soil. How might plant materials respond when confronted with novel soil environments or novel soil biota, and will their response depend on climate novelty? We are testing this question experimentally in common C_4 grasses of the Colorado Plateau. After three years in the field, experimental *Bouteloua gracilis* plants produced less biomass in simulated warmer, drier climates than in their climate of origin. In these warmer-drier scenarios, edaphic influences were expressed, with plants exhibiting better growth in soils from their site of origin. There were some, less consistent, positive influences of soil biota from the site of origin also. We also found that our experimental inoculations with different sources of soil biota, resulted in persistently distinct soil communities, throughout the experiment. Thus, pre-inoculation of nursery stock is one way to reduce soil biota novelty experienced by seedlings. Without manipulating climate, we tested whether *Pleuraphis jamesii* growth depends on soil and soil biota, using two novel soil sources. Soil novelty alone did not reduce the size of plants in the first growing season. Novelty of soil biota did reduce plant size for one soil source, but not the other. Finally, novelty of both soils and soil biota diminished growth, more so for one of the novel soil sources than the other. A third experiment simulates migration of *P. jamesii* to a cooler-wetter climate compared to no climate change. Matching of soil biota to their source soil positively influences plant growth in both cooler-wetter and unaltered environments. These experiments together suggest that decreasing soil and soil biota novelty for plants might promote successful ecological restoration.

The future of Colorado Plateau rangelands in the context of 21st century climate and drought trajectories

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ABSTRACT: Climate projections for Colorado Plateau rangelands indicate rising temperatures and geographically-variable shifts in precipitation throughout the 21st century. Although these long-term climate trajectories are a recognized challenge for resource managers and policy makers, anticipating the impacts of these changes is confounded by two major challenges. First, because the rangelands are primarily dryland, water-limited ecosystems, the composition and productivity of rangeland plant communities is

tightly linked to the spatial and temporal dynamics of soil moisture availability: conditions that are not easily inferred from climate conditions alone. Second, long-term projections of precipitation are less consistent across space and through time than temperature, promoting uncertainty about appropriate expectations for future drought conditions. Here, we examine a suite of ecologically-relevant drought metrics that represent various types of rangeland plant stress, including: moisture deficits in particular seasons and soil depth; long-term, chronic, moisture limitation that promotes sustained growth declines; and short-term extreme dry events that can lead to plant mortality. Using an ecosystem water balance model driven by observed and modeled climate for a broad suite of climate models, we quantified these metrics across rangelands on the Colorado Plateau. The results identify historical trends and future trajectories of drought, highlighting some areas with clear projections for increasing ecological drought stress, and other areas with less severe change. These results also indicate consistent differences in the uncertainty of projected change among drought metrics, with the largest and most consistent increases expected in drought conditions most directly influenced by temperature. Considering future patterns in this diverse suite of ecological drought metrics provides insight into the long-term impacts of climate change on rangeland plant communities and offers a new perspective for mitigating uncertainty in management under climate change projections.

The Escalante River Watershed Partnership: RiversEdge West and assisting watershed partnerships.

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ABSTRACT: Diverse, multisector partnerships have formed in many parts of the western U.S. and northern Mexico to protect and restore natural resource conditions of key watersheds (or sub-watersheds). The Escalante Staircase Partnership is one of numerous great examples. Other examples include partnerships associated with the Rio Grande/Bravo and the Colorado River Delta along the U.S.-Mexico border region; the Verde River and Gila River in Arizona, the north fork of the Gunnison in Utah, the Save our Bosque in New Mexico, and the Dolores River and Purgatoire Watershed in Colorado. To enhance their own longevity and the viability of their conservation and/or restoration work, many watershed partnerships underscore the importance of receiving timely assistance that allows them to better address a range of institutional, socioeconomic, political and environmental challenges associated with their work. RiversEdge West (REW) was founded in part to meet this need head on by providing education, collaboration, and technical assistance to watershed partnerships in the western U.S. As part of our collaborative work with a variety of watershed partnerships, REW: (1) promotes a landscape scale restoration focus that emphasizes threat assessment, setting goals and objectives, and monitoring; (2) connects watershed partnerships with other local and regional natural resource conservation initiatives; (3) assists partnerships to meet communication and fundraising goals; (4) organizes forums where watershed partnerships, stream restoration practitioners, agency personnel, researchers, businesses, municipalities, farmers, funders and others can come together to share lessons learned from their work; (5) provides a range of technical resources on all phases of stream restoration. As part of the Escalante Partnership talk, we will discuss our work with the Escalante Watershed Partners as well as other watershed partnerships, how REW works, some of our achievements, and thoughts on future work and priorities.

Not your father's canyon? Historical, current, and future perspectives of visitor use at Grand Canyon National Park

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ABSTRACT: Even before its designation as a national park in 1919, the Grand Canyon incited awe, wonder, inspiration, and even fear among those who experienced it. A UNESCO World Heritage Site, Grand Canyon National Park, and the surrounding area, is a melting pot of culturally, geologically, and ecologically rich elements. With visitation numbers exceeding six million people in 2018, the park has also become one of the most visited national parks in the country. While the number of visitors may have increased since 1919, the opportunities for recreation have remained, more or less, the same. Hiking, backpacking, mule-riding, and rafting all have roots in the narrative of the Grand Canyon. These, along with other activities, continue to be sought after by the multitude of visitors that come to the area. But what is it that visitors are seeking? The activity itself? Natural beauty? Solitude? And what impacts are those same visitors causing? Using the backdrop of multiple visitor use studies over the past 20 years, this presentation discusses historic and current visitor perceptions regarding Grand Canyon National Park. Additionally, the question of how the parks very nature has changed, if at all, over the years is raised along with future implications of the parks purpose assuming the continued trend of rising visitation numbers.

Encouraging sustainable grazing management innovations for the Colorado Plateau: promise and pitfalls

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ABSTRACT: Livestock grazing is a culturally important land use on the Colorado Plateau for rural and tribal communities. Due to concerns about the impacts of grazing on the region's arid and semi-arid grassland ecosystems, efforts are under way to find new approaches to grazing management that can reduce and mitigate those impacts even in a changing climate. This presentation will discuss potential benefits of proposed grazing management innovations, with emphasis on those being studied at the Canyonlands Research Center in southeastern Utah, as well as challenges that may arise in shifting from field research to widespread implementation. In order for change to occur on a time scale that matches the urgency of this issue, top-down policy-oriented solutions that incentivize management change must be accompanied by bottom-up efforts that can work with individual producers and public land managers to match practices to local contexts. Drawing on nearly two decades of research on innovation adoption by rangeland users and managers, I will describe barriers to uptake of new practices and propose ways to surmount them.

Painting a picture of northern Arizona visitors from multiple visitor studies: research and management implications

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ABSTRACT: This presentation represents the work of three university researchers that have conducted numerous tourism and outdoor recreation studies in northern Arizona for the National Park Service, various tourism offices, tribes, and non-profit conservation groups over the past ten years or so. While the Grand Canyon NP attracts millions of visitors each year and visitation is growing, many communities and other natural and cultural resource sites in the region are part of visitors' itinerary for day and overnight visits. Studies involving primary data collection of visitors/recreationists/members and communities for northern Arizona national monuments, Navajo Nation, Grand Canyon Association, Sedona Chamber of Commerce and Tourism Bureau, and Arizona Office of Tourism will be the focus of the presentation. Some secondary data for additional stakeholders and sites will also be included. The analysis will focus on visitation data and draw attention to single-site visitation in comparison to multi-site. It will also focus on outdoor recreation activities in comparison to touristic activities, and demographic profiles in an effort to synthesis a regional profile of visitors. This profile will be compared to data for the region that the Arizona state tourism office commissions. These visitor data will be reviewed with a focus on potential regional sustainable tourism approaches that can represent collaborative efforts across the various stakeholders and envision what northern Arizona might look like five to ten years from now.

Painting a picture of northern Arizona visitors from multiple visitor studies: research and management implications

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Restoration, mitigation and vegetative recovery…a matter of scale

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ABSTRACT: The Natural Resource Conservation Service (NRCS) provides assistance to private land stewards that want to implement sound conservation practices that focuses on improving SWAPA+HE (Soils, Water, Air, Plants, Animals + Humans & Energy) Resources. Northern Arizona contains diverse settings with many ecological complexities. Two such complexities NRCS deals with are juniper expansion/densification and altered low lying land forms, specifically, bottoms and washes. To determine success of restoration treatments, mitigation or vegetative response, recovery time, scale and economics must be considered in the post-treatment evaluation. Annually, NRCS offices throughout northern Arizona provide financial and technical assistance to treat juniper encroachment on tens of thousands of acres. Through years of experience and research, conservation planners developed decision making tools to prioritize treatments on certain soil types with an understanding of the effectiveness of differing cultural, mechanical, chemical and biological methods. The acreage of low-lying bottoms and washes is a relatively small component of northern Arizona land forms but are considered to have an inverse proportion of species richness and production potential. However, the native plant communities have been altered and have experienced encroachment of both native and non-native invasive species. Currently, NRCS is conducting seeding trials in various areas of northern Arizona to find potential solutions.

Northeastern Arizona Drought Responsive Seeding Strategy

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ABSTRACT: Droughts are projected to increase in frequency and severity throughout the United States, especially in the Southwestern U.S., potentially leading to degraded conditions such as: decreased Air Quality (increased particulate matter from wind erosion, increased particulate matter causing snow pack to melt more rapidly in the Colorado Rockies) along with issues caused by sheet and rill erosion. Current management paradigms and responses are not embracing this reality. Rapid response teams are sent in after natural disasters such as hurricanes and tornados to provide relief while the United States Forest Service reseeds immediately after catastrophic wildfire as part of the Burned Area Emergency Response (BAER) procedures. In the rangeland and agricultural sectors, economic aid due to drought effects does occur, but rarely is it implemented as a conservation strategy, despite the strong need for this action. Northeastern Arizona experienced a devastating drought beginning in mid-2017 and it remains to be seen if an end is near. In March 2019, four counties were declared as primary natural disaster areas (Coconino, Apache, Navajo and Greenlee). Large scale herbaceous/shrub/tree mortality and/or severe reductions in annual production are now apparent. In response to the current conditions, the "*Northeastern Arizona Drought Responsive Seeding Strategy*" has been developed. This strategy utilizes the Rangeland Production Monitoring Service (RPMS) technology that enables quantification of the severity and extent of the drought effects and has implemented a responsive and adaptive management alternative for Coconino, Apache and Navajo Counties. Reseeding following severe droughts, like those being experienced in the Southwest, is a critical step towards being more responsive, requires precise implementation and must be economically feasible.

Responses of desert plant communities to climate warming since the Last Glacial Maximum - 1: community-climate lags

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ABSTRACT: Plant communities typically exhibit lagged responses to climate change due to poorly-understood effects of colonization and local extinction. Here, we quantify rates of change in mean cold tolerances, and contributions of colonization and local extinction to those rates, recorded in plant macrofossil assemblages from North American hot deserts over the last 30,000 years. Colonization and local extinction dates for 269 plant species were approximated from macrofossils in 15 packrat (*Neotoma*) midden

series. Cold tolerances estimated from contemporary climate were used to quantify assemblage-mean cold tolerances through time. Rates of colonization and local extinction, and their effects on rates of change in assemblage-mean cold tolerances, were estimated for 30-20 kybp (Late Pleistocene, no directional warming), 20-10 kybp (deglaciation, rapid warming), and 10-0 kybp (Holocene, no directional warming). Rates of change in all metrics were negligible during the Late Pleistocene. Rates of change in assemblage-mean cold tolerances (mean 1.0 ºC $x10^{-4}$ yr^{-1}) lagged behind warming during deglaciation, and continued at similar rates (1.2 ºC $x10^{-4}$ yr^{-1}) throughout the Holocene. Colonization and local extinction contributed equally to delayed responses to warming, but their dynamics differed through time: Colonization by warm-adapted species predominated during deglaciation, while the most heat-adapted species exhibited long delays in colonization. Only the most cold-adapted species went locally extinct during deglaciation, followed by slow repayment of the extinction debt of cool-adapted species during the Holocene. In summary, responses to rapid warming can persist for millennia, even after cessation of warming. Consistent patterns from different midden series across the region support a metacommunity model in which dispersal interacts with environmental filters and buffers against local extinction to drive community-climate disequilibrium during and after periods of warming.

Responses of desert plant communities to climate warming since the Last Glacial Maximum - 2: life history traits predict colonization and extinction lags

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ABSTRACT: Variation in life-history strategies can affect metapopulation dynamics and the composition and diversity of communities. However, datasets that allow for the full range of species turnover from colonization to extinction over relevant time periods are limited. The late Quaternary record provides unique opportunities to explore the traits that may have influenced interspecific variation in responses to past climate warming, in particular the rate at which species colonized newly suitable habitat or went locally extinct from degrading habitat. We controlled for differences in species climate niches to predict expected colonization and extinction sequences recorded in packrat middens from 15 localities in the Mohave, Sonoran, and Chihuahuan deserts. We tested the hypotheses that dispersal syndrome (none, wind, vertebrate), growth form (herb, shrub, tree) and seed mass mediated variation in postglacial colonization lags among species, whereas clonality (clonal, non-clonal), growth form and seed mass affected extinction lags. Growth form and dispersal syndrome interactively affected colonization lags, where herbaceous species lacking long-distance dispersal mechanisms exhibited lags that exceeded those of woody, wind or vertebrate-dispersed species by an average of 2-5 thousand years. Growth form and seed mass interactively affected extinction lags, with very small-seeded shrubs persisting for 4-8 thousand years longer than other functional groups. Taller, vertebrate-dispersed plants have been shown to disperse farther than shorter plants without specialized dispersal mechanisms. We found that variation along this axis of dispersal syndromes resulted in dramatic differences in colonization rates in response to past climate change. Very small seeded shrubs have a unique combination of long vegetative and seed bank lifetimes that may allow them to persist for long periods despite declines in habitat condition. Readily measurable traits may help predict which species will be more or less sensitive to future climate change, and inform interventions that can stabilize and promote at-risk populations.

Improving the status of roundtail chub in Arizona

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ABSTRACT: Roundtail chub (*Gila robusta*) in the lower Colorado River Basin occupy major watersheds and tributaries throughout Arizona and in a small portion of western New Mexico. Until recently, two additional species of chub were recognized in the roundtail chub complex (Complex), headwater (*G. nigra*) and Gila chubs (*G. intermedi*a). Regardless of the taxonomic ambiguity that has followed (or history that has evolved over time) the Complex since they were recognized as full species status, conservation has been occurring in the Southwest. Two conservation agreements with roundtail chub as a primary species, one representing the greater Colorado River Basin and one within Arizona, were developed in 2004 and 2007, respectively. The commitments in these agreements paved the way forward for a conservation and management strategy with state, federal, and Tribal signatories to ensure the persistence of chub throughout their range. Conservation actions that have been implemented under the agreements have substantially improved the status of chub in Arizona. The primary strategies used have included threat reductions, establishing new populations, and developing hatchery broodstock populations. In 2004, there were 63 populations of chub in Arizona on federal or state lands. Since

then, five populations were discovered, 11 populations were established, 11 refugia populations were created, broodstock populations were developed for multiple lineages, and threat abatement projects have been implemented in 15 locations.

How do plants affect soil microbial communities across drylands?

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ABSTRACT: Soil microbes can regulate plant diversity in drylands, and plants affect microbial communities (plant-soil feedbacks). In this study, we look at how plant species influence the composition of nearby microbial communities in two drylands that vary in temperature and rainfall to determine if effects of plants on microbes are consistent across different environmental conditions. We collected soil samples from the Sevilleta Long Term Ecological Research and Jornada LTER sites in New Mexico from near *Bouteloua eriopoda*, a C_4 grass, and *Gutierrezia sarothrae*, a C_3 shrub, since they were abundant at both sites. We subset samples to estimate abundance of all microbes (chloroform fumigation), non-arbuscular mycorrhizal fungi (ergosterol), and photosynthetic cyanobacteria (chlorophyll a). Microbial communities were influenced differently by nearby plant species at both sites. To determine a significant difference, we conducted an ANOVA, and we found that the total biomass, chlorophyll content, and ergosterol were at least 64% higher under *B. eriopoda* than *G. sarothrae* at Jornada (all $P<0.05$), but only biomass had the same trend with species at SEV ($P<0.05$). Thus, we conclude that the effects of plants on the microbial community are context specific, because the effect varies by site. Soil microbes have been found to have a significant impact on plant productivity by means of nitrogen fixation, nutrient acquisition, and carbon cycling.

Comparisons of LiDAR- and field-derived estimates of crown base height and canopy bulk density in ponderosa pine forests in northern Arizona

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ABSTRACT: Increased frequency and severity of large crown fires in mid-elevation ponderosa pine forests continue to garner much attention in the southwestern and western United States. Accurate estimates of crown base height (CBH) and canopy bulk density (CBD) are critical inputs for many fire modeling programs which assist in predicting fire behavior during these large crown fires. Light Detection and Ranging (LiDAR) is a type of active remote sensing which has proven to be effective in estimating various fuel metrics in a variety of forest types across broad landscapes. This research evaluates the accuracy of LiDAR in estimating metrics needed for calculating plot- and stand-level CBH and CBD in ponderosa pine forests in northern Arizona. Measurements of tree size, crown base height, total tree height, and crown radius were made in the field and derived from associated LiDAR data across the study area. Measurements from both techniques were used to estimate CBH and calculate CBD using regional allometric equations and the Fire and Fuels Extension of the Forest Vegetation Simulator (FVS-FFE). CBH estimates were compared at the plot- and stand-level, with r-squared values of 0.61 and 0.67 respectively. CBD estimates were compared at the plot- and stand-level, with r-squared values of 0.27 and 0.68 respectively for the allometric method, and 0.65 and 0.75 respectively for the FVS-FFE method. Results from this study indicate that LiDAR can estimate CBH and CBD with reasonable accuracy in northern Arizona ponderosa pine forests, with best results at the stand-level using the FVS-FFE method.

Acoustical monitoring of overflight noise on the South Rim at Grand Canyon National Park

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ABSTRACT: In 1975 the Grand Canyon National Park Enlargement Act recognized natural quiet as a resource and therefore requires studies on the impacts of overflights on the park's natural quiet. Subsequently, the 1987 Overflights Act required the "substantial restoration of natural quiet" to be defined as 50% of the park achieving natural quiet (no aircraft audible) for 75 to 100% of the day, as noise from aircraft has a significant adverse impact on natural quiet, wildlife interactions, and visitor experience. Therefore, protecting the natural soundscape is important for reducing these negative impacts and providing the 6.5 million annual visitors in the park with access to the valuable resource of natural sounds and quiet. As of 2015, there are approximately 150,000 flights over Grand Canyon

annually consisting of air tours, additional flights by air tour operators, and general aviation. We present results from collecting ambient sound pressure level and audio data at three stations focused on two air tour corridors at the South Rim during high and low use periods (i.e., summer and winter). The data then processed from these stations measures the duration, frequency, and type of overflight events for a sample of eight days out of the 30-day monitoring period. The program used to process and analyze these data is the Sound Pressure Level Annotation Tool (SPLAT) created by the National Park Service Natural Sounds and Night Skies Division. From these data, we calculate overflight sound level above the natural ambient sound level, the percent time that aircraft are audible, and other metrics. These findings will be used to validate a park-wide noise model and inform future recreation planning for the park's developed, backcountry, and proposed wilderness areas.

Coyotes as a reservoir for the emerging zoonotic parasite, *Onchocerca lupi*, in the southwestern United States

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ABSTRACT: *Onchocerca lupi,* the causative agent for canine onchocercosis, is a zoonotic filarial nematode known to cause infection in dogs, cats, wolves, and recently, humans. This parasite is transmitted by black flies (*Simulium* spp.) and has recently been reported in the southwestern U.S. with increasing incidence in domestic canine populations. Since 2013, there have been seven reported human cases of *O. lupi* in the U.S. It is imperative to understand the prevalence of this parasite in the wildlife in order to develop appropriate surveillance and mitigation strategies for *O. lupi*. To determine if coyotes could be serving as a reservoir, from 2015-2018, skin samples were collected from 707 coyotes in 24 counties in Arizona, Nevada, and New Mexico. Samples were screened for *O. lupi* DNA using a published cytochrome c oxidase (COI) assay, and the amplicon sequenced on the MiSeq platform. We found 37 coyote samples from seven counties in Arizona and one county in New Mexico containing *O. lupi* genetic signal. We identified coyote populations within Arizona and New Mexico serving as a likely reservoir for *O. lupi*, with the potential of perpetuating the spread of this newly emerging pathogen in the Southwest. Understanding that coyotes may be acting as a previously unknown and unstudied *O. lupi* reservoir is crucial for developing surveillance and intervention strategies to mitigate the continued dissemination of this parasite in both canine and human populations in the United States. This recent emerging zoonotic disease appears to be established in the United States and requires immediate attention from public health officials and the scientific community to address this currently limited, but increasing, public health and veterinary threat.

Proposed changes in endangered species classification of two Colorado River fish: part I - U.S. Fish and Wildlife Service proposes downlisting the humpback chub (*Gila cypha*)

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ABSTRACT: The USFWS uses species status assessments (SSA) as the basis for a variety of decision-making processes [e.g., Endangered Species Act (ESA) Section 7 consultations; species recovery plan revision; and ESA Section 4 species classification decisions]. SSA's review the best available information on a species' needs, its current condition, and future condition. The SSA is not a decision-making document. An SSA for humpback chub was completed in March 2018. The USFWS relied on the findings of the SSA to develop a 5-Year Review for the species. A 5-Year Review is a decision-making document; in this case, the USFWS-Mountain Prairie Regional Director has decided to propose: 1) reclassification of humpback chub from endangered to threatened status, i.e., downlisting, and 2) revision of the species recovery plan. We will review the major findings of the SSA, which serve as the basis for the USFWS's Proposed Downlisting Rule (PDL; scheduled for publication in the *Federal Register* by December 31, 2019). We will also review the content of a proposed 4(d) rule that will be published with the PDL. The authors will host a 15-minute Question and Answer period with the audience to discuss this proposed listing action and a similar action for razorback sucker (*Xyrauchen texanus*).

Proposed changes in endangered species classification for two Colorado River fish: part III – question and answer session

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ABSTRACT: In the previous two presentations the authors reviewed the basis for the USFWS' recent decisions to propose downlisting humpback chub (*Gila cypha*) and razorback sucker (*Xyrauchen texanus*). Because these decisions affect collaborative partnerships and others involved in the conservation of these species and the Colorado River ecosystem, the authors wanted to devote time to discuss these decisions with the audience and to answer as many of their questions as possible. Time permitting, we can provide a report on the development of a species status assessment for Colorado pikeminnow (*Ptychocheilus lucius*) and a draft 5-Year Review for bonytail (*Gila elegans*).

The post 2023 future of two endangered fish recovery programs in the Upper Colorado River Basin

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ABSTRACT: The Upper Colorado River Endangered Fish Recovery Program is a ten stakeholder partnership established in 1988 and is tasked with recovery of four federally listed Colorado River fish: the Colorado pikeminnow (*Ptychocheilus lucius*), razorback sucker (*Xyrauchen texanus*), humpback chub (*Gila cypha*), and the bonytail (*Gila elegans*). The San Juan River Basin Recovery Implementation Program comprises twelve stakeholders, was established in 1992, and is charged with the recovery of Colorado pikeminnow and razorback sucker. The goal of both programs is to recover the listed species while water development proceeds in accordance with federal and state laws and interstate and tribal compacts. The Cooperative Agreements that implement these recovery programs sunset in 2023. The program stakeholders are committed (via PL116-9) to work with the Secretary of the Interior to submit a report to Congress by the end of FY2021 that describes our program's progress to date and our recommendation for Post 2023 programs, i.e., recovery actions and associated costs needed beyond 2023 to achieve endangered species recovery. We will review where we are in the development of the report to Congress with consideration for future cooperative agreements and new recovery programs funding legislation.

Engaging southwestern tribes in sustainable water resources topics

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ABSTRACT: Indigenous peoples in North America have a long history of understanding their societies as having an intimate relationship with their physical environments. Their respect for their ancestors and 'Mother Earth' speaks of unique value and knowledge systems different than the value and knowledge systems of the dominant United States settler society. The value and knowledge systems of each indigenous and non-indigenous community are different but collide when water resources are endangered. One of the challenges that face indigenous people regarding the management of water relates to their opposition to the commodification of water for availability to select individuals. External researchers seeking to work with indigenous peoples on water research or management must learn how to design research or water management projects that respect indigenous cultural contexts, histories of interactions with settler governments and researchers, and the current socio-economic and political situations in which indigenous peoples are embedded. They should pay particular attention to the process of collaborating on water resource topics and management with and among indigenous communities while integrating Western and indigenous sciences in ways that are beneficial to both knowledge systems. The objectives are (1) to provide an overview of the context of current indigenous water management issues, especially for the U.S. federally recognized tribes in the southwestern United States; (2) to synthesize approaches to engage indigenous persons, communities, and governments on water resources topics and management; and (3) to compare the successes of engaging southwestern tribes in five examples to highlight some significant activities for collaborating with tribes on water resources research and management. There is a strong recognition of the importance of engaging tribal participants in water management discussions particularly with pressing impacts of drought, climate change, and mining and defining water rights.

Escaping the sun: characterizing fine-scale structural and temporal shade dynamics buffering moss-dominated biocrusts in the Mojave using *Sun Seeker©*

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ABSTRACT: In drylands, organisms face stressful extremes in solar irradiance, temperature, and evaporative demand, which are predicted to increase with further climate change. Moss-dominated biocrust diversity and biomass are often higher in microhabitats shaded by vegetation and topography that presumably reduce these climatic extremes, but the structural and temporal shade dynamics of biocrust have not been quantified and the importance of shade-buffering may increase with climate change; therefore, we sought to quantify the shade-buffer and biomass of 130 *Syntrichia caninervis*-dominated microsites in the Mojave Desert, Nevada, across three scales of aridity and time. We used the smartphone app, Sun Seeker©, to photographically delineate time-referenced shade objects from the vantage point of the mosses and then scored photos to yield annual, seasonal, and bi-hourly shade-time percentages. We quantified variation in moss shade-time across three life zones (creosote-bursage, blackbrush-Joshua tree, & pinyon-juniper), three topographical exposures (north-facing, south-facing, flat), and three microhabitat types (shrub canopy, dripline, interspace). To relate shade-time to incoming solar radiation, we quantified insolation and the insolation buffer for mosses at each life zone by establishing PAR light sensors over 12 biocrust microsites for comparison to ambient PAR measured by on-site weather stations. Using 950 photographs, we report the ecological shade-environment of this common biocrust moss and elucidate its importance in predicting moss, lichen, and total biocrust biomass at fine scales (20 x 20 cm). We report the power of our shade-index to predict seasonal, annual, and bi-hourly insolation buffering (i.e., local reduction in PAR). We suggest how these results contribute to a life zone-microhabitat-specific vulnerability assessment for this keystone biocrust moss threatened by climate change, land use, and desertification. We encourage the application of our novel Sun Seeker shade-index for any biocrust, vascular plant, or animal species where shade-buffering can inform their ecology, restoration, or assisted conservation planning.

Restoration of the US-Mexico Borderlands: three decades of learning, and the science is finally catching up

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ABSTRACT: Ecological restoration is central to human prosperity and biodiversity conservation along the border between Mexico and the United States. For over 30 years, Cuenca los Ojos (CLO) has invested heavily in restoring hydrological and ecological integrity to over 200,000 ac of private and public lands on both sides of the border. The results provide a stunning visual example of how the sustained investment in degraded landscapes can reverse a century of mismanagement and return productivity to the arid region. Productive ecosystems provide the habitat for recovering at-risk species, as well as improving human livelihoods and communities. For the past 5 years, Borderlands Restoration Network, the US Geological Survey, and other partners have focused research and monitoring on restoration outcomes on CLO lands, providing a clearer view of results from this ambitions restoration effort, now writ large across the varied border landscape. We offer an evaluation of restoration outcomes, based on monitoring and observational data, and interpret current trends in the context of past and ongoing management efforts. We also offer lessons learned about collaboration, perseverance, and the resiliency required of both human and ecological systems during this period of global change.

Telemetry-based aerial surveys as an efficient method for estimating abundance of sparse populations

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ABSTRACT: Aerial surveys are commonly used to collect data for estimating abundance for a variety of large animals. Aerial application of common abundance estimators, including distance sampling, closed population mark-recapture models, and sightability models, all require transect-based surveys in which the entire survey area (or the entirety of selected sample plots) is surveyed. For sparse populations, such extensive surveys may be inefficient and costly. We evaluated two telemetry-based abundance estimators that do not require transect surveys. We conducted aerial surveys of Sonoran pronghorn in southwest Arizona in 2017 and evaluated the plausibility of abundance estimates returned by these estimators, as well as the costs of these estimators, relative to sightability surveys. Both telemetry-based methods produced similar, plausible abundance estimates, although there was some evidence of a non-

random distribution of telemetry tags, which could bias estimates. The telemetry-based methods dramatically increased the sighting rate of Sonoran pronghorn during flights and reduced total flight time by up to 80%, a significant time and cost savings. However, telemetry-based approaches incur an additional cost of maintaining telemetered animals in the population. For Sonoran pronghorn and other species, telemetry-based abundance estimators may offer significant efficiency improvements over estimators requiring transect-based surveys, if there are no significant deviations from model assumptions. Telemetry-based methods will be most useful if the cost of telemetering animals is low, if animals are sparse or hard to detect, if the study is shorter duration, and if the study species has a loose social structure and tends to form large groups.

Are Native Americans exposed to uranium mining-related elements in smoke particulates during traditional uses of sagebrush?

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ABSTRACT: The Grand Canyon watershed contains high-grade uranium (U) ore deposits in various stages of extraction. Radiological concerns related to U mines are generally at the forefront of public concern, but other mining-related ore-body elements (e.g., arsenic, cadmium, lead) may also pose health risks. Canyon Mine, which is located near the south rim of the Grand Canyon, is located within a traditional cultural property (TCP). The potential exposures of Native Americans to U and other elements when using cultural resources (e.g., sagebrush, elk tissues, piñon sap) gathered near U breccia-pipe mines are not well known. Previous work by the U.S. Geological Survey has indicated that aeolian transport of dust from the mine sites contributes to elemental-loading on vegetation beyond mine perimeters. The proximity of the mines to culturally-significant areas and the perceived health risks from U mining are a source of concern to tribes. We are investigating the potential for Native Americans to inhale mining-related elements in smoke during ceremonial burning of sagebrush, as part of a larger USGS effort to develop a Native American risk assessment model for breccia pipe U mines. Sagebrush (*Artemisia tridentata*) was collected upwind and downwind of U mines in pre-, active, and post-production stages, from a non-mineralized reference site, and from tribally-significant areas in the TCP. The sagebrush trimmings were burned in an enclosure to simulate traditional use, and the smoke particulates were vacuum-collected on stacked glass fiber filters (2.7 and 0.7 µm pore sizes) to simulate inhalation. The filter-entrapped particulates were characterized for 13 elemental constituents (arsenic, bismuth, cadmium, cobalt, copper, lead, molybdenum, nickel, selenium, silver, thallium, thorium, U). Comparisons of elements in sagebrush smoke among mine, tribal, and reference locations, as well as in cigarette smoke to assess relative risk, will be presented.

Co-production of science: lessons from social science literature

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ABSTRACT: The co-production of science is increasingly called for as a way to address gaps between science and decision-making. The co-production of science can be defined as a collaborative research approach that involves sustained interaction and two-way communication between scientists and the end users of scientific information with a focus on the production of actionable scientific information for decision making. Yet, there are multiple definitions of "co-production of science" in the academic literature, which may confound how the concept is applied in the practice of developing scientific information that is actionable in specific decision contexts on the ground. Additionally, there are multiple ways in which the co-production of science can be accomplished, each with varying levels of required input and potential outcomes. There is also increasing attention to evaluating the practice of co-production of science to determine if the increased capacity required to successfully execute it results in the intended desired outcomes. The purpose of this presentation is to provide an overview of the concept of the co-production of science as it has been discussed in the academic literature, including a brief history of how the concept came into practice and how it has been defined. However, this presentation will primarily focus on explaining the various ways that co-production of science can be accomplished in practice and how it is being evaluated with a few brief examples to ground concepts from the literature. Finally, the presentation will end with concrete lessons learned, as well as recommendations for scientists and the end users of scientific information who wish to attempt the co-production of science in order to facilitate the development of actionable scientific information for decision making.

Destruction of a La Sal Mountains alpine community by non-native mountain goats

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ABSTRACT: Alpine areas in southern Utah are uncommon, making their protection of high importance. The La Sal Mountains alpine area supports unique plants such as the endemic La Sal daisy (*Erigeron mancus*) and seven other sensitive species (as designated by the Manti-La Sal National Forest). The Utah Division of Wildlife Resources (DWR) has been introducing non-native mountain goats throughout Utah since the 1960s. In 2013-2014 DWR introduced 35 mountain goats to a patch of state land (SITLA) in the La Sal Mountains. The mountain goats moved up to the alpine area, their natural habitat, which is Forest Service land and specifically the Mount Peale Research Natural Area (RNA). The population is now over 100 and DWR's goal is 200 goats. In 2017, the Grand Canyon Trust ("Trust") surveyed 44 plots in the RNA previously surveyed by Wild Utah Project. We documented impacts, such as grazed vegetation (including sensitive species), trampling and wallows – where goats dig to create loose soil in which they wallow. Our assessments showed a decline in condition for 59% of sites compared to data from two years earlier. In 2016, the Trust and Utah Native Plant Society filed a lawsuit against the Forest Service arguing, among other things, that the agency violated the law by refusing to remove the mountain goats from the Mount Peale RNA despite regulations that require the Forest Service to keep the RNA in a "virgin or unmodified condition." The suit was dismissed, and that decision was affirmed on appeal in May 2019 on the grounds, in part, that the Forest Service has not yet made a final decision about whether to remove the mountain goats from the RNA. We will repeat the goat impacts survey in 2019, and will comprehensively map the number and size of wallows within the RNA.

Unmanned aerial vehicle based structure from motion for estimating biocontrol impacts on riparian tamarisk

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ABSTRACT: *Diorhabda carinulata* is a defoliating beetle which was first released in 2001 by the USDA in an effort to control increasing tamarisk (*Tamarix ramosissima*) populations. However, researchers highlight the ongoing impacts this eradication poses to wildlife, such as the endangered southwestern willow flycatcher (*Empidonax traillii extimus*), which are adapting to the historical changes in tamarisk cover. The rapid degradation in habitat suitable for supporting birds and other native wildlife requires precise, efficient and broad-scale monitoring of the riparian zones subjected to such threats. Remote sensing via unmanned aircraft systems (UAS; i.e. drones) presents a developing, timely solution to tracking spatiotemporal changes in the natural environment. Multispectral and thermal imagery of coarse resolution have long been used to produce vegetation indices and other valuable metrics of ecosystem health and productivity. Drones offer more precise observations with finer spatial resolutions as well as the ability to produce photogrammetric measurements from a series of high-resolution, overlapping two-dimensional (2D) images. Our study collects and analyzes UAS-derived multispectral, thermal, and Red-Green-Blue (RGB) imagery over Matheson Preserve in Moab, Utah which was flown prior in 2015 to assess changes over time in the value and potential of this high-resolution imagery to support the medium-resolution remote sensing data (i.e. satellite imagery) typically used for monitoring. Our methods aim to extract biophysical and structural plant metrics, including evapotranspiration, as they relate to observable differences between tamarisk stands unaffected by defoliating beetles and post-exposure populations. This presentation constitutes an overview of the application of drone technology to tamarisk monitoring, including our specific progress in support of this research.

Archeological site preservation and management with UAS-collected data at Petrified Forest National Park

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ABSTRACT: The Petrified Forest National Park, located in northeastern Arizona, contains over 600 archeological sites distributed over the 230 square miles that must be monitored and preserved by the National Park Service (NPS). Because of the vast size of the park combined with the significant number of archeological sites the NPS determined that access to high resolution data is crucial to support their efforts to document archeological sites, help assess damage to the sites, and identify newly uncovered sites in the core of the park and within areas of the boundary expansion. In support of these data needs, the U.S. Geological Survey (USGS) National Unmanned Aircraft Systems Project Office, at the request of the NPS, flew data collection missions over five archeological sites within the park in October of 2018. Natural color imagery was acquired from the Ricoh GR II mounted on the 3DR Solo and the Sony RX1R II mounted on the FireFLY6 PRO. This high-resolution imagery was then processed and used to produce highly accurate, high-resolution 3D point clouds, orthomosaics, and digital elevation models for each site. This resulted in the creation of the baseline topographic, erosion, cultural, and archeological data needed to support the preservation and management of these culturally

significant sites. In addition, these baseline topographical products can be used in the generation of future landscape change models to help the park prioritize areas for future stabilization to help preserve the significant historical and archeological record of the park.

Civilizing public land management in the Colorado River Basin

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ABSTRACT: The Colorado River Basin's "sacred places defined the very existence of its Indian people," describes Cordalis—a fact John Wesley Powell was keenly aware of through extensive work with tribes. Yet reservation and allotment policies supported by Powell and others for nearly seventy years have resulted in basin tribes currently being separated from ancestral homelands and sacred places located on public lands managed by the federal government. This separation, of course, was not inadvertent. Can it be considered "civilized" in the twenty-first century? Flipping on its head Powell's theory about human cultures inevitably progressing through stages of savagery, barbarism, and civilization, tribal-federal cooperative management of public lands arguably should be considered "the most civilized progression modern American society can make." This sentiment reflects a fundamental proposition: future management of the Colorado River Basin's public lands will be a defining aspect of our collective navigation of the contemporary "Great Unknown." Although relevant across the entire basin, this perspective has special traction in relation to Bears Ears National Monument, which offers a model (albeit a nascent one) of how tribal-federal collaborative governance might be approached.

Joining forces to facilitate habitat restoration and climate adaptation along the Little Colorado River

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ABSTRACT: Riparian areas in the southwestern United States are hotspots of biodiversity that face the combined challenges of warming, drying conditions and competition with invasive species. The Landsward Foundation is collaborating with Northern Arizona University (NAU) and the American Conservation Experience to replace invasive tamarisk with Fremont Cottonwood (*Populus fremontii*) and other native plant species on Babbitt Ranch lands along the Little Colorado River. The Landsward Foundation and NAU have a common interest in utilizing the latest scientific findings to improve restoration outcomes for foundation tree species and ultimately the wildlife that depend upon them. We describe the goals of the combined restoration effort, including a long-term vision that keeps partners committed despite day-to-day challenges. We also detail the contribution of each partner to the success of the project and the approaches the group has taken to secure funding, encourage open communication, involve members of the community and overcome the significant challenges of restoring an area where invasive plant species dominate an arid landscape.

From water to land: analysis of prehistoric shell from Wupatki Pueblo

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ABSTRACT: This research examines prehistoric shell artifacts from Ancestral Puebloan, Sinagua, and Hohokam sites. Shell artifacts are good indicators of trade relationships between different cultural groups. Therefore, shells found at Ancestral Puebloan and Sinagua sites shed light onto the trade relationships between the Ancestral Puebloans, Sinagua, and Hohokam. By looking at shell assemblages from one Ancestral Puebloan site: Wupatki Pueblo; three Sinagua sites: Elden Pueblo, Winona Village, and Ridge Ruin; and two Hohokam sites: Shelltown and the Hind Site, this paper attempts to determine Hohokam influence on Ancestral Puebloan and Sinagua sites. Specifically, shell manufacturing techniques were examined on the shell assemblage from Wupatki Pueblo to determine if the Hohokam traded or brought shells artifacts to Wupatki Pueblo as finished products or if shell manufacturing occurred at Wupatki Pueblo. Ultimately, this research adds valuable information about trade, migration, and social networks between the Hohokam, Sinagua, and Ancestral Puebloans, which is important to the understandings of function, complexity, ideology, adaptation, resilience, and the foundation of modern Pueblo cultures.

New hands in U.S. public lands management: the role and influence of non-agency partners in U.S. Forest Service stewardship agreements

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ABSTRACT: As the United States Forest Service (USFS) faces shrinking resources for its core land management duties, the agency has increasingly turned to partnerships for much-needed capacity. This cooperation with non-agency actors aligns with two key environmental governance trends: (1) collaboration among diverse stakeholders and (2) hybridity, which is the integration of structures and actors from community, state and market sectors. Despite growing popularity of these governance concepts, limited research has explored their occurrence within the implementation, as opposed to the planning, of ecosystem management initiatives. We conducted case studies of four USFS stewardship agreements in Arizona, California, and New Mexico to assess the extent to which key characteristics of both hybridity and collaboration exist in on-the-ground restoration implementation. Additionally, we explored how nonprofit partners help shape the way stewardship projects are carried out. We interviewed 32 participants comprised of district-level USFS staff and nonprofit partner staff with direct involvement in each stewardship project. Through preliminary analysis, we found several characteristics of hybridity and collaboration across cases including the emergence of new roles, institutions, and structures unique to the stewardship agreement, as well as increased interactions, joint decision-making, and mutual learning between partners. At the same time, engrained USFS hierarchies and operational practices often prevented truly consensual decision-making and rearranging of power structures that also define hybridity and collaboration. Even so, we did find that partners influenced location of restoration activities, timing and scope of work undertaken, and methods for completing that work. Effects of non-agency partner involvement included: adoption of larger-scale approaches, greater exploration and testing of USFS policy structures and a shift in USFS focus toward partner oversight, cooperation, and support. In an era when government agencies exhibit a growing reliance on assistance from outside cooperators, our findings show how these non-agency entities can significantly influence public lands management.

A general model framework for evaluating management choices for freshwater fishes

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ABSTRACT: Simulating an endangered species' demography in variable contemporary habitats is fraught with difficulty. The most important is *there is no single set of vital rates that will be valid for all environmental conditions*. For simulations of demography to be useful, we need a general frame of reference for individual species from which we can deduce the relative sensitivity of that species to various perturbations or management alternatives. We use population ecology theory to develop a hypothetical species-specific population equilibrium baseline in an unperturbed environment that is extensible to many fish species. With Bayesian meta-analysis, we provide equations for estimating species-specific fecundity at mean length at-age that facilitate comparing different species in a common frame of reference. Comparative simulations of transient variation in vital rates in different environmental scenarios, such as changes in survival, can be compared to deduce the relative impact to a population's growth. We used this general frame of reference to compare how reduced adult survival (age truncation) would be expected to affect drivers of population growth. Results suggest most fish species would respond similarly to perturbations that drive age truncation, and the effect of reduced adult survival on population growth is amplified with delayed reproduction and/or increased fecundity. We extended the matrix population model to include a parameter representing age-specific mortality caused by a temporally variable perturbation, in our example river drying. We used an equilibrium population baseline from which to simulate long term stochastic population growth rate as a function of level of mortality caused by a perturbation and the annual frequency with which the perturbation may occur. Results show clearly that reduced adult mortality with an environmental perturbation is far more harmful than if only juvenile mortality occurs with the perturbation.

Uranium bioaccumulation in aquatic invertebrates: A comparative study in spring outflows in Grand Canyon National Park

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ABSTRACT: The risks of uranium (U) exposure to endemic species in Grand Canyon National Park are not well understood. To address uncertainties about exposure pathways and forms of bioavailable U, we conducted a series of laboratory and field studies to gain a better understanding of the biogeochemical factors influencing U bioaccumulation in aquatic macroinvertebrates. Relationships between U body burdens in field-collected caddisflies (*Limnephilus*) and dissolved U concentrations indicated that U was bioavailable. *In situ* experiments using caddisflies collected from two springs with different dissolved U concentrations were conducted to parameterize uptake and elimination processes. Results showed that the rate constant of U uptake from water for *Limnephilus* (0.24 l/g/d) is similar to that reported for a laboratory model invertebrate species (0.28 l/g/d) exposed to aqueous U concentrations in artificial water simulating concentrations of dissolved species in Kanab Creek. These results suggest that some of the process-based knowledge gained while working with model species can be applicable to endemic species. Tracing the elimination of U accumulated in *Limnephilus* from Horn Creek, a site with elevated U, along with that of aluminum, which was used to trace the presence of sediment, showed that nearly 70% of the accumulated metals were eliminated after 2 days of depuration, reflecting the elimination of ingested sediments from the gut and to a lesser extent, the desorption of U weakly adsorbed to the insect's integument. The U body burdens measured in *Limnephilus* collected in nature might thus be more representative of the ingested inorganic particles present in the insect's gut rather than U internalized in tissues, unless insects are depurated from their gut content prior to analysis. Delineation of major uptake pathways, prediction of U accumulation under environmentally realistic exposures and characterization of the role of mineralogy in dietary uptake are additional outcomes of this study.

Silvicultural treatments to reduce mortality and decline of aspen from oystershell scale

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ABSTRACT: Quaking aspen (*Populus tremuloides*) is in decline across much of the western United States, and this decline is especially pronounced on the southwestern edge of the tree's range, which includes Arizona. This is concerning because, as one of the few hardwood species present on the landscape, aspen provides critical biodiversity in addition to other ecosystem services such as watershed management, carbon sequestration, hunting revenue, and aesthetic and recreational value. A number of factors likely contribute to this decline including drought, ungulate browse, fire suppression, insects, and disease. Of particular concern in Arizona is the emerging invasive insect, oystershell scale (OSS; *Lepidosaphes ulmi*). Fenced exclosures have been a successful management strategy to promote aspen regeneration, but the long-term success of exclosures is uncertain, as OSS is presently impacting aspen stands within exclosures. No research has been conducted on how management activities could reduce OSS infestation, which may be critical knowledge for promoting long-term sustainability of aspen in Arizona. The objective of our study is to quantify the effect of silvicultural treatments on OSS infestation in aspen stands located within exclosures on the Coconino and Kaibab National Forests. These treatments include a clearfell, a pre-commercial thin, and an untreated control. Treatments on the Coconino National Forest are currently being implemented, while those on the Kaibab National Forest will be implemented in 2020. Pre-treatment data describing each stand and quantifying OSS infestation within the stands have been collected for exclosures in the Coconino National Forest. We will present average stand conditions and OSS severity for both forests and provide a visual comparison of pre- and post-treatment conditions on the Coconino National Forest sites. Analysis is ongoing and will explore relationships between pre-treatment OSS severity and tree-level variables such as tree size, crown dieback and ratio, and presence of other damaging agents.

Quantifying and reducing uncertainty of sediment transport through two 'run-of-the-river' mega-dams on the Madeira River

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ABSTRACT: The Madeira River contributes up to half the sediment load to the Amazon, which has extensive global social and ecological importance. Until recently, basin-wide sediment dynamics and river geomorphology have not been well quantified due to data scarcity. As the Madeira region continues to develop, understanding these dynamics is paramount. In the last decade, two mega, hydroelectric "run-of-the-river" (ROR) dams were installed along the Madeira River. ROR reservoirs are expected to quickly fill up with sediments and stabilize to a dynamic equilibrium. However, this depositional expectation may not hold along large, tropical rivers with high and historically sparse sediment load estimations. Here the uncertainty of present and future Madeira Hydroelectric

Complex (MHC) sedimentation is rigorously reassessed using the dam companies' monitoring data, data collected on an independent field campaign, and a sediment transport model. First, recent field data are synthesized with relevant data from the literature. The synthesized data and model structure uncertainties are then tracked through a model sensitivity analysis to identify the model´s parameter uncertainties. Modeling of sedimentation is done for both present and coarse, future climatic conditions. Results show that there is considerable variability and uncertainty in estimated annual sediment load (250-715Mt/yr). Additional discrepancies in historical data are expected to increase the uncertainty of on-going impact studies of the MHC and future land use and climate change. Sedimentation just upstream of the hydroelectric intakes has already exceeded the intake elevation. This highlights the importance of reducing uncertainty of sediment transport predictions by improving discharge and sediment load forecasts through continued sediment monitoring and consideration of basin-wide development and downscaled climate change projections. The developed one-dimensional modeling framework will be a helpful tool to quantify the cumulative effects of upstream changing climate, dams, and land use change for improved sediment management through the MHC reservoirs and turbines.

Southwestern pits and caves as planetary science analogs

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ABSTRACT: After showing pictures of several martian and lunar cave-entrance candidates, we will describe the favorability of southwestern caves as planetary science analogs, and discuss the various data collected from a few of these caves.

Geomorphic change, biogeomorphic feedbacks, and the downstream transformation of floodwaves in the Little Colorado River, Arizona, USA

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ABSTRACT: The Little Colorado River (LCR) in northern Arizona, has undergone substantial hydrologic change. Streamflow analyses show that there have been four alternating periods of high and low total flow; 1926 to 1943 (high), 1944 to 1964 (low), 1965 to 1995 (high), and 1995 to present (low). Previous research showed that fluctuations in total flow were primarily driven by variations in climate. Irrespective of these variations in total flow, peak flow has progressively declined, and coincident geomorphic change has occurred. Since 1936, the channel in alluvial valleys of the LCR has narrowed by up to 88%. Since the 1930s, there have been only 2 floods that caused channel widening; in 1972/73 and 1993. Channel narrowing resumed shortly after each of these floods, such that these floods had minimal long-term effect on channel geometry. Although the 1940s decline in peak flow can be attributed to climatic variation, the continued decline in peak flow despite the rebound of wetter conditions between 1965-1995 indicates the importance of other forcing mechanisms: (1) large-scale water development decreasing the occurrence of floods; (2) biogeomorphic feedbacks associated with vegetation encroachment on the channel and floodplains, which caused an increase in roughness, sediment trapping, channel narrowing, and peak-flow attenuation; (3) the increase in channel length by approximately 34-48% because of increases in sinuosity resulting in additional peak-flow attenuation. Hydrologic modeling shows that geomorphic changes, combined with increased vegetative roughness, have had large effects on downstream peak-flow attenuation, at times resulting in declines in peak discharge by approximately 80%. Thus, water development and biogeomorphic feedbacks have likely been the main drivers of the post-1940s progressive decline in peak flow in the LCR. These results have substantial implications regarding the downstream delivery of sediment, and the growth of travertine dams in the lower reaches of the LCR.

Butterfly and plant responses to climate change in montane meadows

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ABSTRACT: Montane ecosystems are regions of the earth associated with mountains. These ecosystems are highly sensitive to climate change. Montane meadows are especially diverse and productive with respect to their plant communities, and as such, provide important food sources for a diverse group of herbivores, from small insect pollinators to large mammals. Temperature increases associated with climate change will likely lead to a decrease in the amount and duration of snow cover. This change could have a significant effect on the ecology of these ecosystems. Butterflies can serve as ecological indicators to quantify changes in montane

meadows because they are abundant, showy, and easily identified. Parnassius butterflies lay their eggs each year in mid-summer. These eggs overwinter under the deep snow, hatching into caterpillars in the spring when snowpack melts, and then flying as butterflies in summer. My students and I have been studying Parnassius butterfly population dynamics for over two decades. We have also experimentally simulated how climate change may affect their nectar plant resources and associated plant phenological responses using warming and snow removal treatments. The species studied included arrowleaf balsamroot (*Balsamorhiza sagittata*), an early-season emerging and flowering species, and buckwheat (*Eriogonum umbellatum*), a semi-woody, late-season flowering plant. Both are widely distributed and locally abundant key forbs for pollinator and nectar-using animal communities in western North America. We found that snow removal advanced green-up, bud break, and flowering. Warming increased plant height and reduced frost damage to flowers. However, some of these responses were species specific. All of these changes could have significant impacts on pollinators in montane meadows. This presentation will tell the story of how a small white butterfly may provide a window into understanding how climate change may be affecting montane ecosystems in North America and other northern circumpolar and montane regions.

Stewart Udall, John Wesley Powell, and the emergence of a national American commons

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ABSTRACT: There is an intellectual genealogy between John Wesley Powell and former Interior Secretary Stewart Udall. “Both had the essence of the redrock country in their blood,” describes deBuys, subjects of the “constant pull” of the Colorado River and its canyons. While a host of similarities exist between the two historic figures, perhaps chief among these connections are their respective contributions to the creation of a “national American commons.” Powell’s vision for the Arid Region’s public lands, including his watershed commonwealths proposal, intersects in this space with Udall’s advocacy for federal reservations as Interior Secretary and publication of *The Quiet Crisis*. Yet nothing about this historical intersection foreordains the fate of the Colorado River Basin’s public lands—except perhaps that it “may well prove to be a bellwether for the nation.” Love of place, embodied by Powell and Udall, is the medicine prescribed for navigating this aspect of the contemporary “Great Unknown.”

Impacts of fire to the herbaceous/shrub layer of the mixed conifer and spruce-fir forests of Grand Canyon National Park

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ABSTRACT: The mixed conifer and spruce-fir forests of the North Rim of Grand Canyon National Park have experienced an increase in fire frequency over the past 20 years with the increase used of prescribed fires and management of lightning. Much research has focused on the historical role of fire in these forests with respect to forest structure and composition, with few studies examining how fire influences the herbaceous and shrub layer of these forests. Taking advantage of vegetation monitoring plots that the Southern Colorado Plateau Inventory and Monitoring Network established across these forests, I have examined the effects of fires on the herbaceous and shrub layers. I used 2 types of analyses: a retrospective analysis that compared plots that had burned over the past 30 years with the plots that had not burned, and an experimental analysis that compared pre- and post-burn samplings of plots that had burned since they were established. Both analyses suggest that fire results in an increase in foliar cover of forbs and graminoids. Two species showed a strong positive response to fire*: Carex* spp. and *Fragaria virginiana*. Species richness was greater in burned plots. Six nonnative species occurred in plots that burned; in contrast, there were no nonnative species in plots that did not burn. A Nonlinear Multi-Dimensional Scaling (NMDS) ordination of the pre-burn/post-burn plots demonstrates overlap between the pre-and post-burn plots, but also suggests directional change.

Combining aerial and terrestrial sensors to support archeological research and documentation at Montezuma Castle National Monument

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ABSTRACT: Located just west of Montezuma Castle are the remains of the cliff dwelling known as “Castle A,” a similar but larger structure than its more intact and famous counterpart. Constructed between A.D. 1150 and 1300, Castle A has yielded important

information for understanding prehistoric human life in the Verde Valley through past and ongoing research at the site. However, prior to this project, the spatial documentation of Castle A was limited in scope and is out of date. In order to update the situation, a multi-disciplinary team of NPS personnel conducted a series of data collection efforts at the site using UAS-based photogrammetry and terrestrial laser scanning. These two technologies have become ubiquitous tools in documenting and researching cultural resources, and have many similar properties and can be substituted in many situations, differences in their capabilities and platform characteristics have implications for their level of suitability for different applications. This presentation details how the combination of sensor types at Castle A, using imagery collected from a UAS platform to augment a terrestrial laser scan dataset, can be used to enhance cultural resource management and support ongoing research. This approach allowed the team to leverage the most suitable aspects of each technology in order to create an optimized end result. The derived products will be a valuable management tool used to conduct condition assessments, assist in determining construction sequence, create a three-dimensional baseline for detecting changes to the resource over time, and supporting further archeological research at the site.

Influences of seed source selection and drought conditioning on seedling physiology and outplanting success of *Pinus ponderosa*

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ABSTRACT: Planted tree seedlings in arid and semi-arid regions experience harsh site conditions due to drought and disturbances such as wildfire and surface mining. Future climate regimes in these regions are predicted to be warmer and drier on average, further impeding reforestation success using conventional stocktypes. Thus, alterations in the genetic and nursery components of the Target Plant Concept are critical in order to develop restoration methods that translate to improved survival and performance after transplanting into these harsh environments. With regards to genetic changes, expanding seed source selection beyond the traditional "locally adapted" sources may result in improved survival and growth when selecting from those sources with known warmer and drier conditions relative to the outplanting site. In the nursery, current and traditional practices are based on optimal (i.e. non-limiting) growing conditions. However, the optimal conditions for seedlings may also be limiting the physiological and morphological performance of seedlings in harsh planting environments. To address these issues, this study was developed to test both the combined effects of seed source and drought conditioning on seedling morphology, physiology, and survival both in the nursery and in the field. Seedlings from 10 seed sources of ponderosa pine (*Pinus ponderosa* Douglas ex C. Lawson) were grown in containers in a greenhouse, with the seed sources representing an elevational and temperature gradient across New Mexico and Arizona. All seedlings were subjected to one of two levels of moisture availability (85% and 55% of container capacity). Data from several gas exchange parameters, including instantaneous water use efficiency, are currently being analyzed. We expect the results from this study to be an initial guide for land managers regarding seed selection and transfer guidelines as well as nursery managers to implement potential drought stress during the nursery growth phase.

Differences in seedling drought adaptation between southwestern provenances of ponderosa pine

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ABSTRACT: Ponderosa pine (*Pinus ponderosa*) forests of the southwestern US are threatened by climate change. Deforestation and drought-related tree mortality have already started in southwestern ponderosa pine forests and will intensify over the next century as atmospheric temperature and drought severity increase. We are conducting greenhouse and field common garden studies to investigate genetic variations in growth, drought-adapted structural and physiological traits, and survival in ponderosa pines sampled from 21 sites across Arizona and New Mexico over elevational and environmental gradients. The objectives of the study are to 1) identify ponderosa pine populations in the southwestern US most suitable for future reforestation projects in increasingly arid conditions; and 2) investigate which traits in ponderosa pine are most strongly associated with genetic adaptation to dry and warm conditions. The greenhouse study is being conducted at the Northern Arizona University Greenhouse Facility in Flagstaff, Arizona. The experimental common gardens have been established across the thermal range of ponderosa pine in July 2018. The hot edge site is located at Blue Chute, AZ [elevation 1930 m, mean annual temperature (MAT) 9.7°C], the range core [Flagstaff Arboretum site, AZ (elevation 2200 m, MAT 7.6°C)], and the cold edge [Cedar City site, UT (elevation 2700 m, MAT 4.9°C)]. Approximately 1150 seedlings are being used for the greenhouse study and 1000 seedlings are planted at each of the field common garden sites in a randomized block design. We expect populations from the lower elevation drier sites to have greater genetic adaptation to aridity as compared to core and cold edge populations, and the early mortality results at the hot site have shown the expected pattern.

Effects of human activity on the behavior, physiology, and demography of the endangered Sonoran pronghorn

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ABSTRACT: The U.S. population of endangered Sonoran pronghorn (*Antilocapra americana sonoriensis*) has declined in recent decades as human activity has increased throughout the species' range. Wildlife managers are implementing an intensive recovery plan that includes captive breeding and forage and water supplementation. The effects of human activity on these recovery efforts and on the behavior, physiology, and demographics of Sonoran pronghorn are poorly understood. To address this, we partnered with state and federal agencies to conduct a 3-year study on responses to human activity over multiple spatio-temporal scales. We observed behavior of Sonoran pronghorn and collected fecal samples to quantify vigilance and a measure of the stress response, concentration of fecal glucocorticoid metabolites (fGCMs), respectively. We categorized human activity as immediate risk associated with the presence of a motorized vehicle, distance to road (predictable, controllable risk), and an index of unpredictable and uncontrollable risk. We used generalized linear models to assess the effects of these categories of anthropogenic risk on vigilance, to detect trade-offs between vigilance and other behaviors, and to assess the effect of off-road vehicle tracks on fGCM levels. Vigilance increased as distance to the nearest road decreased and as immediate risk increased. The documented trade-off between vigilance and foraging implies increased vigilance could have food-mediated costs. Fecal glucocorticoid levels increased with off-road vehicle tracks, suggesting Sonoran pronghorn may exhibit a stress response to less predictable, less controllable human activity. To more accurately measure demographic parameters of the Sonoran pronghorn population, we collaborated with the University of Idaho to implement non-invasive genetic sampling of fecal pellets. Following Pollock's Robust Design, we collected fecal samples in areas frequented by pronghorn to estimate population size and survival by capture-recapture methods. Results have numerous applications to conservation and management and may help managers more effectively evaluate mitigation efforts.

Documenting an adaptive management process to establish records of engagement and decision-making

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ABSTRACT: Adaptive management is an established tool for land managers to include communities in natural resource decisions. Numerous practices for engagement have been developed, despite little cohesive direction on how to make place-based models more effective. A collaborative process between Western Colorado University (WCU) and the Grand Mesa, Uncompahgre, and Gunnison National Forests (GMUG) has endeavored to establish Records of Engagement and Decision-making (ROED) to benefit future adaptive management efforts. In this case study, WCU assists the GMUG in development and facilitation of an Adaptive Management Group (AMG) to compliment the Taylor Park Vegetation Management Environmental Assessment and project. The purpose of ROED is to combine documentation of collaborative outcomes with documentation of the "biases, beliefs, behaviors, and values that are always present in decision-making processes." As a graduate research assistant, the author has worked to ensure the process of AMG formation is inclusive of these aspects in addition to being transparent and accessible to the community. Strategies included a series of public learning workshops pre-group formation with "distance" sessions for interested community members who could not attend the in-person workshops, working with the GMUG and AMG to craft an MOU and charter, taking effective meeting minutes and gathering supplemental material (made available to the public via the AMG's website, https://www.centerforpubliclands.org/taylor-park). This research evaluates the impact of these ROED strategies on stakeholder engagement, public awareness, and agency effectiveness. These actions aim to benefit not only the Taylor Park community in its relationship with the GMUG, but also to explore how record-keeping can assist future adaptive management efforts.

Using pilot projects and co-producing science with managers

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ABSTRACT: Managers of the drylands of the western US are faced with a wide array of challenges, including adaptively managing newly permitted activities (e.g., development of conventional and unconventional energy sources), long-term permitted activities (e.g., domestic livestock), and unpermitted activities (e.g., dispersed recreation). Additionally, many lands remain in undesired conditions due to historic over-grazing, droughts, invasive species, and other historic drivers of change. Finally, future climates of the desert Southwest, combined with increased land use pressures, layer on additional risks and challenges. Given these complex and challenging issues, there is a great need for scientific investigations to identify and prioritize specific barriers to achieving management goals, and provide guidance for likely routes to successful management. We share here approaches the US Geological Survey has taken to collaborate with resource managers, as well as industry and non-profits, to co-produce scientific research pertinent to dryland management. We provide three examples of collaborations, highlighting the approach we used and outcomes of the partnership; these include: an adaptive management restoration action in Canyonlands National Park, a heritage cattle experiment at the Dugout Ranch, and numerous reclamation studies on energy-production land across the region. While all collaborations develop and evolve in unique ways, in this presentation we share commonalities in process and actions that have led to success, as well as those that have posed challenges. Although scientific research pertaining to important management concerns can be conducted without collaboration with the science-users, we have found from our experiences that co-producing science with resource managers tends to be more relevant and readily applied to real-world scenarios. We conclude that these types of cooperative efforts are critical for addressing the immense challenges faced by dryland ecosystems of the Southwest.

Photogrammetry of historic resources through CESU partnership: an example from San Antonio Missions National Historical Park

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ABTRACT: Appropriate management of historic property requires knowledge about physical conditions, how the place came to be as it is, and why it is important to humanity. In the case of one resource at the San Antonio Missions National Historical Park (SAAN), the ruins of a Spanish colonial convento at Mission San José, a new method of knowledge acquisition advanced the field of historic preservation, and substantial findings about the resource were collected. Through the collaborative process of the Cooperative Ecosystem Study Unit (CESU) national network, the University of Texas at San Antonio (UTSA) worked with SAAN leadership to produce a comprehensive planning document called a Historic Structure Report (HSR). The knowledge gained is now available to guide and support decisions on future use and care. The San José convento was in obvious need of conservation treatment, yet without the HSR the work could not advance. One of the great, new developments utilized by the UTSA team at Mission San José was digital photogrammetry using specialized software to generate reliable drawings with sufficient detail for stone-by-stone condition assessment. This presentation will explain the process and results of the photogrammetry method used, as well as the integration of this method with a standardized approach to documentation of deterioration patterns. The detailed physical investigation resulted in substantial findings about how the building had changed over time, which was key to proper diagnosis and treatment recommendations. The methods used by the UTSA team showed that digital photogrammetry is a valid and useful alternative to LiDAR technology for detailed documentation and assessment of stone masonry buildings. The collaboration between a university partner and the NPS allowed the intensive investigation necessary to reach this conclusion.

Environmental drivers of humpback chub population dynamics in the Colorado River and Little Colorado River

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ABSTRACT: Humpback chub (*Gila cypha*) are federally listed as an endangered fish species found in multiple distinct populations throughout the Colorado River (CR). Humpback chub evolved in a river network characterized by seasonal variation in flow, temperature, turbidity and food inputs. Closure of Glen Canyon Dam in 1963 separated the Grand Canyon segment of the CR from upper basin populations and created a cooler, less turbid and less seasonally variable environment. Here, we focus on humpback chub that inhabit the CR near its confluence with the Little Colorado River (LCR). This population of humpback chub exhibits a partial migratory system where movement rates between the LCR and CR are specific to life history stage and season. Environmental conditions are much less modified in the LCR compared to the CR and thus the LCR/CR contrast provides a rare opportunity to see

how the population dynamics of a native large-river fish relates to flow, temperature, and turbidity. We use mark-recapture methods to evaluate environmental drivers of survival, movement, spawning, growth, and abundance of different life history stages. Understanding how humpback chub population dynamics respond to environmental conditions can provide insights into how restoration of more natural environmental conditions in the Grand Canyon could benefit this species.

Youth engagement in Color Country: a solution for conserving the Southwest's land, water, biodiversity and cultures

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ABSTRACT: The Color Country region of the Colorado Plateau is made up of a high density of public land agencies engaged in science and conservation work for land, water, biodiversity and cultures. Youth engagement is a popular and important solution for science and conservation across these lands to develop youth into tomorrow's science and conservation professionals or advocates and to accomplish work on the ground. This presentation will report on youth engagement within Color Country identifying the types of youth engagement occurring in public lands, the public and private funding available, and a summary of the science and conservation work being accomplished. In addition, challenges in engaging youth along with current practices will be discussed. Appreciative inquiry methods were employed to interview land management leaders in the US Forest Service, Bureau of Land Management, National Park Service, Counties, and State Parks. Youth from 16-25 is the focus. Initial results show youth are engaged in scouting service projects, school service projects, mountain bike teams, conservation youth crews, internships, as research assistants, as citizen scientists, and as seasonal employees. Disciplines in which youth are engaged include wildlife, botany, visitor services, engineering, reality surveying, tribal relations, range, wilderness, and IT. Funding sources vary by agency, but there are multiple public and private funding sources focused on engaging youth in science and conservation work. Benefits include developing the future workforce, employee morale boosts, and accomplishing work in partnership. Challenges include liability of minors, changing expectations within work environments between different generations, and recruiting in rural areas.

Analyzing recreation impacts across the Recreation Opportunity Spectrum

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ABSTRACT: Recreation Impacts across the Recreation Opportunity Spectrum are apparent from monitoring across Red Cliff Desert Reserve, the Grand Canyon Parashant and Vermillion Cliffs National Monuments. People impact the areas they recreate in. The question for managers, has been, and continues to be, "how do we manage people to protect the natural and cultural resources they encounter while enjoying the land?" This poster reviews the recreation impacts across the Grand Canyon Parashant, Vermillion Cliffs, and Red Cliff Desert Reserve. It analyzes the results within the Recreation Opportunity Spectrum and gives insight into balancing resource protection with offering recreation opportunities from wilderness to urban in an area with increased demand through a growing population and increased visitors. For the past five years, the authors have been monitoring recreation impacts in some unique places where managers are balancing recreation opportunities with specific management objectives to protect endangered species, cultural resources, and in some cases unique recreation opportunities. With an increase of demand, mangers can refer to monitoring data, management plans, and reviewing the recreation opportunity spectrum to provide quality recreation while protecting natural and cultural resources. Initial results confirm intuition, the closer to urban areas, the more impacts there are and with more people recreating there have been a steady increase of impacts. At the same time, it also shows site management can reduce and direct impacts with site infrastructure and signage. Further analysis will breakdown impact trends within campsite and on trails. Each analysis will be made within a Recreation Opportunity Spectrum category in order to show different trends across the spectrum.

Restoring processes: soil health and restoration in a disturbed semi-arid grassland

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ABSTRACT: A primary goal of restoration is to return processes and functions to degraded ecosystems. Soil is responsible for supporting diverse communities of organisms and is a fundamental actor in providing ecosystem processes and services. This research investigates the impacts of surface disturbance, seeding, and livestock grazing on plant communities, soil micro-organisms and soil

properties three years after the restoration of a buried pipeline corridor in southeastern Arizona. Using soil samples collected from the restoration site and adjacent control, we compared among treatments the taxonomy and functional groups of bacteria and fungus, soil fertility, and soil water holding capacity. We also measured plant cover by species. We found that the initial soil disturbance, regardless of restoration treatment or grazing, was the most influential factor in determining differences in both plant cover/species and bacteria communities and functional groups. The disturbance footprint also significantly influenced the soil physical properties such as organic matter and pH. Arbuscular mycorrhizal fungi were associated with differences in plant species composition, but bacteria groups were more tightly correlated to soil properties than plant species. Fundamental questions regarding what a healthy below-ground ecosystem looks like and how management actions impact these communities remain unanswered. We hope that this research sheds light on ways to restore important ecosystem processes and functions (e.g., soil water holding capacity, primary productivity, and soil stability) from a below-ground perspective and contribute to future management applications including soil manipulation strategies and soil microbial inoculations.

When to inoculate?: characterizing temporal and spatial variability in biocrust growth conditions across the Colorado Plateau

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ABSTRACT: Biological soil crusts (biocrusts) are important functional components of ecosystems on the Colorado Plateau, yet their vulnerability to disturbance and slow recovery rates make active restoration necessary in many contexts. Assisted recovery of biocrusts is often limited by the fact that these communities persist at the soil surface, where temperature and moisture fluctuations are more extreme than in the air or deeper in the soil profile, and the temporal windows for metabolism and growth are relatively marginal. Hence, short-term variations in weather ('year' effects) and small-scale variation in topography and soils (micro – 'site' effects) may play an outsized role in determining the eventual success of a given biological soil crust restoration. Drawing on published ecophysiological relationships between biocrusts and microclimatic conditions, I estimate periods of potential biocrust activity throughout a set of weather station timeseries across the Colorado Plateau and characterize levels of intra- and inter-annual variability in potential biocrust activity, as well as spatial variation in these values. I also assess the degree to which reductions in ambient temperatures (e.g., as induced by microtopographic effects) or increases (as from warming) would affect potential activity. I find high levels of inter-annual variability but more predictable levels of intra-annual variability in suitable biocrust growth conditions, which vary across the Colorado Plateau's monsoonal gradient. Temperature reductions which might be expected from microtopographic shading dramatically extend potential periods of activity. While yearly climate variation is not under the control of restoration practitioners, the timing of inoculation within a year and placement of inoculum within a site may be used to maximize expected growth time for a given geography.

Twenty years of successful federal-nonfederal collaboration: the CESU Network…past, present, and future

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ABSTRACT: The Cooperative Ecosystem Studies Units (CESU) Network is one of a number of federal collaborative science programs that leverage partnerships to support natural and cultural heritage decision-making and enhance public trust resource stewardship. Authorized by Congress in 1998, on-the-ground implementation launched in 1999, with competitions over five years to establish a nation-wide system of regional CESUs. The program concept sought to restore and advance science and stewardship capabilities of federal agencies through formal partnerships with academic institutions and allied nonfederal organizations. Now in its twentieth year, the CESU Network comprises a national consortium of more than 460 partners, including 16 federal agencies, in 17 CESUs encompassing all 50 States and U.S. territories, and adjacent landscapes in Canada and Mexico. At its core, the program is about collaborative problem solving responsive to long-standing and contemporary science and resource management priorities. CESUs bring together scientists, resource managers, students, educators, and other conservation professionals from across the biological, physical, social, cultural, and engineering fields (from Anthropology to Zoology), who together possess the expertise and experience required for co-production of "usable knowledge" to inform decisions and actions. To gain a better understanding of the reach, effectiveness, impact, and potential future directions for the network, recent program evaluation activities have employed qualitative and quantitative methods to characterize program elements over the first twenty years. Efforts included developing performance criteria and indicators to assess program structure, implementation, outcomes, and efficacy vis-à-vis program goals and objectives (e.g., vital program statistics, tangible and intangible benefits, distribution and typology of projects, partner engagement, best practices, potential opportunities), and help guide present actions future programmatic directions. This presentation will highlight

outputs from the recent evaluation and include a brief history and overview of the CESU program – the past, the present, and the future.

Science and management: never the twain shall meet? Progress in Canyon Country

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ABSTRACT: Scientists want to conduct excellent science that is relevant to real-world problems, and NPS managers wish to use that excellent relevant science. But wanting and wishing are not enough, they must be harnessed to work together to achieve actionable results. NPS resource managers occupy a world in which decisions must be made regarding management of resources and the options can range from no management to limited action, to taking extraordinary steps manipulating the environment to achieve a desired result. We are constrained by law and policy related to actions that can be conducted within parks and often have burdensome compliance responsibilities. Data availability and quality are key elements, and are often lacking. Time, blessed time, to think, evaluate, plan, and implement is exceedingly precious and vanishingly rare. However, hope and solutions exist to bring scientists and managers together in producing research of striking value. Progress begins with a joint effort to frame a management problem, for example, how will climate change affect our parks? What resources are most susceptible and why? What tools are available to mitigate the worst effects of climate change and where do we begin? Jointly framing a problem allows scientists and managers (and other stakeholders) to refine key questions and define data needed to answer those key questions. The joint framing process allows scientists to gauge how their research and overall body of knowledge fit into the sphere of park needs, and park managers have a frame of reference regarding the status of the science: what is known versus what is unknown and needs to be determined. Subsequent vital actions in enhancing progress in developing actionable science include joint development of a research proposal including scope of service and deliverables, and building management relevancy into the proposal.

A geospatial meta-analysis of global crop water productivity of leading world crops over three decades: implications for feeding the planet and saving water in a changing climate

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ABSTRACT: Crop water productivity (CWP) is a ratio of crop output over water input for a given area used to measure how productive an agricultural growing site is relative to water used to produce an amount of crop expressed in units of kg/m³. The purpose of this research was to perform a comprehensive geospatial meta-analysis of irrigated agricultural CWP of the world's three leading crops: wheat, corn, and rice based on over three decade-long remote sensing and non-remote sensing-based studies. Together, these three crops occupy 31.9% (569,291,021 ha) of the total global cropland area of 1.873 billion ha. Overall, data from several benchmark areas were gathered from study sites spread across the world based on published peer-reviewed articles. Methods include utilizing Geographic Information System (GIS) to map crop growing regions, analyzing geospatial relationships to global climate, latitude, soil type and combinations of these variables accompanied with statistical analysis. Also, a methodology utilizing CWP to determine the quantum of water that can be saved from each crop in each study country by increasing CWP was developed. This study established significant differences in CWP for each of the crops based on GIS analysis with significant implications for feeding the planet in a changing climate. Overall conclusions reveal that there is a very high scope for increasing or maintaining crop yields while reducing water use of wheat, corn, and rice in most countries of the world. Based on data in this study, the highest consumers of water for crop production also have the most potential for water savings providing global insight on food and water security in the 21st century.

Legacy effects influencing *Populus fremontii* success at Rio Mesa

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ABSTRACT: Significant shifts in riparian plant composition and land cover are evident across the western U.S. State and federal agencies have expended a great deal of effort and money to restore these communities. Such efforts may be thwarted due to rapidly changing environmental conditions and ecological legacies operating at multiple scales. We seek to understand the relative role of several legacies (provenance site climate regime, population-level genetics, antecedent agricultural land use, and plant-soil interactions) on native *Populus fremontii* (Fremont cottonwood) survivorship and growth by utilizing a research garden at the Bonderman Field Station at Rio Mesa (BFSRM) in southwestern Utah. This garden, established in 2014, was planted with 1,024 *P. fremontii* trees sourced from 16 populations in Arizona with locations varying in mean annual temperature and precipitation due to differences in elevation. Each source population is represented in the garden by 16 unique genotypes replicated across four study blocks. We found that *P. fremontii* survivorship and growth differed amongst provenance sites, suggesting a legacy of population-level genetics. However, we found no differences in survivorship and growth related to the climate regime associated with provenance sites. Although the BFSRM has a history of ranching and crop production, we found no difference in soil characteristics that would suggest a legacy of these land uses persists. We are now exploring whether differences in soil microbial community composition and physiology, as measured by ecoenzyme expression, varies amongst soil samples collected from beneath trees sourced from a subset of provenance sites that reflect the broader elevational gradient. Our goal is to determine if differences in soil community composition or physiological behavior exists and may be related to plant traits associated with distinct populations of *P. fremontii* or affect soil nutrient cycling rates to the advantage of some populations of *P. fremontii* over others.

The spread of white-nose syndrome in the West

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ABSTRACT: White-nose syndrome (WNS) is a fungal disease that has devastated bat populations throughout the Eastern United States and Canada. First detected in New York in 2006, the pathogen responsible for WNS, *Pseudogymnoascus destructans*, was initially restricted to east of the Mississippi. However, WNS was confirmed as far west as Washington state in 2016 and the fungus has now been detected in at least 37 states. The primary questions are: how the disease is spreading, which bat species it will affect, and where will be the next states to be affected? Initial data suggest that the Colorado Plateau is among the next locations where *P. destructans* will likely arrive but the future effects of WNS on Western bat populations are unknown. We will discuss how WNS may impact Western bats differently. We will also discuss current sampling to date, a sampling strategy for the West and possible management implications for land managers, researchers, and the public in Western states.

Joys and challenges of manager-scientist collaboration in a tribal nation context

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ABSTRACT: Managers of natural resources of Tribal Nations have critical needs for reliable information but often find limited support from researchers due to a variety of barriers. We describe a series of research projects carried out over five years in a collaboration between the Navajo (Diné) Nation, the Mescalero Apache Tribe, and Northern Arizona University. Although forests of Tribal Nations make up approximately 11.6 million acres in the Southwest, roughly half the area managed by the US Forest Service in this region, the research data directly linked to Native American lands is very disproportionately small. Yet the ecosystem services provided by these lands are exceptionally important to tribal communities, which often rely more heavily and directly on natural resources than other communities. Our collaboration focused on assessing climate change impacts to forests through complementary lines of study: quantitative natural science research aimed at disturbance ecology and simulation modeling, as well as qualitative social science research on perceptions of climate change effects and management priorities from rural tribal community members and eliciting expert opinions. Lessons learned related to manager-scientist collaboration include developing a common understanding of research needs, following tribal guidelines for research activities, flexibility and sensitivity toward cultural distinctions, active communication with numerous publics, and willingness to step up on behalf of collaborative projects even when it requires extra effort. While the challenges involved in collaboration in the tribal nation context are notable, there is great value and joy in working together to develop useful co-produced knowledge. It can be especially rewarding for Native American researchers to develop scientific information in a culturally sensitive manner.

NEON: open data to understand our changing ecosystems

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Abstract: The National Ecological Observatory Network (NEON) is a large-scale, long-term, NSF-funded program providing open access data and infrastructure to the scientific, education, and land management communities. Data are available from 81 locations across the United States, with the Southwest and Colorado Plateau represented by field sites outside Tucson, AZ; Phoenix, AZ; Las Cruces, NM; and Moab, UT. Over 180 different data types are available allowing researchers and educators to get a detailed picture of the ecosystem. Data are collected across three main systems: in-situ automated instrumentation, biological observations, and airborne remote sensing. Terrestrial and aquatic field sites are strategically placed in ecosystems across the US to allow for spatial extrapolation of research conclusions. In addition to data ranging from genetics to atmospheric fluxes to lidar, the NEON Biorepository provides access to over 100,000 specimens and samples collected each year. Limited data collection started in 2014 with full operations having started in early 2019 and planned for the next 30 years. Access to the NEON infrastructure for principal investigators to collect data adjacent to ongoing NEON data collection is available on a cost-recoverable basis. Data, science designs, protocols and related training/educational resources are available on the NEON portal: NEONScience.org.

Intraspecific trait variation of restoration species at early developmental stages

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ABTRACT: In recent decades, quantitative trait-based models have been used to predict how plant communities will respond to abiotic and biotic perturbations. Species trait values from published literature or large databases that are most often obtained from mature plants are typically used to inform such models. These values may not be appropriate for understanding community processes of early successional or restored systems for two reasons: (1) trait values from different populations of the same species may vary and (2) trait values of mature plants may not reflect seedling traits that are important for establishment and survival. To address these concerns, we measured traits (e.g., specific leaf area, growth rate, leaf dry matter content, root length) of eight grass and forb species commonly used in arid land restoration from several populations at different ontogenetic stages. We then used Bayesian point estimates of population trait means and variability at each ontogenetic stage and compared them to one another as well as trait values from the TRY Plant Trait Database or values published in the literature. We found that mean trait values as well as population-level trait variability differed by population, trait measured, and ontogenetic stage for all of the species investigated. In some cases, differences in trait values at specific ontogenetic stages resulted in unique ordering of populations within a species at different timepoints. In several cases, trait values of young seedlings differed greatly from those reported in the TRY Plant Trait Database or the literature. Since traits expressed during early stages of plant growth are critical to plant establishment, a better understanding of variation in seedling traits will inform seed source selection for restoration and improve the use of trait-based models for predicting re-vegetation outcomes.

Comparing three platforms for creating point clouds for forest inventory

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ABTRACT: Traditional area-based forest inventories are estimative, labor intensive, and costly. Light detection and ranging (LiDAR) and structure from motion are relatively new methods of describing terrestrial systems with 3D point clouds. The objective of the present study is to assess the effectiveness, measured as the cost/results quality, of three different sensors used to produce 3D point clouds. The sensors are mounted on three different platforms: a quadcopter unmanned aerial vehicle (UAV) with a multispectral sensor (UAV-MS); an octocopter UAV with a lidar sensor (UAV-L); and a mobile terrestrial lidar scanner (MLS) to produce overlapping point clouds for a small shelterwood stand in the McDonald-Dunn forest near Corvallis, Oregon, USA. The platforms vary in cost, data collection time, processing time, expertise required for implementation, and the quality of data. The least expensive platform, UAV-MS, requires the least expertise, but also produces the lowest resolution point clouds by far (0.1 points per cm^3 versus 1.17 and 5.91 for UAV-L and MLS, respectively), and typically requires ground control for georeferencing. The MLS platform, which

is the most expensive, scans trees from a profile perspective, which allows for returns along the length of the tree stem and as much as 100 m into the stand. Although there is a trade-off between platform cost and performance, strong correlations exist ($r^2 > 0.85$) between the height estimates from all three platforms. Our analyses highlight the advantages of combining an aerial dataset (such as UAV-MS or UAV-L) with a ground level dataset such as those from a MLS. Because tree form varies with distance from roads, an edge effect was detected in all point clouds. A double sampling strategy for stem and crown characteristic could expand findings based on the overlapping MLS and UAV point clouds to include areas where only UAV data is available.

Hot and dry versus hot or dry: consequences for mycorrhizal fungi and their host plants

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ABTRACT: Recent drought events in the southwestern USA are warmer than previous droughts, but the consequences of this change for belowground plant-associated fungi and their host plants remain poorly understood. Mycorrhizal fungi can promote host plant establishment and growth, with recent evidence indicating that beneficial effects are increased under stressful conditions. Dark septate fungal endophytes are less well studied, but hypothesized to be especially important in dryland ecosystems. We sampled ectomycorrhizal fungal and dark septate root endophyte communities in association with a six-year field experiment in which *Pinus edulis* trees were exposed to precipitation reduction (-45%) and warming temperatures (+ 4.8 ºC), alone and in combination. We found that root colonization by both ectomycorrhizal fungi and dark septate endophytes was similar in control, warmed and precipitation reduction treatments but reduced by more than 30% in the combined treatment (warming + reduced precipitation). Dark septate endophyte diversity and species composition was similar among treatments, but ectomycorrhizal fungal diversity dropped >75% in the warming + precipitation reduction treatment relative to the control. Even ectomycorrhizal fungal species well known for their tolerance of dry conditions were absent from the drought + precipitation treatment. Ectomycorrhizal fungal diversity was significantly positively associated with *P. edulis* growth, suggesting that the loss of these fungi may have negative consequences for pinyon performance. Given their greater resilience in the face of the combined stressors of drought and warming temperatures, more studies on dark septate endophytes are necessary to determine if they fulfill functions that may be lost as ectomycorrhizal fungi diversity declines with warmer droughts.

Drone-based photogrammetry of natural rock arches

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ABSTRACT: Structure-from-motion photogrammetry provides a rapid and economical means of accurately capturing landforms and structures in three dimensions. Across the Colorado Plateau, natural arches represent some of the most well-known geological structures, prominent in several popular protected areas. With dozens of documented collapses since the 1970s, arches are fragile and ephemeral features, reflecting the impact of processes currently acting to shape the Plateau landscape. However, the inherent vulnerability of these features necessitates non-invasive techniques to better understand these processes. With a combination of commercial and open-source tools, we employ drone-based photogrammetry to create virtual representations of arches for use in structural health monitoring research. 3D models provide a baseline assessment of the features that can be utilized in a number of ways, aiding studies ranging from Plateau-wide assessments of sandstone material properties to the impacts of environmental and anthropogenic stresses on the landscape. Photogrammetric models have additional value as archival representations of arches that have recently collapsed, allowing us to explore failure hypotheses. Beyond research applications, photogrammetry has proven invaluable for outreach education efforts, where we employ 3D printing and virtual reality to reduce accessibility barriers and help people experience these unique landmarks of the Colorado Plateau.

General indicators of hydro-ecological change for the continental United States

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ABSTRACT: Streamflow alteration studies often follow a streamflow-ecological response framework comparing hydrologic alteration to changes in aquatic ecology (e.g., number of fish species). Developing quantitative relationships between flow alteration and species richness is important for developing environmental flow standards that can be applied to all rivers and streams. In our

study, this framework linked hydrologic flow data, open access ecological databases, and modeling, such as random forests (RF), to create a large-scale analysis of streamflow regimes and ecosystem functions. We examined a database of 6,494 stream reach points containing values of flow alteration for 43 relevant hydrologic metrics in comparison with native fish richness. Our RF model used USGS reference and non-reference streams to predict flow alteration across gauged and ungauged reaches. We examined how metrics of streamflow alteration and their impacts to river ecosystems vary regionally across the conterminous U.S. Furthermore, we discussed how this variation can be quantified in ways that are useful for management of river ecosystems. The product is a best-fit streamflow-ecological response relationship for each HUC (hydrologic-unit-code) 4 catchment in the U.S. Seventy-five percent of the best metrics were those that explained the magnitude and duration of the streamflow regime. Low, high, and average flow metrics were evenly distributed across the U.S., with regional differences and patterns present. The findings from this research supports the reasoning for general indicators of hydro-ecological change. These generalized metrics could provide rules of thumb and a starting point for other U.S. states when adopting statewide environmental flow policy and law aimed at balancing both human and ecosystem requirements for water. Lastly, we address limitations to this study by identifying regions of the U.S. (i.e., west and southwest) where native fish richness data was lacking.

Using citizen engagement to monitor wilderness character in BLM Wilderness Study Areas in Montana

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ABSTRACT: The four federal wilderness-managing agencies are all moving decisively toward wilderness character monitoring to inform stewardship and improve accountability, transparency, and defensibility. Although there is broad consensus in support of this effort, dwindling wilderness budgets deeply compromise managers' ability to implement new protocols and meet emerging standards. With staff workloads increasingly spread across multiple areas, and with budgets stretched thin, citizen science provides a promising approach to help agencies accomplish wilderness character monitoring. Since 2014, the University of Montana's Wilderness Institute has worked closely with Bureau of Land Management (BLM) and community partners through the Rocky Mountains CESU to recruit citizens to help trained field staff assess on-the-ground conditions and monitor wilderness character in the 32 Wilderness Study areas in Montana managed by the BLM. This citizen-powered monitoring program provides high-quality data to inform stewardship (e.g. management plans), assists agencies in meeting legal requirements of Wilderness management, and builds citizen support and capacity for wilderness character preservation. Importantly, as monitoring standards are refined and integrated into land management practices nation-wide, the role of project partners must evolve to reflect changing agency needs. Furthermore, field protocols must be adjusted to incorporate wilderness-specific attributes and measures. Incorporating this kind of flexibility maximizes the utility of the data collected, and the program's ability to provide functional models for getting good work done. This presentation will highlight what can be accomplished with citizen science facilitated through CESU partnerships, including recent project successes and lessons learned. As agencies grapple with standardizing and implementing wilderness character monitoring across the National Wilderness Preservation System, this project provides a working model for community, NGO and agency collaboration in a climate of shrinking federal support for wilderness stewardship.

Logging machinery impacts to soil fauna and physical properties during forest restoration

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ABSTRACT: Despite the likelihood of significant impacts to soil micro- and mesofauna from heavy machinery during mechanical thinning, thresholds for disturbance remain poorly quantified. We characterized changes to soil faunal assemblages and soil physical properties with increasing traffic (1, 3, and 9 passes) by a tracked feller-buncher in a xeric mixed conifer forest undergoing fuels reduction at Valles Caldera National Preserve, New Mexico. Within the tracks of the machine and in adjacent undisturbed locations, we collected nematodes and microarthropods from the uppermost 10 cm of soil, where densities of micro- and mesofauna are highest. We also measured surface resistance to penetration and quantified bulk density changes at increments of 2-6 cm, 9-13 cm, 16-20 cm, and 23-27 cm. While churning from the feller-buncher reduced penetration resistance and bulk density near the soil surface, compaction was evident at deeper increments. Effects were more pronounced above one feller-buncher pass, although bulk density tended to be higher, and penetration resistance lower, at this minimal level of disturbance. We illuminate how important micro- and mesofauna respond to these habitat disturbances and discuss potential implications for soil food web functions.

Eighty-two years of plant functional type, species richness, and cover changes in an Arizona chaparral community

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ABSTRACT: Understanding plant species response to environmental change is one of the greatest challenges ecologists face. Plant functional types (PFTs) are a set of plants that are grouped according to their function in ecosystems and their use of resources. Few studies have documented shifts in PFTs over long time periods because long-term data sets are limited. We analyzed a long-term ecological data set from the Sierra Ancha Experimental Forest in central Arizona to evaluate how PFT, species richness, and basal cover by species have changed between 1935 to 2017 in a chaparral community. We examined relative abundance of plant functional types (C3 vs. C4 graminoids, forbs, shrubs, and subshrubs). We also analyzed percent basal cover of individual species. Twenty-four permanent 1-m^2 chart quadrats, which were established and mapped as early as 1935, were remeasured in 2017. Results indicate that, over 82 years, plant basal cover of all PFTs increased by approximately 26%, and species richness increased by 1⁄2 species per square meter. This increase could be caused by a number of factors including past land management practices (grazing or shrub control via chemical herbicide) or by climactic (precipitation and temperature) variation. An increase in shrub and subshrub basal cover indicates that woody plant encroachment (WPE) is occurring at the study site. The presence and 20% increased basal cover of the invasive, annual graminoid *Bromus rubens* (red brome) should be managed as this species is similar to *B. tectorum* (cheatgrass) in that it has the potential to increase the size, frequency and severity of wildfires. Our findings illustrate how the usefulness of long-term historical plots extends beyond their original objectives and increases our understanding of plant population and community changes.

Tamarisk invasion and the ecological and evolutionary consequences for native riparian ecosystems in the southwestern U.S.

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ABSTRACT: Invasive species are a primary cause of decline in ~42% of endangered or threatened native species. Here, we present a model for connecting exotic invasions to their impacts on plant function and whole genome responses in the native foundation tree, *Populus fremontii* (Fremont cottonwood), which is currently in decline due to invasion of riparian areas by *Tamarix ramosissima* (tamarisk) on the Colorado Plateau. Few studies have linked exotic species' invasion to plant function and genome response across critical life-history stages. One response, plasticity, may play a role at the phenotypic or genomic level, but few studies have investigated the potential for plasticity in foundation species and how it relates to adaptation, extinction and evolution. To examine how cottonwood responds to exotic invasion by tamarisk, I propose to: 1) examine recruitment and survivability in successive seed germination stages with and without exposure to tamarisk-invaded soil; 2) link developmental phenotypes to gene expression at the whole genome level; 3) assess differential gene expression in juvenile (seedling-derived) plants exposed to tamarisk-invaded soil. These studies will be the first to integrate plant function and whole genome responses across critical life history stages. They will also set the stage for understanding and predicting the mechanisms by which native foundation species compete for niche space, and if the putative phenotypic or gene expression responses are sufficient for adaptation to exotic invasion. My studies will also have important ecological and evolutionary implications for conservation management by providing new data on: 4) how seedling recruitment in cottonwood is impacted by tamarisk; 5) how plant genomes respond to exotic invasion, and whether gene expression plasticity is a viable mechanism for adaptation; and 6) how juveniles exposed to tamarisk at early life history stages perform and whether they survive tamarisk as an agent of selection.

Cultivation of the Southwest Seed Partnership – the stage of interesting seed quandaries

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ABSTRACT: The Southwest Seed Partnership (SWSP) took root in 2015 to improve the supply of ecologically appropriate native seed for New Mexico and Arizona and has been steadily growing in partners, capacity, and plant materials. Partners recognizing the great need for native seed in this region have contributed funding, technical expertise, facilities, equipment, data, labor, and land to

further the goals of the SWSP. In exchange, most partners simply want to see more local sources and greater diversity of native seed become commercially available in the next 3-5 years. Alternatively, partners who have made the most significant financial contributions see a future where harvested seed comes directly back to their agencies for use in restoration and research. When resources have been leveraged from multiple agencies, who does the seed belong to? Keeping it fair keeps partners happy. A great deal of effort has gone into wild collecting seeds over the past 3-4 years, and these seeds are now being put into the hands of growers. However, the majority of growers in the Southwest lack the expertise and capacity to grow native seed production fields. How do we maintain the integrity of native plant materials and the support of our funders while developing these new growers? Also, many growers lack the motivation to engage in native species production until a viable marketplace with clear and consistent demand is demonstrated. How do we make native seed farming (in particular, from untested local sources with higher diversity) attractive to commercial farmers? While the SWSP can celebrate many successes as well as significant progress in native plant materials development, there will always be obstacles to overcome. This presentation will take a closer look at some intriguing challenges that have arisen from our model in our region and describe approaches moving forward.

A functional approach to endangered bird habitat suitability in an invaded system

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ABSTRACT: In order to fully understand ecosystem changes due to removal of invasive species, it is important to address not only taxonomic species composition but also ecosystem functioning via traits of individual plants. This proposed research explores how *Tamarix spp.* treatment impacts functioning of the surrounding plant community, specifically habitat for the endangered Southwestern willow flycatcher (*Empidonax traillii extimus,* abbr. SWFL). SWFL nesting habitat is associated with tree functional traits and abiotic site characteristics rather than taxonomy of plant species; the SWFL requires morphological complexity of branches and an intact canopy, but it is as yet unknown whether restoration activities are producing such conditions. Our research asks: Which site characteristics in formerly *Tamarix* dominated stands predict ecosystem function optimal for endangered bird habitat? To answer this, we have compiled a functional trait database for the plant communities found in *Tamarix* removal sites across the southwest, and are collecting additional, bird-specific traits in a subset of sites. We can then investigate the relationships between the presence of particular functional traits and restoration status and/or abiotic site conditions. Previous work in our lab shows that plant guilds in *Tamarix*-dominated sites exposed to biocontrol defoliation can be organized into guilds primarily defined by the ability to reproduce vegetatively and to resprout after damage or fire, and that the relative abundance of these groups was associated with abiotic factors such as elevation above river water level, soil percent sand, precipitation and the deviation from the original flood regime of the adjacent river. Results from this study will improve our understanding of the functional trajectory of degraded environments after restoration activity has occurred. The model will be able to predict factors influencing desirable traits post-restoration, which will continue to be of high importance for SWFL management as climate change causes shifts in species ranges.

Vegetation indices trends in restoration and non-restored riparian vegetation sites: Exploring the potential to detect changes in foliar cover through Landsat and UAV vegetation indices in the Colorado River Delta, Mexico

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ABSTRACT: Minute 319 (2014-2017) and Minute 323 (2018-2026) binational agreements under the 1944 Water Treaty between the U.S. and Mexico provided a framework to allocate Colorado River water to restore riparian vegetation in the Colorado River delta. During the release of water over Morelos Dam in 2014, 195 million cubic meters (mcc) were delivered as a pulse flow and base flow. Minute 323 allocated 24 mcc for the environment. In plant communities dominated by *Tamarix spp*. (saltcedar) active restoration efforts are crucial for the success of native vegetation establishment. Specifically, the removal of saltcedar and arrowweed (*Pluchea sericea*), to create bare ground for new planting, was among the approaches used in conjunction with different irrigation and planting methods in restoration sites. The goal of this study was to investigate the trends in Vegetation Indices (VI′s) in restoration sites where native riparian species were planted as well as in the control sites, the plant communities dominated by saltcedar without any habitat manipulation. We estimated both the Normalized Difference Vegetation Index (NDVI) and the Enhanced Vegetation Index (EVI) from both a drone and Landsat from 2013 to 2018 to analyze the plant community response and determine the feasibility of using these platforms to detect changes in vegetation cover. Results indicate that Landsat NDVI and EVI decreased in control sites (8% to

50%), in contrast to restoration plots, which depicted NDVI and EVI increases (10% to 270%) in the last five years. NDVI trends in both restoration and control sites are related to land clearing, fire effects, water table changes, age of the forest as well as drought stress. NDVI derived from a UAV multispectral sensor was higher compared to Landsat NDVI and showed R^2 that ranged from 0.21 to 0.90, indicating the use of UAV's NDVI need to be evaluated by site.

Testing the adaptive significance of song in willow flycatchers (*Empidonax traillii*)

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ABSTRACT: In birds, song is an important signal that allows birds to differentiate members of their own species from other species. How differences in song arise and how they are maintained, remain an important question in evolutionary ecology. Acoustic signals may be shaped by the need to acquire mates (sexual selection), or by factors that affect survival of the individual (natural selection). In both cases, different environments may lead to different song characteristics. For example, song quality may degrade over distance faster in complex environments than simpler ones, and individuals in a population that can optimize their transmission should have higher reproductive success and pass those song traits on to their offspring. Frequency and frequency modulations (trills) are commonly affected by habitat structure. Whereas higher frequency songs with more frequency modulations are optimal for sparsely vegetated habitats, lower frequency songs with fewer frequency modulations are optimal for densely vegetated habitats. Adaptation to specific environments is often the first step in the evolution of new species, and conserving all of that adaptive diversity is one of the goals of the Endangered Species Act (ESA). We tested the adaptive significance of previously described song differences in willow flycatchers (*Empidonax traillii*), including the endangered southwestern willow flycatcher (*Empidonax traillii extimus*) subspecies. We found that subspecies living in habitats with denser vegetation sang songs that were 1) lower in frequency and 2) exhibited fewer frequency modulations relative to those in habitats with less dense vegetation. This is consistent with the hypothesis that song structure is shaped by the environment and that song differences among willow flycatcher subspecies may be adaptive. These data also provide support that southwestern willow flycatchers exhibit unique adaptations that deserve protection under the ESA.

A collaborative approach to management and conservation of herpetofauna in the desert Southwest: a principal investigator's point of view

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ABSTRACT: In 2000, I was asked to draft a proposal for the University of Arizona to serve as the host institution for the Desert Southwest Cooperative Ecosystems Study Unit (DSCESU). At that time, the CESU system was brand new, and there was much debate among prospective partners about the role it would play in natural and cultural resource management and conservation. Many opinions about the future of the DSCESU were proffered, ranging from a place to obligate money at reduced overhead, to an opportunity for federal agencies to reach out to scientists outside the federal government, to a truly collaborative framework where a diverse array of partners could combine forces to address important challenges faced by land management agencies. In my experience, as a principal investigator on numerous CESU projects, I can say that it has been all of the above, depending on the pragmatic needs of each project. As a herpetologist, I have conducted research on a variety of herpetofauna throughout the desert Southwest and northern Mexico. The vast majority of these projects have been funded by the federal government and have been administered through the CESU cooperative agreement. In this presentation, I highlight how the CESU partnership has enhanced management and conservation of herpetofauna, a group that has historically received less attention than more popular birds and mammals. Examples include long-term research on the effects of urbanization on a snake community and Gila monster population, anthropogenic effects on flat-tailed horned lizards on Department of Defense and Bureau of Reclamation lands, inventory and monitoring of amphibians and reptiles in National Parks, and management of an endangered rattlesnake species on Forest Service land. I discuss the challenges and importance of conducting research and applying the results to management and conservation using a truly collaborative approach, as envisioned by the CESU Network.

Visitor use and transportation monitoring and management at Bryce Canyon National Park, UT

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ABSTRACT: Bryce Canyon National Park (BRCA) completed a Multi-modal Transportation Plan (MTP) in November 2015 to provide strategies to improve the overall park transportation system and the quality of the visitor experience as total visitation increases. The MTP predicted visitation to BRCA to reach 2.1 million visitors by 2032. However, the park surpassed these visitation numbers reaching 2.3 million in 2016, and 2.6 million in 2018. These dramatic increases in visitor numbers has resulted in congestion on park roads, on the shuttle, in parking lots, and at viewpoints and along trails; resource damage as cars park illegally along roadsides when parking lots are full; and safety concerns due to conflicts between pedestrians and vehicles. BRCA chose an adaptive management approach to address transportation management issues, where management actions will be implemented in phases and performance measures will be evaluated to determine management effectiveness and progress toward relieving congestion. BRCA has partnered with Southern Utah University (SUU) to develop performance measures, associated indicators, and appropriate thresholds and triggers to maintain desired conditions in the park. This will better equip BRCA to manage higher visitor numbers while providing opportunities for high quality visitor experiences and protecting park resources. Visitor use data collection began in May 2019, and focuses on visitor patterns and the effects of increased visitor numbers on the visitor experience, natural and cultural resources, and infrastructure capacity. Measured variables include people-at-one-time at viewpoints and other nodes of visitor use; trail use; vehicle counts on roads and in parking lots; vehicle and hiking travel patterns; resource impact assessments of social trails, unsanctioned parking, and at backcountry campsites; and data regarding visitor experience and demographics. This presentation will discuss preliminary results and highlight how final results will be used to inform transportation management and prioritize future improvements in BRCA.

Real co-production of science: examples and recommendations from Cooperative Extension

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ABSTRACT: Applied science is often done within the vacuum of academia. The absence of any incorporation of stakeholder knowledge or management priorities in applied science significantly attenuates the value of research for on the ground application. For example, researchers often develop management technologies without accounting for costs, which is the dominant factor driving most management decision making. This talk will highlight why applied science should always be done in collaboration with stakeholders based on general data and personal experiences from Cooperative Extension (the group of researchers that deliver the mission of land grant universities). Importantly, this talk will also describe step by step methods for identifying relevant stakeholders and incorporating stakeholders needs and knowledge into every step of the research process to increase the utility of experimental outcomes.

Turning research into action: challenges and opportunities for collaboration across the desert Southwest

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ABSTRACT: While sound scientific understanding is needed to make effective management decisions, improving conservation depends on co-production and improved communication of actionable science that creates useful management tools. The Desert Landscape Conservation Cooperative worked to address these needs across North America's hot deserts by funding research on the most pressing management questions, developing spatially explicit decision-support tools, and communicating research findings. First, Critical Management Question teams addressed key conservation challenges, including prioritizing landscape-scale stressors and assessing the role of fire in riparian ecosystems. Next, the collaborative initiated three Landscape Conservation Designs in 2015, one each in the Mojave, Sonoran, and Chihuahuan Desert. Landscape Conservation Design is a partner-driven approach to identify shared conservation goals and prioritize on-the-ground action. After identifying a shared vision and conservation goals, participants identified landscape-scale challenges requiring collaborative action. A spatial analysis team compiled existing geospatial data on ecological indicators, conservation areas, and wildlife corridors. The ecological indicator framework will allow partners to track how conservation actions are changing the landscape over time. Ongoing efforts include compiling existing decision-support tools and creating new spatially explicit datasets to help prioritize areas for conservation activities ranging from restoration to pursuing protection of lands. Finally, the cooperative launched the Collaborative Conservation and Adaptation Strategy Toolbox (CCAST). This online platform presents case studies to share lessons learned from both research and on-the-ground conservation actions. The goal is to create a community of conservation practice to increase communication and improve effectiveness of science communication for practitioners. Together these efforts have resulted in useful tools for both researchers and conservation practitioners. More importantly, the cooperative created a forum for increased collaboration. However, sustainability of tools created

by the cooperative are uncertain. Shared leadership and extensive leveraging of resources is required because long-term funding is not guaranteed.

Drought response and water relations of southwestern white pine planted in common gardens

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ABSTRACT: Increasing temperatures and a drying regional climate will present existential challenges to tree populations in the southwestern United States and Mexico. Southwestern white pine (*Pinus strobiformis*; SWWP), an important component of mixed-conifer forests in this region, is expected to face significant range contraction in the next half-century. Therefore, a better understanding of this species' water relations and drought adaptations will inform management actions to sustain SWWP in the southwestern US in the face of climate change. We investigated the drought response of 44 U.S. SWWP maternal families from 10 populations planted at three Arizona common garden SEGA sites across an elevational gradient to simulate climate warming. We applied a drought treatment (50% reduction in water) to half of the seedlings at each site to understand drought response across multiple environments. We characterized drought response and its phenotypic plasticity, through the use of pre-dawn and midday water potential measurements, foliage carbon isotope discrimination, and leaf mass per area (LMA). Overall, our findings indicate that SWWP is a strong drought-avoiding species, preserving tissue water through stomatal closure rather than tracking changes in soil moisture throughout the day. Carbon isotope discrimination decreased along the elevational gradient, reflecting stomatal closure in response to high temperature and vapor pressure deficit. Changes to LMA will be discussed in the context of genetic plasticity, and management recommendations will be offered based on our findings.

Alpine pollinators of the La Sal Mountains, southeastern Utah: community composition and adult host plant use of Hymenoptera and Lepidoptera (with apologies to Dipterists for now)

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ABSTRACT: The high peaks of the La Sal Mountains in southeastern Utah support one of the few true alpine communities on the Colorado Plateau. These isolated alpine habitats support specialized biological communities that are adapted to the harsh environmental conditions, including several endemic plant species. A comprehensive arthropod inventory is not currently available for this unique ecosystem. In 2013-14, 35 non-native mountain goats (*Oreamnos americanus*) were introduced to the La Sal Mountains. The goats were introduced before we could conduct a true baseline survey, but fieldwork began in early summer 2014, and has continued through 2019, with pitfall and pollinator cup trapping and net capture surveys. Here we present Hymenoptera and Lepidoptera net capture data from 2016-2018 at three sites. Over 50 species of flowering plants were documented as host plants (or at least landing sites) for one or more species of Lepidoptera or Hymenoptera; only two plants had no landings recorded. Individual plant species were hosts for zero to 28 Hymenoptera, and zero to 21 Lepidoptera species in a given year. We documented a total of 111 Hymenoptera taxa over the three years. Number of taxa caught each year ranged from 47-81; we caught 85 Lepidoptera taxa in nets over the same period with number caught each year ranging from 48 to 59. There was considerable temporal variability in pollinator communities. Six Hymenoptera taxa were only seen in 2016, 20 taxa were unique to 2017 captures and 43 taxa were not caught until 2018. Eleven Lepidoptera taxa were only encountered in 2016, six taxa occurred only in 2017 captures, and in 2018 we added 14 taxa to the cumulative species list. Use of flowering plants by individual species were recorded and will be presented, along with patterns in flower color and temporal differences within and between years.

High-flow experiments on the Colorado River downstream from Glen Canyon Dam: two decades of adaptive-management for sediment resources in Grand Canyon National Park

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ABSTRACT: Adaptive management has been the paradigm guiding the operations of Glen Canyon Dam and management of the downstream ecosystem along the Colorado River in Grand Canyon National Park and Glen Canyon National Recreation Area for

more than 20 years. In that time, the primary management actions undertaken in this context, and guided by science, have been controlled floods, also called high-flow experiments (HFEs). Although there has been interest in how HFEs affect all aquatic and riparian resources, the focus of the HFEs in terms of design, implementation, and evaluation has been on sediment for building sandbars. Since the first HFE was conducted in 1996, the implementation of HFEs has evolved from an event-based approach, in which each HFE was an individual experiment requiring environmental compliance, to a long-term protocol for conducting multiple HFEs under the umbrella of a single environmental compliance document. To support this evolution in management approach, scientists have developed a range of monitoring and modeling tools that are used by managers in the decision-making process. These include methods for continuous monitoring of sediment-supply conditions, models for predicting sediment-storage changes for each HFE, and methods for monitoring the immediate and long-term effects at sandbar monitoring sites. Results from the five most recent HFEs indicate that the adaptive approach integrated in protocol for conducting HFEs is functioning largely as intended, resulting in deposition on sandbars and increases in sandbar size without causing long-term decreases in sand storage in Marble Canyon. While this example illustrates a successful application of the principles of adaptive management in guiding river operations, it remains an approach that is based primarily on sediment resources. Further efforts are needed by scientists and managers to broaden the scope of HFEs to more explicitly address other resource goals.

University of the Parks meets the Colorado Plateau Native Plant Program: an undergraduate perspective on regional plant conservation activities

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ABSTRACT: Supporting healthy and resilient native plant communities across the Colorado Plateau is important for the maintenance of resilient ecosystems that provide life with crucial ecological services. Regional conservation partnerships such as those formed under the auspices of the Colorado Plateau Native Plant Program (CPNPP) facilitate effective restoration and management of native plant materials. The work of the CPNPP results in direct outcomes and outputs, such as native plant seed collections, research publications, and guidelines for seed transfer. Less known, however, are the indirect outcomes that grow out of the CPNPP's partnerships. Southern Utah University (SUU) is a primarily undergraduate institution (PUI) that has partnered with the CPNPP for over two years to assist with native seed collections and educational outreach related to native plants and pollinators. SUU is driven by its mission to engage students in personalized and rigorous experiential learning and by its designation as the University of the Parks. To this end, faculty mentor participating students not only complete the basic goal of collecting seeds, but also learn how to be independent field biologists capable of data collection and curation. This presentation will feature personal accounts of how the partnership between SUU and the CPNPP has contributed to student learning and the development of new skill sets related to careers in the sciences and natural resource management. Our experience shows that partnerships between federal agencies and primarily undergraduate institutions are mutually beneficial in developing the next generation of land managers, biologists, and scientists. Success of the partnership is further validated by the addition of new partners and funding from the state of Utah and the Dixie National Forest, which implies that the model could be applied at other PUIs.

Can shrub seedlings be a viable restoration tool in arid systems?

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ABSTRACT: Shrub islands can provide seed sources, structural complexity, and refugia for establishing plants in degraded areas, aiding in restoration. The use of seedlings can increase shrub establishment, but is expensive, labor intensive, and can be impractical for large areas. We sought to determine an efficient way to establish shrub islands for restoration purposes. We established five experimental plots in Gunnison Sage grouse habitat that burned in wildfires in 1999 and 2006, in Western Colorado. We considered how moisture, competition, and herbivory affect establishment of the shrub *Artemisia tridentata* Nutt. We used small wood piles next to seedlings to create favorable microsites and supplementary water, seedlings planted with and without seed mixes, and cages around seedlings as treatments. Early results indicate that caged seedlings may have increased survival. Surprisingly, seedlings with a small wood pile had similar survival as those given supplementary water. If shrub islands can be efficiently established as fertile islands then they can be an important component of restoration, leading to passive restoration after an initial investment.

John Wesley Powell's land and water policies and southwestern Native American agricultural practices

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ABSTRACT: Gribb's research offers a proverbial bounty, considering tribal agricultural development within the Colorado River Basin from historical, contemporary, and prospective angles. Which Native American tribes inhabited the basin at the time of John Wesley Powell's 1869 expedition? How engaged, if at all, were they in agriculture? Gribb sheds light on these subjects and others involving the historical context in which the expedition occurred. Yet nothing about this work is stationary. Consider the plethora of treaties, statutes, and executive orders that shape the basin's tribal land base in modern times. Witness, too, the relative prevalence and diverse modes of agriculture on reservations. The contemporary state of tribal water rights, quantified and unquantified, is also a critical topic. It speaks to an intractable truth: basin tribes' agricultural activities will be directly impacted by climate change as the twenty-first century progresses. Powell's legacy resurfaces here. Four of his strategies for land and water management may prove fruitful for basin tribes' future agricultural plans.

Active and passive rehabilitation of fire mosses in severely burned forests of the southwestern US

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ABSTRACT: With wildfires increasing in extent and severity in the southwestern US, practitioners need new tools to rehabilitate recently burned ecosystems. Fire mosses consist of three species, *Ceratodon purpureus, Funaria hygrometrica,* and *Bryum argenteum,* that naturally colonize burned landscapes, aggregate soils, and can be grown rapidly in the greenhouse. We explored the efficacy of fire moss as a passive and active postfire rehabilitation tool. First, we conducted a natural survey of moss colonization and function on 10 severely burned areas in the southwestern US. We tested 11 landscape scale predictors of fire moss cover and found that it is most strongly influenced by insolation, pre-fire vegetation type, soil organic carbon, and time since fire. We also found that, when compared to bare soils, fire mosses increase infiltration by 50% on average and soil stability by more than 100%. Using this information, we selected two study sites in the Southwest to inoculate greenhouse grown fire moss. Directly after a wildfire near Kendrick Peak, Arizona we added sieved moss, finely ground moss, and moss combined with diatomaceous earth and rolled into pellets (n=15). After two growing seasons, no treatment had attained more than .5% cover on average, but pellet treated plots had significantly higher moss colonization ($P<0.001$). Four months after a wildfire in the Jemez Mountains of New Mexico, we added greenhouse cultivated moss that was ground into fragments as well as high and low cover of pellets (n=12). One year after inoculation, we found slightly increased moss cover with a mean of 4.3% on plots that received high cover of pellets compared to 1.7% cover for controls ($P=0.07$). Our results indicate that fire mosses are functionally important colonizers of north facing severely burned hillslopes, however more research is necessary to develop them as an active rehabilitation tool.

Prioritizing dam removal sites for optimal river restoration in the western U.S.

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ABSTRACT: For centuries dams were built to power mills, produce energy, and to provide flood control, transportation, and irrigation. To that end, dams are socio-political structures that have been fundamental to human population growth and technical innovation. Today many of these structures are aging and are no longer used for their original intended purpose, and some pose a significant threat to both humans and ecosystems. For instance, dams have significantly altered the connectivity and biodiversity of rivers as well as riverine physical attributes such as natural flow regimes, temperature, and sediment and nutrient transport. As a result, dam removal is an increasingly accepted strategy for river restoration across the United States –since the 1970s more than 1,400 dams have been removed. In the future, important decisions must be made regarding which dams are still ecologically and economically viable and which are best suited for removal and subsequent river restoration. Therefore, it is critical to prioritize dams for removal where rivers, freshwater resources, and ecosystem services will benefit most from restoration and conservation. To that end, this research evaluates which dams are most suitable for removal in the 11 western United States as well as takes a closer look at watershed dynamics in which these dams are situated. Preliminary results reveal sites for river restoration to repair waterways that are no longer performing essential ecological and social functions; for example, mitigating floods, providing clean drinking water, removing excessive amounts of nutrients and sediments, supporting fisheries and wildlife, and recreation.

Native Plant Increase and Research Activities at the Great Basin Research Center (GBRC), Ephraim, Utah

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ABSTRACT: The Utah Division of Wildlife Resources (UDWR) Great Basin Research Center (GBRC) in Ephraim, Utah is a multi-faceted facility with a long history of work and research in wildland restoration and revegetation. The GBRC conducts research on rangeland restoration techniques and native plant materials development, as well as providing restoration equipment and seed resources for restoration projects throughout Utah. Native material increase work, a current research update, and potential collaboration opportunities with the GBRC will be outlined in this presentation.

Supporting science under shifting sands – reflections from one National Park Service employee

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ABSTRACT: The presenter shares her perceptions and experiences from three National Park units in addressing science needs and some of the challenges and successes in supporting science and research at the park level. Context of shifting social, political, and agency priorities are discussed, along with challenges of funding, the National Park Service research permit review process, and oversight of research in parks. Lessons learned will be shared, including techniques to successfully advocate for science-based management within parks with multiple competing resources and priorities.

A review of a decade of conservation actions for imperiled desert fishes in Grand Canyon tributaries: implications for conservation of large-river fishes

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ABSTRACT: Like many imperiled riverine ecosystems, the Colorado River was subjected to extensive damming and water withdrawals, which homogenized flow, fragmented habitats, and facilitated establishment of numerous invasive fishes, including salmonids in dam tailwaters. Native large river fishes have since declined, and several were listed under the Endangered Species Act, including the humpback chub (*Gila cypha*). To conserve humpback chub in Grand Canyon, the National Park Service, with funding by the Bureau of Reclamation, has implemented a program of tributary invasive salmonid control and translocations of juvenile humpback chub, to reduce predation risk and establish population redundancy. Juveniles were translocated from the Little Colorado River to two additional Colorado River tributaries, Shinumo and Havasu creeks, between 2009 and 2016. A third tributary, Bright Angel Creek, received translocated humpback chub in 2018, following six years of intensive mechanical suppression of invasive salmonids. Growth rates and survival of humpback chub in Shinumo and Havasu creeks were equal to or greater than those of the source population, until an ash-laden flood extirpated translocated fish from Shinumo Creek in 2014. Reproduction and recruitment of humpback chub continues in Havasu Creek, and fish produced *in situ* comprised approximately 50% of the total abundance as of 2018. In Bright Angel Creek, responses of native fishes to mechanical trout removal have been positive: speckled dace (*Rhinichthys osculus*) and bluehead sucker (*Catostomus discobolus*) increased in abundance, and large cohorts were produced during recent high-flow years, coincident with large year-classes in flannelmouth sucker (*Catostomus latipinnis*). An additional translocation is planned for Bright Angel Creek in 2020 and monitoring of translocated populations will continue. These results demonstrate the successful implementation of conservation measures in Colorado River tributaries and underscore the importance of natural flow regimes and water temperatures, along with invasive fish suppression, in the recovery of native fish populations.

The Middle Rio Grande Collaborative Program and New Mexico's role

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ABSTRACT: The Rio Grande is one of the most significant rivers in the western USA. It flows for nearly 1,900 miles through the states of Colorado, New Mexico, and Texas before emptying into the Gulf of Mexico. The river provides water for nearly 20 million people, with the heaviest demand in the Middle Rio Grande (MRG) in New Mexico, from the Colorado state line to Elephant Butte Reservoir. The Middle Rio Grande Endangered Species Collaborative Program was established in 2002 as a collaborative effort among 16 federal, state, local, and tribal stakeholders for the purpose of implementing conservation activities to benefit endangered species and their habitats, while protecting existing and future water uses in compliance with state and federal laws. The increasing incidence of drought and human demand for water have stressed water management in the MRG and the State of New Mexico has a major role in ensuring water delivery through the Office of the State Engineer and the Interstate Stream Commission. The Office of the State Engineer is charged with administering the state's water resources, and the State Engineer has authority over the supervision, measurement, appropriation, and distribution of all surface and groundwater in New Mexico, including streams and rivers that cross state boundaries. The Interstate Stream Commission has broad powers to investigate, protect, conserve, and develop New Mexico's waters including both interstate and intrastate stream systems, consistent with interstate compacts. The Commission's authority under state law includes negotiating with other states to settle interstate stream controversies, and to investigate and develop the state's water supplies and institute legal proceedings for planning, conservation, protection and development of public waters. These authorities position the State of New Mexico as a key and major stakeholder in the Collaborative Program to ensure conservation of natural resources in balance with water needs.

The middle Rio Grande – a water user's perspective

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ABSTRACT: During the past two decades, the federal listing of endangered species has required a new approach in water management within the middle Rio Grande that must balance species needs with the historic irrigation uses that have taken place for hundreds of years. Like most western rivers, the Rio Grande is erratic in its rates of flow and depends upon snow pack and late summer monsoons for predictability of water use. This reach of the river—from the Colorado border to Elephant Butte Reservoir—has been successfully managed by the Middle Rio Grande Conservancy District and its partners during severe shortages. This has required methods to allocate water to meet the senior needs of the six Pueblos within its boundaries, the new demands under the Endangered Species Act for protective habitat, and the obligation to ensure that growth in urban demand is managed regionally while ensuring a vibrant agricultural economy. This is being accomplished by providing for water markets that allow water to be allocated to urban and ecological uses in a minimally disruptive approach to the remaining users as well as extensive multi-agency coordination on a daily, monthly and now annual basis through utilization of surface and ground water modeling techniques. An historical backdrop will aide in the discussion of the methods developed in managing available water supplies within a complex system of reservoirs, canals and drains to balance the needs of Pueblo and non-Pueblo farmers, meeting Rio Grande Compact obligations, ESA requirements under the 2016 biological opinion, and growing urban demands.

Climate and tree source effects on *Pinus edulis* mortality, bud performance, and growth in Southwest United States

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ABSTRACT: Climate change is causing *Pinus edulis*, pinyon pine, mortality and growth declines throughout its range. We sought to understand which tree seed sources and sites will have the highest survival and productivity. Local adaptation suggests that seeds from differing climates will vary in optimal growing conditions and phenology. Furthermore, planting sites with different climates will also influence survival, growth, and phenological variation. Pinyon pine seedling survival, growth, and phenology was surveyed at two common gardens to help understand variation in pinyon pine seed sources and their acclimation to different environments. Pinyon pine seed from the Navajo Nation and from Sunset Crater Volcanic Field, AZ were grown in two common gardens, one in Crownpoint, NM and the other at Sunset Crater Volcanic Field, AZ. For the first year in the common gardens, we assayed survival and overall plant size. To understand the progression of pinyon pine growth through the second year in the gardens we measured bud stage, bud type, bud size, and needle elongation, as an additional representation of pinyon pine performance. The Sunset Crater garden generally had lower survival and plant size. Plant size in the first year did not show local adaptation. Instead, one of the Navajo Nation seed sources consistently had the largest plants at both gardens. For phenology measures in the second year, Crownpoint garden and

Sunset Crater garden data showed that seedlings performed better in a climate more similar to their source climate, showing evidence of local adaptation.

A new low in cultural resource management: insights from monitoring archeological resources re-exposed by low levels of Lake Powell in Glen Canyon National Recreation Area

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ABSTRACT: In 1963 the diversion tunnels closed at Glen Canyon Dam and Lake Powell began to fill, inundating hundreds of archeological sites. Since the late 1990s persistent drought conditions have dropped the elevation of Lake Powell in Glen Canyon National Recreation Area (Glen Canyon) to well below full pool. As a result, archeological sites that had been inundated for most of the last 50 years are once more above water. For several decades, Glen Canyon managers have considered inundated archaeological sites to be destroyed. Glen Canyon and Museum of Northern Arizona archeologists are testing this assumption by monitoring previously-inundated sites recorded during the Glen Canyon Archeological Survey in the late 1950s. By comparing original descriptions and photographs to current conditions, we find that re-exposed sites range from completely destroyed to well-preserved. Additionally, our monitoring shows that wave action and visitor impacts can cause severe damage—including erosion, graffiti, and fallen masonry—to archeological sites near the shores of Lake Powell. With lake levels likely to remain at 50 to 150 feet below full pool for the foreseeable future, managers cannot assume that once-inundated sites are gone; many of them still need protection and monitoring.

Developing a framework for assessing vulnerability of western cultural heritage

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ABSTRACT: Climate variability and change pose risks to National Park Service (NPS) Intermountain Region landscapes and ecosystems, and the cultural and heritage resources found in NPS management units. Cultural resource vulnerability assessment is a first step in developing a plan for adapting to climate-related risks. The NPS has invested in multiple cultural resource vulnerability assessment studies across its assets in the U.S., which have produced a variety of methods for conducting such assessments. Many of these focus on assets from coastal and mesic regions, and no assessments have been conducted in the NPS Intermountain Region, which stretches from Montana to Texas. Moreover, some assessments lack consideration of projected climate changes. The goals of this work include the development of (a) a consistent framework for conducting vulnerability assessments, (b) tools for quantifying exposure of cultural and natural resources to climate and other environmental factors, (c) a method for scoring the sensitivity of cultural resources and landscapes to these exposures, and (d) identification of the most at-risk resources in the Intermountain Region. The framework is based on the results of an expert elicitation workshop, and it includes recommendations for minimum vulnerability assessment elements, criteria, and dealing with sparse and imperfect cultural resource data. The vulnerability assessment tool utilizes National Climate Assessment projections of future climate, as well as GIS data of environmental variables such as soil erosion and wildfire risk, augmented by NPS cultural resource manager assessments of resource sensitivity to climate variables. The output of initial evaluation through the assessment tool is intended as input to park-based scenario planning processes, for development of potential adaptation strategies.

The Trait and Plant Performance Database: linking plant traits to plant performance to improve restoration outcomes

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ABSTRACT: Plant functional traits are often used to evaluate local adaptation, phenotypic plasticity and general growth strategy. Plant performance measures can include mortality, fecundity or growth rates. Linking traits with performance data is often done in common garden experiments and can be used to predict success or maladaptation in restoration and climate change contexts. When comparing performance across contrasting environments, some traits are better predictors than others. The context dependent nature of functional traits demand that these data be housed with relevant provenance, treatment and site information. Our poster will present the Trait and Plant Performance Database (TaPPD), a database linking plant traits with plant performance to inform restoration on the Colorado Plateau. With a database focused on the Colorado Plateau, we can include specifics of regional importance (e.g. cultivars) to inform native plant materials development and appropriate deployment. We will present current dataset summary statistics, schema and technical details of the database, and will encourage involvement and participation from conference attendees.

A meta-analysis of context-dependency in plant responses to biocrusts

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ABSTRACT: In recent decades, numerous studies have additionally demonstrated biological soil crusts ("biocrusts") influence the performance of plants with which they coexist. However, plant responses to biocrusts can be positive, neutral, or negative, generating uncertainty about the overall nature of biocrust-plant interactions and the factors driving outcomes of these interactions. We conducted a meta-analysis of the influence of biocrusts on vascular plant species, using a global data set encompassing 1,009 studies of biocrust-plant interactions. We used meta-regression models to assess the relative importance of nine biocrust, plant, and environmental factors in determining plant responses to biocrusts in five data subsets: 1) overall plant performance; 2) germination; 3) survival; 4) growth; and 5) cover. We found biocrusts had a slight negative effect on overall plant performance, driven by negative plant germination, survival, and cover responses to biocrust presence, while contrast, biocrusts increased plant growth. However, within each of the data subsets, it was clear that plant species responses to biocrusts are context-dependent. Biocrust community type, plant functional group, and plant nativity were important factors for predicting plant responses to biocrust presence across data subsets. Overall, cyanobacteria- and lichen-dominated biocrust communities negatively impacted plant performance, while moss-dominated and taxonomically-mixed biocrust communities had more positive effects. Non-N-fixing forbs and woody plants and C_4 grasses responded more positively to biocrust presence than plants with N-fixing bacterial symbionts and C_3 grasses. In addition, annual plant species were generally more negatively influenced by biocrusts relative to perennial species. Plant nativeness was also important in predicting plant responses to biocrusts. Non-native plant species' germination was decreased with biocrust presence, while native species were neutrally affected. Collectively, results highlight context-dependency in plant responses to biocrusts and have broad implications for understanding the importance of plant-soil interactions for dryland communities.

Restoration seeding success across Southwest ecosystems

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ABSTRACT: Recovery from disturbance represents a substantial challenge to agencies that manage large tracts of land in water-limited ecosystems of the Southwest. Despite the demand for restoration and rehabilitation, little information is available to help managers effectively reestablish native perennial vegetation and stabilize soils, especially given changing climate and disturbance regimes. The RestoreNet field trial network is a collaborative effort between scientists and land managers that systematically tests restoration techniques across environmental gradients. This network tests the suitability of a broad range of species used in seed mixes

for restoration, coupled with soil treatments to promote plant establishment and growth by increasing soil moisture [i.e., connectivity modifiers ("ConMods"), mulch, pits], in different soil and climate conditions. We tracked plant germination, establishment, and growth following restoration treatments for one year following seeding treatments at 10 network sites across the Colorado Plateau in summer 2018 – summer 2019. Preliminary results suggest seedling recruitment is mediated by seed mix type, soil treatment, and their interactions with local environmental covariates. Results from RestoreNet will help to better understand variation in seeding success and restoration treatments and provide critical information to land managers on methods that improve restoration outcomes.

Monetizing the health impacts and economic value of using wood biomass as a renewable energy source

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ABSTRACT: Fuels-reduction treatments such as mechanical thinnings extract small diameter wood and reduce fuel load and subsequent fire intensity. Utilizing small diameter wood and slash from treatments as a renewable energy source presents an opportunity to offset treatment costs and enhance forest health, environmental quality and local economies. This project examined the environmental and health benefits of using harvested wood as a renewable energy source to generate electricity and reduce air pollutants from coal- or gas-fired power plants in Arizona. Our objectives were to 1) quantify reduced emissions associated with forest bioenergy scenarios for three levels (low-, medium-, and high-use) of biomass power generation and 2) quantify pollutants emitted from electricity production using fossil fuel sources to generate baseline data for comparison. To assess the forest bioenergy and business-as-usual scenarios, we utilized the Environmental Benefits Mapping and Analysis Program–Community Edition (BenMap-CE) that estimates the health and environmental costs of power generation with respect to types and amount of air pollutants and population size. In addition to direct energy impacts, using wood energy can generate multiple benefits, including air quality benefits (e.g., reduced criteria air pollutants and greenhouse gas emissions), human health benefits (e.g., reduced mortality, hospital admissions, and asthma effects), and economic benefits (e.g., changes in employment). By comparing the negative or adverse effects between the scenarios with respect to the impacts on human health and the environment, we determined the benefits of using woody biomass as a renewable energy resource in Arizona. These results permit us to assess economic impacts of pollutant emissions associated with electricity production, and inform state and federal agencies, local utilities, stakeholders and the bioenergy industry of the benefits of forest bioenergy.

The Southwest Experimental Garden Array: sites, facilities and capabilities

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ABSTRACT: The Southwest Experimental Garden Array provides infrastructure for research into plants ability to react to climate change. Each garden includes a standardized set of environmental sensors for site monitoring. We will present climate comparisons among SEGA sites using both modeled data and the first several years of environmental data collected with the site sensors. Air temperature, soil temperature, precipitation, drought index, modeled evapotranspiration, and other environmental statistics will be compared across time and across the elevational gradient.

The human ecology of Tamarix removal and native recovery in the Southwestern U.S.

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ABSTRACT: *Tamarix* control projects in riparian systems vary widely in their success at meeting project goals. Researchers have investigated the role of removal methods and the environment to explain this variability, but the human component has rarely been explored. A lack of communication between scientists and land-managers is often cited as a limitation to successful restoration outcomes, however the existence of such a gap in information exchange is rarely measured. This research quantifies the science-practice gap in *Tamarix* removal projects throughout the southwestern U.S. and examines how information exchange between these groups may influence variability in restoration outcomes. To address these questions, we utilize vegetation data from 244 *Tamarix* removal sites in the southwestern U.S., as well as survey data from 45 corresponding managers and 23 scientists specializing in *Tamarix* related research. We assess the degree of adherence to scientific recommendations and perceptions science in restoration as

well as the relationship between these and actual restoration outcomes. We found that in this system, regardless of background or attitudes, land managers mostly follow scientific recommendations and scientists often tailor their research to address land managers' needs. The perception of the role of science in restoration had no bearing on whether land managers adhered to scientific recommendations. We attribute this success in communication in large part to effective boundary organizations involved in nearly all of these restoration projects. Preliminary findings suggest that increased collaboration and involvement of multiple agencies were associated with increased native vegetation. To determine whether this actually reflects improvement in the sites, we have employed a BACI design to measure how change in *Tamarix* cover and native understory cover relate to management approaches, including degree of collaboration. This project provides insight into how the actions of organizations, scientists and land-managers influence plant community outcomes in riparian management projects.

Environmental monitoring of uranium exposure experienced by Navajo Nation community livestock in Cove, Arizona

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ABSTRACT: Uranium contamination has long been a major concern on the Navajo Nation, as both an environmental contaminant and cause of adverse health effects. Uranium is naturally abundant on Navajo lands and was mined throughout the reservation between 1930 and the late 1980's. The community of Cove, AZ, located in the Four Corners region of the Colorado Plateau, was one of the first sites mined for uranium in the 1940's. The community has been exposed to mine-related contamination from tailings runoff in their watershed as well as dust particulate exposure. The community of Cove has requested an assessment of their livestock's exposure to uranium in order to address concerns associated with the sale or consumption of the animals. This research is focused on the chemical characterization of water, plants and soils from the areas that are grazed by community livestock. Preliminary sampling was conducted through two trips and results yield evidence of concentration ranges for water, plants and soil in unconfirmed areas of grazing. Collaborative work with the University of New Mexico and Diné College has led to the collaring of sheep, goats and cattle from the area and will provide boundaries of heavily grazed areas. Strategic field sampling and inductively coupled plasma mass spectrometry (ICP-MS) analysis will be conducted based on the GPS collar grazing data. Exposure routes can then be documented and used to create recommendations for the community. The end goal is to clearly convey the associated risk of uranium and other elemental contamination through livestock to the community of Cove.

Results and remaining data gaps from biological studies at breccia-pipe uranium mines in the Grand Canyon watershed

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ABSTRACT: A key factor in the 2012 decision to withdraw lands from future uranium mining in the Grand Canyon watershed was the limited amount of scientific data available to assess potential impacts. Biotic exposure and potential health effects of mining-related elements and radionuclides due to breccia pipe uranium mining were largely undocumented. The USGS has assembled a diverse team of scientists to address biological data gaps. This presentation will highlight completed studies and their conclusions, ongoing lines of research, and remaining data gaps. Examples of completed studies include exposure pathway (terrestrial and aquatic) delineation, species surveys (including environmental DNA metagenomic methods); chemical characterization and effects in plants, invertebrates, and mammals; mammal radiation assessments; and invertebrate and amphibian toxicity testing in mine pond waters. Ongoing research is focused on addressing remaining data gaps related to ecological and cultural resource risk analysis, temporal variability of chemical concentrations and their risk to biota in mine pond water, potential effects of off-site mining contamination to humans and wildlife via dust transport, identification of mitigation measures to minimize exposure and risk of mining-related constituents to biota, and documentation of human use to facilitate economic valuation.

Thinking like a RePublic: public lands in the Colorado River Basin

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ABSTRACT: Climate change and attendant challenges facing the Colorado River Basin's public lands are formidable but nonetheless should be viewed in context. They are elements of longstanding, often polarized dialogue across the United States about private versus

public property and optimal public lands management. “That debate is the price of democracy,” explains Hirt, drawing attention not only to John Wesley Powell’s utilitarianism and idealization of local governance—“utopian vision of human-scaled, self-governing island communities”—but also the gaping disconnect between that vision and transformative changes that occurred across U.S. society during the decades following Powell’s death. Public lands are now a cherished “birthright” of all Americans. And, in the Colorado River Basin and elsewhere across the Arid Region, we don’t have the luxury of antiquated, simplistic modes of public lands management. Rather, careful attention is needed in the contemporary “Great Unknown” to democratic processes, science-based decision-making, and collaboration as key features of public lands governance.

Native milkweed species in Arizona and their use by monarch butterflies

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ABSTRACT: The Southwest contains an extraordinary abundance of milkweed species and over half of the milkweed species in North America occur in the western U.S. Arizona alone contains 41 species and is second only to Texas in milkweed diversity. The elevational gradient, diverse ecotones, and high elevation habitat in Arizona make it an ideal location to focus on milkweed species and ecotypes for habitat restoration and monarch usage of particular milkweed species. The locations and quality of existing monarch breeding sites, and the general use of many of these milkweed species for either monarch caterpillar development or nectar sources for pollinators are generally unknown. Our objectives are to enhance monarch conservation, better understanding the phenology of native milkweeds, and increase the availability of appropriate native milkweed species. We accomplish this by utilizing Master Gardeners whom can effectively grow and promote milkweed use in urban gardens. We focus on ~10 *Asclepias* species native to Arizona. Master Gardeners throughout the state monitored, care for, and collected data on these plant species. We hope that these efforts will dramatically improve habitat resources for monarchs, while producing significant quantities of milkweed seeds from species not currently available. Although, Arizona is traditionally thought to have very few monarchs, adult monarchs are reported every month of the year and over 12,000 monarchs have been tagged in Arizona since 2003.

Collaborative conservation: updates from the Kane and Two Mile Research and Stewardship Partnership

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ABSTRACT: Resource limitations and disparate goals can serve to decouple the otherwise coactive efforts of scientific research and on-the-ground management of public lands. This disconnect can lead to a range of counterproductive outcomes, from research questions that lack application for real-world land management challenges to status quo natural resource management uninformed by best available science or other relevant knowledge sets. We believe that strategies for successful conservation-oriented public lands management are rooted in meaningful partnerships with support, expertise, and buy-in from multiple stakeholders working on shared conservation goals. While this ideal can be difficult to implement in practice, we argue that it is absolutely necessary with a rapidly changing climate, increasing restrictions in management agency resources, and deepening political divides, among others. We present lessons learned from the development and coordination of the Kane and Two Mile Research and Stewardship Partnership (RSP). This multi-stakeholder collaborative group formed in 2012 to generate knowledge, information, and tools to inform conservation-oriented resource management practices on the Kane and Two Mile Ranches – collectively known as the North Rim Ranches – an 830,000-acre landscape of predominantly federally-managed public lands north of the Grand Canyon. Comprised of local land managers from the U.S. Forest Service and Bureau of Land Management, state wildlife managers, academic and agency researchers, and a ranching partner, the RSP has made progress on priority research questions outlined in its Applied Research Plan, supports ongoing on-the-ground restoration efforts, and has informed landscape-level management planning. We discuss challenges and successes with bridging the science-management gap within the RSP, and hone in on the common ground and collaborative learning elements needed for a functional and resilient collaborative process.

Collaborative climate adaptation: riparian restoration on northern Arizona’s public lands

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ABSTRACT: In addition to mitigating the region’s contributions to greenhouse gas emissions that drive global warming, on-the-ground actions are necessary to support the resilience of communities across the Colorado Plateau amidst a changing climate. We are working on several initiatives in collaboration with an array of partners to protect and restore the Colorado Plateau, including efforts

to improve ecosystem resilience on public lands. We present case studies of collaborative restoration from two northern Arizona regions as examples of on-the-ground climate adaptation action. North of the Grand Canyon, pilot projects and our climate change adaptation plan have informed our riparian restoration work on an 830,000-acre swath of public lands. Here, we have been working with national forest staff, our ranching partner, and many volunteers to protect and restore small but critical riparian ecosystems. Over a six-year effort, volunteers have contributed more than 3,000 hours to restoring springs and lakes and 190 hours to assessing restoration needs for another 30 riparian areas. This combination of citizen science and on-the-ground engagement has strengthened new relationships among collaborators, bolstered a stewardship ethic, and provided key examples of restoration approaches for multiple-use public lands. Most importantly, it has improved protections for eight riparian areas that serve as water resources, biodiversity hotspots, and climate refugia. South of the Grand Canyon, more recent collaborations have continued these riparian assessment and restoration efforts in the footprint of the Four Forests Restoration Initiative, a 2.4 million-acre collaborative effort to return a natural fire regime to four northern Arizona national forests. In the last two years, we have worked with volunteers and partners to collect condition information on more than 70 springs and to complete restoration work at three sites. Though initially small in scale, this collaborative restoration work is moving toward landscape-scale climate resilience.

Legacies of fire and woody vegetation on soil seed banks of four North American desert systems

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ABSTRACT: Dryland plant community recovery after wildfire can be variable and legacies of these fires can extend not only to the above ground plant composition, but also to the soil seed banks. These collections of germinable seeds within the soil can provide insight into the future potential of a site, yet even with this fundamental role in structuring future plant communities, the degree to which dryland soil seed banks are impacted by fire and their subsequent post-fire succession is poorly understood. We use a fire chronosequence approach to investigate the changes in soil seed bank communities 10 and 30 years after fire (relative to paired unburned sites) and to address the influence of aboveground vegetation and microsites (e.g., shrub and interspace) on seed bank composition. We address these changes in soil seed bank composition across four dryland systems. Our four systems include the Colorado Plateau, Great Basin, Chihuahuan and Sonoran deserts. Soil samples were collected in the field and a greenhouse emergence technique was used to characterize germinable seeds in the soil seed bank. Preliminary results show that soil seed bank species richness and seed abundance is highest in the Sonoran and lowest in the Great Basin and Colorado Plateau. Across deserts, soil seed bank abundance tends to be higher under shrubs than in interspaces. Interestingly, seed bank abundance is generally higher in burned than unburned sites for the Great Basin, while the opposite trend is found in the Sonoran. By investigating both the above- and belowground plant communities we hope to better understand ecosystem resiliency after fire in dryland systems across the Southwest and provide useful information to resource managers tasked with managing burned landscapes.

Partnering with the University of Pennsylvania: students, mortars and weather stations at Wupatki National Monument

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ABSTRACT: Over the past three years, the Architecture Preservation Program at the Flagstaff Area National Monuments has partnered with the University of Pennsylvania's (UPENN) Historic Preservation Program via the Colorado Plateau Cooperative Ecosystem Study Unit (CESU) to provide hands-on archeological preservation training, enhance preservation materials studies and implement a vulnerability assessment program. Located 30 miles northeast of Flagstaff, Wupatki National Monument was created in 1924 to help preserve architectural sites in the Wupatki Basin and Antelope Prairie. Wupatki contains 2800 archeological sites, nearly 2000 of which contain above grade architectural remains and 200 contain walls over one meter high. For the benefit of the monument's traditionally associated tribes, the visiting public and scientific research, the FLAG Architecture Preservation Program actively manages architectural sites by focusing on periodic architecture condition assessments and hands-on preservation maintenance. The program focuses the majority of preservation activities at seven front country sites, while 40 additional previously stabilized backcountry sites demand attention. Further challenging the FLAG Architecture Preservation Program's capacity is a shift in weather patterns, challenges with recruiting and maintaining permanent National Park Service staff and a lack of preservation skills training outside the National Park Service. The greatest NPS-UPENN partnering benefit to the FLAG Architecture Preservation Program has been implementing a condition survey approach based on a vulnerability assessment strategy. This strategy will assist in understanding the current climatic elements driving architectural deterioration relative to the performance of applied preservation materials. Equally beneficial are training opportunities for archeologists and traditional trades staff that are not being met by academic programs or certificate programs prior to employment with the National Park Service.

Tribal preferences for Colorado River water management and the Glen Canyon Dam

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ABSTRACT: Despite being a high priority for federal agencies, the perspectives of Southwest Native Americans have been underrepresented in previous research on the effects of Glen Canyon Dam management on hydropower generation and downstream Colorado River resources. A series of small group in-person surveys with members of the Navajo Nation were used to investigate tribal perspectives on the condition of and preferences for managing the Colorado River's natural and cultural resources in the Grand Canyon. Resource outcomes presented include attributes related to the size of sandbars along the river, the abundance of non-native rainbow trout, and the abundance of native fish. Data are used to investigate the determinants of preference formation for Navajo Nation tribal members with respect to natural resources along the Colorado River. Also investigated is how tradeoffs are perceived between the production of energy and the condition of natural and cultural resources, as well as how tribal preferences for these resources may differ with the general population in the Southwest. Because there is almost a complete absence of similar prior socioeconomic studies, this project provides fundamental research into the development of survey methods to better understand Native American relationships to resource conditions and their management.

Historical forest conditions in trailing edge ponderosa pine ecosystems of northern Arizona

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ABSTRACT: Forests occurring at the trailing edge of their geographic distribution and environmental limits of the dominant species are vulnerable to rapid transition as climate changes. In northern Arizona and other areas of the Colorado Plateau, trailing edge ponderosa pine (*Pinus ponderosa*) ecosystems are found in transition with interior chaparral and Madrean evergreen woodland communities. Concerns over high fuel loading, dense stand conditions, and high-severity wildfire in these forests have led public land managers to aggressively pursue implementation of various treatments aimed at reducing crown fire hazard and protecting human communities. However, compatibility of these activities with ecological restoration principles is unclear, and there has been increasing interest in understanding past dynamics in these "shrubby" forests and current degree of departure from pre-1900 reference conditions. To address this information need, we used dendroecology to reconstruct historical fire regimes and stand structure at five sites located on the Prescott and Tonto National Forests in northern Arizona. Composite analysis of fire scar dates indicated that mean fire return intervals were less than 2.2 years at all sites, and point fire intervals were less than 11 years prior to 1879. Historically, sites were open in structure, and tree-form oak was often more numerous than ponderosa pine in forest overstories. Similar to those of montane ponderosa forests, fire regimes at the study sites were abruptly interrupted, and few fires were recorded in the tree ring record after 1879. Tree densities have increased 350-700% across the five sites, and species composition has shifted toward greater numbers of conifers, particularly ponderosa pine and alligator juniper (*Juniperus depeanna*). Restoration approaches for these forests should focus on increasing resilience to stand replacing-fire and lowering vulnerability to type conversion.

Incorporating tribal youth and elders and other tribal guidance into management of nonnative brown trout and other aquatic species below Glen Canyon Dam

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ABSTRACT: The management of nonnative aquatic species below Glen Canyon Dam and throughout Glen, Marble and Grand Canyons is complicated by the fact that several Tribes consider these canyons as Traditional Cultural Properties. Currently there are also two species of endangered Colorado River fish, the humpback chub (*Gila cypha*) and razorback sucker (*Xyrauchen texanus*) that call these same canyons home further adding to the management complications. Species such as German brown trout (*Salmo trutta*) and green sunfish (*Lepomis cyanellus*) continue to reproduce and try to get a foothold below the dam, and several other highly piscivorous species including walleye (*Sander vitreus*), smallmouth bass (*Microterus dolomieu*), striped bass (*Morone saxatilus*), and northern pike (*Esox lucius*) can and have passed through the dam successfully, but are not yet known to be reproducing. The National

Park Service has prepared a management plan for nonnative aquatic species that also addresses a number of Tribal concerns. One innovative tool is the use of an incentivized harvest for removing brown trout by paying 'rewards' to anglers who turn brown trout heads in for scientific research purposes. A second component of this incentivized harvest program focuses on providing guided trips for Tribal youth, accompanied by Tribal elders, to harvest brown trout and learn about traditional cultural practices related to harvesting fish and wildlife. These Tribal youth will also be able to feed their families or communities with the harvested fish. A number of other innovative adjustments were made to the management plan that allow for adaptive management tools, using a tiered approach, to be implemented as defined trigger points are reached or new nonnative aquatic species begin to reproduce in the project area. This also allows for additional consultations and further input from the Tribes before these tools are implemented. Key points of the Expanded Nonnative Aquatic Species Management Plan and the adjustments made to address Tribal concerns will be focused on during this presentation.

Tree and opening spatial patterns vary by tree density in two old-growth remnant ponderosa pine forests in northern Arizona, USA

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ABSTRACT: Forest spatial patterns influence many ecological processes in dry conifer forests. Thus, understanding and replicating spatial patterns is critically important in order to make these forests sustainable and more resilient to fire and other disturbances. The labor and time required to stem-map trees and the large plot size (>0.5 ha) needed to study tree spatial patterns have limited our examination of how these patterns change as a function of site conditions and tree densities. We stem-mapped all trees >40 cm DBH within two large relict (minimally logged) pure ponderosa pine study sites on experimental forests at Long Valley (73 ha) on sedimentary soils and Fort Valley (32 ha) on basalt soils in northern Arizona, USA. We also simulated 1,000 4-ha plots from models of each study site incorporating field data parameters. Using cluster analysis and field data, we found that an inter-tree distance (ITD) of 9-11 m best separated single trees and groups within our study sites. Using a fixed 10-m ITD, the more productive Long Valley (LV) site had 62 trees ha^{-1} and groups of up to 113 trees, compared to the Fort Valley (FV) site, which averaged 41 trees ha^{-1} and had 22 trees in the largest group. However, the sites differed only slightly in terms of single trees ha^{-1} (LV 7.3; FV 5.6) and group of trees ha^{-1} (LV 7.2; FV 8.1). Simulation results indicated that when tree densities are equal, the spatial patterns were very similar between the two sites, suggesting that tree spatial pattern variability is a function of tree densities and only indirectly related to site productivity. As the number of trees increased, the additional trees integrated into existing groups rather than creating new groups. In addition to tree spatial patterns, we quantified gaps (defined as <30 m wide stem-to-stem) and openings (defined as >30 m wide stem-to-stem) within the two study sites. Although both sites were dominated by small openings most of the open area was found within a few large openings. Our large plots allowed us to incorporate variability and capture a larger range of tree and openings spatial patterns than have been captured in previous studies to provide insights on spatial heterogeneity that can inform management of this important forest type in North America.

Overview of the Grand Canyon National Park UAS Program

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ABSTRACT: The airspace above Grand Canyon National Park is complex and highly regulated. The use of Unmanned Aircraft Systems (UAS) technology for natural resource, search and rescue, wildland fire, law enforcement and other aerial missions has the potential to increase safety and decrease exposure to park employees and the public. Although, in order to fulfill the park's overall mission and land management objectives, UAS missions must integrate into the complex airspace with manned aviation operations. This presentation will provide an overview of Grand Canyon National Park's UAS Program within the context of these airspace challenges.

Assessing the durability, stability, and usability of genetic resistance to a non-native fungal pathogen in five-needle pines

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ABSTRACT: Many tree species are susceptible to non-native pathogens or pests. Their level of susceptibility can be so severe that they may be extirpated from the landscape, and their use for forest restoration or reforestation is limited. Because trees are long-lived, disease resistance must be effective for decades to centuries to be useful. Resistance needs to be durable, stable and present at a useful level. Field plantings provide the best opportunity to assess resistance durability and stability across a range of environments, but take many years to decades to provide results useful to management. We examine the durability and stability of resistance levels previously identified in seedling screening trials of three white pine species: *Pinus monticola* (western white pine), *P. lambertiana* (sugar pine), and *P. strobiformis* to white pine blister rust using 10 to 20-year-old white pine blister rust trials. We found that resistance varies for each host species and in different environments. Major gene resistance (MGR) may have limited utility due to virulent pathogens and the search for resistance should include all types of resistance, as quantitative disease resistance (QDR) appears to be more durable than MGR in the long-term at many sites in our study. Our data provide encouragement and support for the use of long-term field validation studies in combination with quantitative genetic resistance breeding programs. We advocate for an increased use of field trials to ensure that resistance is effective for restoration and recovery against invasive pathogens and pests.

Post-treatment livestock grazing management on mechanical vegetation treatment sites

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ABSTRACT: Mechanical sagebrush removal is often proposed in sagebrush communities with reduced herbaceous functional groups under the assumption that shrubs are outcompeting desirable herbaceous species and removal of shrubs will restore them. However, in many cases utilization of herbaceous species by grazing after treatment is a complicating factor in ascertaining degree of treatment success. Similarly, in areas where herbaceous vegetation is in poor condition, particularly within sagebrush communities invaded or recolonized by pinyon-juniper trees, the signs of ecosystem degradation that are attributed to pinyon-juniper encroachment are often difficult to tease apart from the symptoms caused by the resumption of livestock grazing in the treatment site. We conducted a comprehensive literature review of nearly 300 published studies to determine trends with success of mechanical vegetation treatment in both sagebrush and pinyon juniper systems across the western U.S. Out of those ~300 studies, we found only seven that meaningfully controlled for post-treatment livestock grazing in terms of systematically addressing it with experimental design. Seeing that a solid majority of mechanical vegetation treatments (conducted on either private or public lands) are grazed again within two years of treatment, we posit that the thousands of acres of mechanical treatments conducted and then grazed constitute a largely uncontrolled experiment throughout the West. We share early results from a large scale, long-term study underway since 2010 at Kennecott Utah Copper in northern Utah that is investigating the interaction between mechanical sagebrush treatment and post-treatment (spring and fall) cattle grazing. We feel that many more studies of this nature are called for, to fill a large hole in the ecological restoration literature.

Assessing the utility of gravity data in inferring enhanced permeability zones due to faults

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ABSTRACT: Conceptual and numerical groundwater flow models of the Coconino Plateau have identified a need for additional data to reduce uncertainty of modeled scenarios. One example is improved understanding and estimates of zones of postulated enhanced porosity and transmissivity associated with geologic structures – particularly those within the fracture zones surrounding extensional faults. These zones provide preferential pathways for groundwater flow, as the permeability of undeformed rock in the area is extremely low. The density contrast between fault gouge and the surrounding bedrock is detectable by detailed and highly accurate surveys of the local gravity field. Interpretation of gravity data collected across faults in the Coconino Plateau may enable improvements to existing groundwater models of the study area by identifying faults that can be modeled as enhanced permeability zones. The gravity method was initially applied to three known faulted areas accessible off route 64; the Bright Angel fault – a normal fault that intersects the Grand Canyon, an unnamed normal fault to the south that does not extend to the Grand Canyon, and the Tusayan graben faults near the Tusayan airport. Data for all three transects were analyzed but only data from one transect exhibited significant contrasts across the fault. These data were collected across the smallest feature, the unnamed normal fault. This suggests that this result should be tested for repeatability by additional data collection using more than one gravimeter. However, the preliminary results show promise and are being used to inform currently scheduled data collection.

The Amazon Dams Network: advancing integrative research and adaptive management of social-ecological systems transformed by hydroelectric dams

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ABSTRACT: The Amazon Dams Network (ADN) is an international, interdisciplinary group of researchers, students, and stakeholders studying the social-ecological effects of hydroelectric dams across the Amazon. In 2015, the ADN was awarded an NSF Research Coordination Network (RCN) grant that aims to synthesize and share lessons learned from hydroelectric dam development, focusing on an adaptive management approach within complex social-ecological systems (SES) theory. The geographical focus of the RCN is on the Tocantins, Madeira, Tapajós and Xingu River watersheds in the Amazon, and the Colorado River watershed in the US, leveraging the experience and expertise of the USGS Glen Canyon Dam Adaptive Management Program. The network includes a diversity of participants, represented by researchers from diverse academic fields and institutions, representatives from governmental and non-governmental institutions, as well as indigenous and other underrepresented social groups from the US, Brazil, Bolivia and Peru. This diversity presents a unique opportunity to motivate and coordinate international research and policy-making to address problems of dammed freshwater ecosystems. The overarching goal of the RCN is to build capacity for the advancement of integrative (inter- and trans-disciplinary) research on social-ecological systems transformed by hydroelectric dams in the Amazon, with five specific objectives related to gathering and synthesizing data, and facilitating knowledge exchange, learning and decision-making. In this poster, we summarize the goals and objectives of the ADN and highlight significant outputs and outcomes achieved in the past 5 years including: two international workshops that brought together >200 academic and non-academic participants, the engagement of younger scientists from many disciplines and countries and their integration into inter- and trans-disciplinary teams to work with senior scientists and other stakeholders, 22 presentations at national and international meetings, and 24 published papers.

Overcoming barriers to restoration in highly degraded semiarid rangelands on the Colorado Plateau

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ABSTRACT: Ecosystem degradation reduces important ecosystem services including erosion control, biodiversity maintenance, and net primary productivity. Threshold dynamics make restoring these services challenging and can often limit successful dryland restoration, due to a lack of plant propagules, unpredictable water availability, and destabilized soils. For this study, we evaluated innovative technologies and implementation strategies to stabilize the soils, establish native plants, and restore ecosystem services in a highly degraded semiarid grassland on the Colorado Plateau. Specifically, we compared a "business as usual" treatment of drillseeding native species to reduce native seed limitations to two novel restoration strategies. The novel strategies consisted of drillseeding plus the addition of an organic soil stabilizer (psyllium) and finer scale addition of greenhouse-grown biological soil crust to stabilize disturbed soils, and second, installation of small mesh barriers ("ConMods") to increase sediment and litter retention while hand seeding the same native species seedmix as the drillseeding. Results after one exceptionally dry year, followed by a very wet year, suggest that there are tradeoffs between restoration techniques depending on restoration goals. ConMods effectively reduced soil erosion, however native plants did not establish, possibly due to seed burial under excessive amounts of trapped sediment in the ConMod. The soil stabilizer promoted native seedling establishment, seemingly by inhibiting weed growth and reducing resource competition. These results illuminate existing challenges in restoration, even following a wet year and after utilizing the latest technologies and restoration strategies. However, our findings also demonstrate the utility of soil stabilizers and ConMods in providing short-term erosion control and native seedling establishment. By developing a deeper understanding of these different restoration techniques our findings can be of use to land mangers tasked with restoring drylands across the Southwest.

Response of biological soil crust to restoration trials on highly disturbed arid landscapes

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ABSTRACT: Despite a recent surge in research around biological soil crust (biocrust) restoration, re-establishing persistent communities of these organisms in highly disturbed field settings remains a significant challenge. In arid landscapes, loose and unstable soils can undermine crust adhesion to the soil surface and exposure to high temperatures and variable precipitation can lead to biocrust desiccation and mortality. Furthermore, inoculation methods can be critical, including biocrust source material (field-collected vs. greenhouse-grown) and timing of field inoculation. Here, we present initial results of two sets of field inoculation trials on the Arizona Strip in northern Arizona and at the Canyonlands Research Center (CRC) in southeastern Utah, which were aimed to address these restoration challenges. On the Arizona Strip, field-collected biocrust was inoculated at a 30% rate in fall 2017. At the CRC, we installed both large- and small-scale studies to comparing greenhouse-grown biocrust inoculated at a 12% rate in spring 2018 to that inoculated at a 20% rate in fall 2018. At the small scale, we also compared greenhouse-grown biocrust to field-collected crust, crossing these source materials with applications of a soil tackifier (psyllium husk). At both study sites, biocrust was applied as small peds on the soil surface, and watered enough to saturate the topsoil. Some biocrust from all inoculation sets persisted 1-2 years post-inoculation. Both field and lab biocrust inoculated in fall had higher biocrust cover and greater soil aggregate stability compared to uninoculated controls, but the only response for biocrust inoculated in spring was for field biocrust, which had higher cover compared to controls. Moss and lichen were much more prevalent in greenhouse source material. Soil tackifier amplified soil aggregate stability and the apparent cover of cyanobacteria. Overall, we found the most promising tactic to be late fall application of field-collected biocrust, in association with soil tackifier, which together can increase soil stability and its resistance to erosion.

Glen Canyon Dam Adaptive Management Program

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ABSTRACT: Adaptive management is a dynamic process where stakeholders representing a variety of often conflicting interests come together to make the right decision in the best interests of the resources. In compliance with the Grand Canyon Protection Act of 1992 (GCPA), the Environmental Impact Statement (EIS) for the operations of the Glen Canyon Dam proposed a process of adaptive management whereby the effects of dam operations on downstream resources would be monitored and assessed. The 1996 Record of Decision (ROD) established the Glen Canyon Dam Adaptive Management Program (GCDAMP) to provide organization and process for cooperative integration of dam operations, downstream resource protection and management, and monitoring and research information, as well as to improve values for which the Glen Canyon National Recreation Area and Grand Canyon National Park were established. The Adaptive Management Work Group (AMWG) is the advisory arm of the program mostly focused on policy issues; the Technical Work Group provides detailed technical guidance to the AMWG; the science arm of the Grand Canyon Monitoring and Research Center, conducts the research and monitoring needs to evaluate dam operations; and the independent review panel arm provides outside review for the program. Multiple resources considered under the GCDAMP include tribal, archaeological and cultural resources, humpback chub and other native fish, rainbow trout fishery, riparian vegetation, hydropower, and sediment. In 2016, the Secretary of the Interior signed the ROD for the Long Term Experimental and Management Plan EIS based on scientific information developed by the GCMRC and recommendations by the AMWG. The 2016 ROD provides a comprehensive framework for adaptively managing Glen Canyon Dam over the next 20 years consistent with GCPA and other applicable Federal law.

Decadal-scale patterns in overnight visitor use patterns in Grand Canyon's backcountry

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ABSTRACT: After a decade of near constant numbers, recreational visitation to Grand Canyon has risen by nearly 50% since 2009 and has exceeded six million in each of the last two years. The implementation of zoning and limits on backcountry permits in the 1988 Backcountry Management Plan has limited the growth of visitation to the inner canyon and the backcountry parts of the North and South Rims so that the number of visitors and groups has risen less than ten percent in those areas. Here, we explore patterns in how those changes have developed in different management zones and overall. In the non-wilderness areas of the Corridor Zone, where developed campsites, potable water, and frequent ranger patrols encourage less experienced canyon hikers, visitation has increased more than 10%, with much of the change taking place in the cooler months of the year. This growth may have resulted from changes in hiking-related technology and the rise in commercial services. In Threshold Zone areas, with no developed water and limited campsite development, visitation has increased only 5%. Most of the increase appears to be related to increasing commercial

services which generally have larger group sizes. he least developed parts of the park, the Primitive and Wild Zone use areas, show very little change during this period.

John Wesley Powell and the National Park idea: preserving Colorado River Basin public lands

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ABSTRACT: The meandering string of national park units lying along the Colorado River and its tributaries constitute the Colorado River Basin's "crown jewels." In light of its 2019 centennial and prominence, Grand Canyon National Park cannot go unmentioned. While its existence traces to the preservation ethic of John Muir, one of John Wesley Powell's most notable contemporaries, other classes of lands in the basin, both public and private, directly reflect Powell's recurring emphasis on conservation as a distinct environmental philosophy. In the twenty-first century, these bodies of thought—preservation and conservation—are of "co-equal status" in Keiter's view, with the national parks and other preserved lands defining the basin's character as much as "the precious water sources that Powell sought so adamantly to harness in his day." Yet navigating the contemporary "Great Unknown" across this intertwined landscape entails confronting multi-faceted challenges stemming from climate change, unprecedented visitation and recreational demands, and myriad other stressors. It is this trek and the novel tools for surviving it to which our collective attention must be paid.

Colorado River ecosystem responses to the 2018 Bug Flow experiment from Glen Canyon Dam

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ABSTRACT: Research by our group has demonstrated that the low diversity and low abundance of aquatic insects in the Colorado River downstream of Glen Canyon Dam was partly due to acute mortality of aquatic insect eggs arising from large daily fluctuations in releases for hydropower generation. In the summer of 2018, flow management of Glen Canyon Dam was experimentally modified to benefit aquatic insect populations in the Colorado River in Grand Canyon (Arizona, USA). These "Bug Flows" involved steady, low flows on weekends to improve survival of aquatic insect eggs coupled with standard daily flow fluctuations for hydropower generation during weekdays. Bug Flows were the first experiment conducted as part of the recently completed Long-Term Experimental and Management Plan EIS (LTEMP-EIS) for Glen Canyon Dam, and its final design was revenue neutral for hydropower. Here, we report on Colorado River ecosystem responses to the 2018 Bug Flow experiment. Time lapse video demonstrates that Bug Flows was successful at reducing desiccation of aquatic insect eggs laid during low and steady weekend flows as predicted. Caddisflies, an aquatic insect that has been extremely rare in the Grand Canyon over the past several decades, increased nearly 4-fold during last year's Bug Flow experiment compared to average summer abundance from 2012-2017. Non-biting midges, another type of aquatic insect that is a key prey item for fish and other wildlife, were up to 800% more abundant during weekend steady flows compared to weekdays when flows fluctuated. Recreational fishing also improved as shown in data collected by the Arizona Game and Fish Department, which indicated the average angler caught 18% more rainbow trout in Lees Ferry on Bug Flows weekends compared to weekdays. Collectively, these results demonstrate that subtle changes in dam management practices can improve Colorado River resources.

Conceptual models of groundwater flow in the Grand Canyon region, Arizona

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ABSTRACT: Conceptual models of groundwater flow synthesize what is known and hypothesized about the regional groundwater flow systems that discharge to the Grand Canyon of Arizona. The regional groundwater flow systems in the area occur in the saturated parts of the lower Paleozoic carbonate section exposed in the walls of the Grand Canyon; specifically, the Mississippian Redwall Limestone down through the Cambrian Muav Limestone. The saturated part of this stratigraphic section is referred to as the R-aquifer. All major springs in the Grand Canyon discharge from the R-aquifer. Local to sub-regional flow systems also occur in the sedimentary units of the overlying Permian section, chiefly in the Coconino Sandstone but also in the Toroweap and Kaibab Formations. This saturated zone is referred to as the C-aquifer. Structural highs associated with major faults and folds form most of the groundwater system boundaries. Highly fractured areas provide conduits for vertical and horizontal movement of water. The magnitude and

direction of groundwater flow in each system is heavily influenced by the connections of the karstic conduit networks. We used the locations, flow rate, and geochemical signatures of spring discharge to delineate flow systems and estimate groundwater residence time. Locations of likely zones of potential groundwater recharge are identified using a transient distributed-parameter Soil-Water-Balance model. Percolation pathways through overlying geologic units to the regional aquifer and groundwater flow paths toward points of discharge are likely to be strongly influenced by these geologic structures. We describe several unknown properties or conditions that likely contribute to the greatest uncertainties in our current understanding of the regional groundwater flow systems.

Interactions between drought stress and induced defenses determine mortality of ponderosa pine to bark beetles

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ABSTRACT: Interactions between water stress and induced defenses and their role in tree mortality due to bark beetles are poorly understood. We performed a factorial experiment on 48 mature ponderosa pines (*Pinus ponderosa*) in northern Arizona over three years that manipulated a) tree water stress by cutting roots and removing snow; b) bark beetle attacks by using pheromone lures; and c) phloem exposure to biota vectored by bark beetles by inoculating with dead beetles. Tree responses included resin flow from stem wounds, phloem composition of mono- and sesqui-terpenes, xylem water potential, leaf gas exchange, and survival. Phloem contained 21 mono- and sesqui-terpenes, which were dominated by (+)-α-pinene, (-)-limonene, and δ-3-carene. Bark beetle attacks (mostly *Dendroctonus brevicomis*) and biota carried by beetles induced a general increase in concentration of phloem mono- and sesqui-terpenes, whereas water stress did not. Bark beetle attacks induced an increase in resin flow for unstressed trees but not water-stressed trees. Mortality was highest for beetle-attacked water-stressed trees. Death of beetle-attacked trees was preceded by low resin flow, symptoms of water stress (low xylem water potential, leaf gas exchange), and an ephemeral increase in concentrations of mono- and sesqui-terpenes compared to surviving trees. These results show a) that ponderosa pine can undergo induction of both resin flow and phloem terpenes in response to bark beetle attack, and that the former is more constrained by water stress; b) experimental evidence that water stress predisposes ponderosa pines to mortality from bark beetles.

Investigating the role of animal burrows on the ecology and distribution of *Coccidioides* spp. in Arizona soils

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ABSTRACT: The lack of knowledge regarding the ecology of *Coccidioides* spp. makes modeling the potential for disease outbreaks and predicting the distribution of the organism in the environment challenging. No single ecological parameter explains the biogeography of the pathogen and the desert mammal association hypothesis has some support, but should be reexamined using modern molecular techniques. Therefore, the ecology and biogeography of *Coccidioides* spp. in Arizona was assessed by using molecular tools to analyze soils associated with animal activity (i.e., burrows). Soils were collected from locations outside of the established endemic regions to better understand the ecological niche of the organism in this state. Our central hypothesis is that soils taken from within animal burrows will have a higher abundance of *Coccidioides* spp. when compared to soils not directly associated with animal burrows. Results show that there is a positive relationship with *Coccidioides* spp. and animal burrows. The organism was detected in two locations in northern Arizona at sites that are not known previously to harbor the fungus. Moreover, this fungus is able to grow on keratinized tissues (i.e., horse hair). These results provide additional evidence that there is a relationship between *Coccidioides* spp. and desert animals, which sheds new light on *Coccidioides*' ecological niche. These results also provide evidence that the geographic range of the organism may be larger than previously thought, and the concept of endemicity should be reevaluated for *Coccidioides*.

Captive husbandry research informs conservation of federally-threatened narrow-headed gartersnakes

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ABSTRACT: The NAU Gartersnake Research Project (https://in.nau.edu/gartersnake-research-project/about/) includes a unique captive breeding and research facility for a federally threated species, the narrow-headed gartersnake (*Thamnophis rufipunctatus*), hosted on a university campus. The captive husbandry program began in 2010 in collaboration with the Phoenix Zoo, and is built upon student-led husbandry and research that promotes species conservation. Since its inception, the program has been instrumental in using field research on the habitat use, distribution, and behavior of wild snakes to inform development of naturalistic housing and husbandry protocols. Although this species appears extremely susceptible to a variety of pathogens, included common environmental bacteria, microscopic mites, and protozoans not previously documented as threats, we have developed effective protocols and treatment responses that allow captive-born snakes to thrive. The first captive-bred narrow-headed gartersnakes were born at NAU in 2014, and released into an outdoor enclosure at the Arizona Game and Fish Department Region 1 office in 2016. Currently, the husbandry program houses narrow-headed gartersnakes collected from Oak Creek, Arizona, following the 2014 Slide Fire. Since 2017, these snakes have produced 43 neonates in four litters. Recent student projects have investigated non-invasive assessment of stress hormone, as well as behavioral and hormonal responses to human handling in captivity. This research showed hormonal differences among age classes and seasons, as well as differences in behavioral and hormonal responses to handling dependent on age and captive status. The breeding focus of the program is currently officially off-line due to concerns about snake fungal disease, but research will continue. Collaborations will examine captive and wild narrow-headed gartersnake physiology, microbiome, and behavioral and immunological responses to pathogens and human predation threat.

Do rock lichen represent an important component of the dryland carbon cycle?

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ABSTRACT: Exposed bedrock is prevalent throughout the Colorado Plateau and drylands worldwide. Lichen – a symbiosis of algae or cyanobacteria living with fungi – are commonly found living on these exposed lithic surfaces. Photosynthesis and respiration rates of lichen have not been quantified in most landscapes and their contribution to global carbon cycles is largely unknown. Thus, this study aims to quantify CO_2 exchange of epilithic lichen to determine their relative contribution to carbon cycling. We focused our measurements on lichen growing on Navajo Sandstone and Kayenta formation bedrock near Moab, Utah. The CO_2 exchange of lichen-covered rocks and bare rocks was measured in the late winter to early spring, when we believed the lichen might be most active, and we standardized the time of day sampling occurred to maintain consistency in moisture, temperature, and photosynthetically active radiation (PAR). Our results showed variable exchange rates among different lichen. As expected, temperature and moisture content of the lichen were important for regulating CO_2 exchange. On days when temperatures were cooler (<10°C) and the rock surface was still moist, rock lichen surfaces produced negative fluxes as lichens were photosynthesizing more CO_2 than they were respiring. Contemporaneous measurements on rocks without lichen showed near zero fluxes. When temperatures were warmer (>21°C) and the rock lichen surfaces were dry, we measured positive fluxes on lichen covered surfaces and near zero fluxes on bare rock surfaces. These results suggest rock lichen may be active in times of the year when plants are dormant or senesced. Although the per-unit-area fluxes of lichen are small in comparison to plants, much of drylands contain exposed rock outcrops and epilithic lichen are ubiquitous across these surfaces; their contribution to carbon cycling on these landscapes may be important.

Common water commonwealth: the paradox of a shared resource

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ABSTRACT: Localized, democratic water governance was a topic of chief concern for John Wesley Powell, reflecting two paired romances: “the romance of centralized authority” and “the romance of local control.” Although relevant to the Colorado River Basin as a whole, this topic certainly has traction within southwestern Colorado’s Dolores River Basin, where extensive water development and ecological changes have occurred since Powell’s time. This pattern is exemplified most tangibly by the infrastructure that currently impounds the Dolores River: McPhee Dam and Reservoir. There is a pronounced divergence of views on how the Dolores River should be utilized in modern times, posing interesting questions about how to bridge the gap among the sub-basin’s diverse stakeholders, including the role to be played by embracing paradox in formulating a collaborative vision. This process not only harkens back to Powell’s grassroots perspective on water governance, but also holds much contemporary relevance for other watersheds across the Arid Region.

Using NASA Earth Observations to quantify tree mortality and burn severity to inform management on ranches and open lands

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ABSTRACT: Both wildfires and conifer-defoliating insect outbreaks have increased in frequency and severity in recent years. The western spruce budworm (*Choristoneura freemani*), a widespread defoliator in western U.S. forests, has impacted over 6,000 hectares of forest in southern Colorado. The forest managers for southern Colorado's ranches are concerned that fuel loading from budworm-related tree mortality will increase the risk of catastrophic wildfire on their land. To address this, we selected a study area encompassing the 2018 Spring Creek Fire footprint and two local ranches. Then, we used remote sensing observations from NASA sensors to map, quantify, and analyze both regional tree mortality prior to and burn severity of the 2018 Spring Creek Fire. From twenty-four predictor variables, we identified key predictors using the Variable Selection Using Random Forests (VSURF) R package and modeled pre-fire tree mortality using the randomForest R package. Burn severity quantification metrics included differenced Normalized Burn Ratio (dNBR), Relative differenced Normalized Burn Ratio (RdNBR), and Relativized Burn Ratio (RBR). Using these outputs, we explored interactions between pre-fire tree mortality and burn severity using generalized linear models (GLM). The maps created from this analysis provided our ranch partners and the Colorado State Forest Service with a comprehensive assessment of tree mortality on affected lands, facilitating future restoration and management efforts without the need for extensive *in situ* data collection. Expanding modeling efforts to examine the relationship between burn severity and tree mortality at larger spatial extents, across more varied forest types, and with more robust predictors could further elucidate the complex relationship between insect outbreak and wildfire.

Managing National Forest System lands in a changing climate: the Kaibab National Forest plan approach

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ABSTRACT: National Forests across the United States are expected to undergo widespread changes in response to climate change and associated biotic and abiotic stressors. When the Kaibab National Forest revised its land and resource management plan in 2014, we recognized that climate change would likely exacerbate an already difficult challenge. We took an approach where we looked at the existing conditions, trends, and climate related impacts that are likely to occur. We evaluated the resources that would be most vulnerable and used that information to develop desired conditions, objectives, and standards and guidelines to promote resistance and resilience in those systems. Notable trends included an increase in the frequency, extent, and intensity of wildfires; increased susceptibility to insects, diseases, and invasive species; and increased visitation pressure from people coming up to the cool pines to escape the heat. Vulnerabilities included water related resources and high elevation habitats that are more likely to support restricted and narrow endemic species. Recognition was given to interactions that magnify effects such as recreationist often concentrate in the most vulnerable areas, spread weeds, and serve as wildfire ignitions sources. The plan desired conditions include concepts of ecological integrity, diversity, and connectivity; objectives focus on increasing resistance and resilience, such as reducing fuel loading, treating invasive species, decreasing competition related stress, and restoring springs and wetlands; and standards and guidelines minimize impacts to protect vulnerable resources from recreation and other activities. Additionally, because we know we are operating in an environment with incomplete information and uncertain outcomes, the monitoring plan enables change detection and supports adaptive management.

Status of the Mexican spotted owl 15-years after the Rodeo-Chediski fire, Arizona

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ABSTRACT: The Mexican spotted owl is an iconic species of dry forests of the Colorado Plateau. These forests are threatened by post-settlement disruptions to historic fire regimes and anthropogenic climate change which have combined to drive an influx of large, severe forest fires over the last two decades. These fires may threaten the persistence of spotted owls. We studied the effect of 2002's Rodeo-Chediski fire (187,000-ha, 36.6% at high severity) upon spotted owls up to 15 years post-fire. Within our 18,800-ha burned study area we surveyed spotted owls during the 2014, 2015, and 2016 breeding seasons. We compared observed occupancy and

fecundity to results from pre- and post-fire surveys from burned and unburned sites collected by the U.S. Forest Service. We also modeled 2014-2016 site occupancy rates as a function of fire severity, forest structure and composition, and topography at two spatial scales: a grid of 100-ha cells across the landscape and 201-ha circles around historic sites only. Finally, we modeled 2014-2016 selection of nest and roost habitat at multiple spatial scales ranging from 100-5,000-m using machine learning. We found that observed site occupancy declined shortly after the fire and has since remained lower than at unburned sites. From 2014-2016 we found no significant change in site occupancy rates. The observed influence of fire upon site occupancy depended upon whether we focused upon the landscape or only upon historic sites. We did find that spotted owls avoided nesting and roosting within a 200-400m radius around areas where fire killed 33% or more of pre-fire tree canopy. In sum, our results indicate that large, severe wildfires may depress spotted owl populations up to 15 years post-fire and exert a significant influence over habitat selection even in occupied areas.

A new multifunctionality index: improving information to support rangeland management for multiple purposes

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ABSTRACT: Rangelands provide a wide range of benefits for society, in addition to supplying forage for livestock and thus our food, rangelands are critical in providing recreational space, carbon sequestration in soils, freshwater, and a variety of natural medicine sources. Simultaneously managing for these multiple purposes is challenging and here we propose to explore a "multifunctionality index" approach to evaluating and prioritizing multiple ecosystem functions for rangelands. We hope this tool could support federal resource managers in their mission to manage for multiple uses (such as energy development, livestock grazing, recreation, etc.) while ensuring natural, cultural, and historic resource conservation. We also hope a multifunctionality index could help ranchers assess and evaluate ecosystem benefits from rangelands in addition to livestock forage. Although multifunctionality indices are increasingly used in the scientific literature, here we propose that, to become a practical management tool, these indices should more strongly relate to and reflect human benefits (also called ecosystem services), even though these can be hard to measure. In the framework described here, we consider a new category for conceptual models of multifunctionality; namely, "supporting ecosystem services". We hope supporting ecosystem services could act as a middle ground between ecosystem functions, which are often measured by scientists, and benefits from nature, which are often managed for by resource managers. Within this model, ecosystem processes could be clustered in four equally important ecosystem supporting services: soil quality, water cycling, plant production, and biodiversity. In sum, we hope to work toward an improved framework for multifunctionality indices in rangelands that would allow scientific and management communities to better work together toward our joined goals.

Case study: landscape-scale erosion and invasive-woody species impacts to archaeological sites at Canyon de Chelly NM and Navajo NM in northeastern Arizona

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ABSTRACT: Canyon de Chelly National Monument contains one of the longest continually occupied landscapes in North America. Since 2003, the NPS in collaboration with various partners have studied and implemented landscape-scale invasive-woody species removal in an effort to preserve its unparalleled archaeological heritage as well as to restore the ecological integrity of the canyon's watershed. At Navajo National Monument, severe arroyo-cutting and mass wasting have altered landscapes that impact access to its primary archaeological sites as well as directly impacting others. The NPS has worked with various partners to explore the causes of landscape-scale change while adapting and planning for the future. This paper presents a case study of collaborative efforts to document and improve conditions of these significant national treasures.

Native bird responses to tamarisk (*Tamarix* spp.) biological control

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ABSTRACT: Non-native species establishment has resulted in native species loss globally, so controlling the spread of non-natives remains an important management challenge. Classical biological control (biocontrol) is the practice of introducing a pest species natural enemy to its introduced range, with the intention to manage populations of pest species, however this often has indirect consequences for the broader community. In the American west, non-native tamarisk (*Tamarix* spp.) has become extensively naturalized in riparian habitats, areas important for native plants and animals, particularly birds. Tamarisk is hypothesized to be inferior habitat for native animals, reduce native vegetation, increase soil salinity, and alter fire regimes. In 2001, the tamarisk leaf beetle (*Diorhabda* spp.) was released as biocontrol to manage tamarisk. Since then tamarisk leaf beetles have spread throughout the southwest including riparian habitat previously thought to be inhospitable. The primary effect of tamarisk leaf beetles on tamarisk is defoliation, and this can potentially change habitat structure and insect food base for riparian nesting birds. Little information is available on how birds respond to the tamarisk leaf beetle and the changes it causes to riparian areas, but these data are critical for management purposes. During the summer of 2013 and 2014 we used point counts to quantify native bird use of sites that varied in the amount of native vegetation and tamarisk defoliation along the Virgin River in Utah, Arizona, Nevada, USA. We found 1) overall bird density and richness was negatively correlated with tamarisk biocontrol, 2) species composition based on bird presence/absence and functional groups differed by sites that varied in the amount of tamarisk biocontrol, and 3) birds exhibited species-specific responses (positive, negative, neutral, or unimodal) to tamarisk biocontrol. Our results highlight the need for active restoration in areas where tamarisk biocontrol has occurred to maintain bird occupancy along riparian systems.

Identifying resilient rivers for wild and scenic designation in the Arizona/New Mexico ecoregion using geospatial analysis and statistical modeling

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ABSTRACT: Accelerating climate change and human demand are threatening ecosystem services provided by free-flowing rivers. Certain riverine ecosystems may remain resilient in the face of these threats by withstanding disturbance and rebounding to pre-disturbance condition and function. Therefore, identifying resilient rivers is important to managers and conservationists so that limited fiscal and human resources are optimized. The Nationwide Rivers Inventory catalogs over 3,200 rivers in the U.S. that are potentially eligible for inclusion in the National Wild and Scenic Rivers System that protects free-flowing rivers and the ecosystem services they provide. In light of threats facing these riverine ecosystems, this research seeks to answer two questions; 1) What bio-physical indicators are predictive of general resilience of riverine ecosystem services in response to climate change and increasing human demand of water resources? 2) How does land use influence riverine ecosystem resilience in NRI rivers of the Arizona/New Mexico Mountain ecoregion? Preliminary modeling results using extant datasets as indicators of resilience that allow for analysis of individual NRI stretches within the ecoregion will be revealed in this presentation. Each NRI segment in the ecoregion is analyzed using the R statistical programming language and assigned a resilience rating. These ratings are intended for use in decision-making for conservation policymaking and river resource governance.

Vegetation response in reclamation studies on highly disturbed lands across the Colorado Plateau

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ABSTRACT: On the Colorado Plateau, harsh environmental conditions often hinder reclamation progress, including unstable soils, low and variable precipitation, invasive species, and granivores. Highly disturbed lands associated with energy exploration and development in arid regions provide an opportunity to compare traditional and novel approaches to reclamation across an environmental gradient. We have initiated independent reclamation studies in areas disturbed by energy development and agricultural practices on the Arizona Strip in northern Arizona, in southeastern Utah near Canyonlands National Park, and in the Uintah Basin in northeastern Utah. We evaluated traditional reclamation practices (drill seeding, mixed-origin seed mixes) as well as techniques tailored to ameliorating harsh site conditions, including alternative seeding methods (broadcasting seed over hummocked soil, connectivity modifiers), all-native seed mixes, and stabilizing soil amendments (soil tackifier, biological soil crust, mulch). Observations 1-2 years post-treatment indicate that connectivity modifiers and broadcast seeding over hummocked soil appear to increase establishment of seeded plants compared to drill seeding, except in highly depositional environments in which sediment buries seeded plants. With adequate precipitation, all-native seed mixes have performed as well as a mixed-origin seed mixes (native

and non-native species), when precipitation is favorable. Soil tackifier (psyllium husk) and biological soil crust have not yet shown to be consistently associated with a vegetation response, although they do contribute to soil stabilization which may facilitate long-term plant establishment. Surface mulch (cedar chips) did increase plant establishment, apparently by deterring harvester ant activity. Ultimately, regional networks of reclamation experiments on developed public lands and in partnership with the energy industry can help to improve modern reclamation practices in challenging arid environments.

Mind the myco gap (between research and management potential)

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ABSTRACT: Despite critical ecosystem services provided by beneficial fungi, the gap between research-demonstrated potential and management application looms large in this field. Yet, many of their characteristics, like risk-spreading underground structures, make them logical allies in adapting to new environmental conditions. We review current knowledge of the ecosystem service roles of beneficial fungi. We then systematically search current United States national grassland, and state and national forest, management plans to identify intersections between goals targeted by the plans, and the services provided by beneficial fungi. Most management plans reviewed (80-100%) are concerned with eight of the ten ecosystem service categories where beneficial fungi have important roles, yet fail to mention beneficial fungi as a part of management. Of the management plans that include a mention of fungi, five out of six times they are merely mentioned (without other action/implementation), and three out of four references to fungi are as threats, not resources or management solutions. There are logical reasons this gap (between what research tells us fungi can do, and how we are implementing their skills and conservation) exists. We explore causes of this gap, including the inherent difficulty of research methods; the lack of recognition, protection, and funding for these cryptic organisms; and the resulting geographic, taxonomic, and functional spottiness of knowledge which makes the specificity required for management challenging. We examine lessons learned and positive examples to suggest solutions. We also seek feedback from land managers and researchers, to improve and build consensus around solutions, and ignite ongoing dialogue such that researchers and land managers can better work together to narrow this gap.

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. 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 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.

Recent changes in federal legislation supports “cross-boundary” restoration treatments on culturally sensitive tribal lands

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ABSTRACT: Reservation lands cover a total of 36.59 % of the Colorado Plateau. This includes 33 federally recognized reservations which encompass 30,443,327 acres. Reservation lands are diverse and include commercial forest and woodlands that are critical to tribal economies and political well-being. Management of these forest acres has historically been the responsibility of the Bureau of Indian Affairs (DOI). This is the primary federal agency for fulfilling the federal government's trust responsibility for ensuring the sound management of tribal natural resources. Since the passage of PL 93-638, tribes and tribal organizations have been able to assume management of their own resources and other services such as education, law enforcement, and health care. Recent legislation and actions, including The Tribal Forest Protection Act, Reserve Treaty Rights Lands, Good Neighbor Authority, and the 2018 Farm Bill have all expanded the tribes' ability to pursue management of resources off their reservations. This has greatly increased the opportunities for tribes to pursue restoration treatments not only on their own forest but also on adjacent land bases that may contain resources critical to their ecological, social, political, and spiritual integrity. Notably, the 2018 Farm Bill expanded PL 93-638 contract authorities to include management activities within the realm of the U.S. Forest Service. It also provides $20,000,000 annually through fiscal year 2023 and requires the U.S. Forest Service to pursue 4 pilot projects per year. The BIA's new Reserve Treaty Rights Lands program provides $10,000,000 annually for tribes to "participate in collaborative projects with non-tribal landowners to enhance the health and resiliency of priority tribal natural resources at high risk to wildland fire." All these actions provide an environment that allow tribes to be more proactive in their plans to implement forest and rangeland restoration treatments.

Changes in N-aquifer groundwater levels within the Black Mesa area, northeastern Arizona, 1971–present

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ABSTRACT: The Navajo (N) aquifer is an extensive aquifer and the primary source of groundwater for industrial and municipal uses in the 5,400-square-mile Black Mesa area in northeastern Arizona. Availability of water is an important issue in the Black Mesa area because of continued water requirements for industrial and municipal use by a growing population and because of the arid climate. The U.S. Geological Survey water-monitoring program in the Black Mesa area began in 1971 and provides information about the long-term effects of groundwater withdrawals on groundwater levels and discharge to springs and streams. Peabody Western Coal Company began a strip-mining operation in the northern part of Black Mesa in 1968 and is the primary industrial user of groundwater in the N aquifer. Withdrawals from the N aquifer in the Black Mesa area increased fairly consistently from 1971 through 2005 and then decreased markedly in 2006. At its peak operation, the mine used about 4,700 acre-ft of water per year, but since 2006 water use at the mine has decreased to around 1,300 acre-ft per year because the mining operation no longer uses a coal slurry to transport coal. Over the last 10 years, municipal groundwater use in the Black Mesa area has averaged around 2,700 acre-ft per year. Generally, groundwater levels in the unconfined portion of the N aquifer have changed little since the 1970s, while levels in the confined portion of the aquifer have declined from the 1970s to the mid-2000s. However, since 2006 the long-term trend in water level declines in the confined portion of the N aquifer has leveled off and in many cases the trend has been reversed.

Using patterns of genetic differentiation as the foundation for seed transfer guidelines

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ABSTRACT: As restoration needs for natural landscapes increase due to higher frequency and/or intensity disturbances, the establishment of invasive species, and impacts resulting from climate change, considerable time and resources are being invested to guide the development and deployment of native plant materials (NPMs) to improve restoration outcomes. For example, genetic sequence-based approaches are increasingly applied to restoration species to elucidate adaptation to environmental gradients, which can assist the development of seed transfer guidelines. However, the underlying patterns of genetic diversity within such datasets may also provide important knowledge to guide the use and development of NPMs. For example, natural patterns of genetic differentiation (e.g., a species' genetically defined populations), which are increasingly recognized as an inherently valuable resource, would best be protected by explicitly using them to create regional seed transfer boundaries. In turn, such genetic differentiation-informed boundaries may help mitigate other issues that can impact restoration outcomes, such as outbreeding depression or the decay of interactions among species within a community and the subsequent loss of community resilience. Here, we detail a new method that utilizes species distribution models, landscape resistance analyses, and empirical patterns of genetic differentiation to estimate the geographic distribution of genetically defined populations for two species, *Pseudoroegneria spicata* (bluebunch wheatgrass) and *Hilaria jamesii* (James' galleta grass). Furthermore, we use these boundaries to regionally constrain estimations of adaptation inferred either from common gardens (in the case of *P. spicata*) or from genetic sequencing data (in the case of *H. jamesii*). As such, we

develop guidelines that can be used to minimize both genetic and adaptive differentiation during seed transfer or when selecting seed sources from which to generate new NPMs.

Recent San Juan River Basin highlights for Colorado pikeminnow and razorback sucker

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ABSTRACT: The San Juan River Basin Recovery Implementation Program (SJRRIP) was established in 1992 with the goal of recovering federally listed Colorado pikeminnow (*Ptychocheilus lucius*) and razorback sucker (*Xyrauchen texanus*) while water development proceeds in accordance with federal and state laws and interstate and tribal compacts. Prior to the establishment of the SJRRIP, Colorado pikeminnow and razorback sucker populations were nearly extirpated from the San Juan River. The SJRRIP has implemented recovery management actions for almost 30 years in conjunction with ongoing water development in the San Juan River Basin. Recovery management actions include: 1) hatchery augmentation of Colorado pikeminnow and razorback sucker, 2) protection and augmentation of habitat, 3) management of nonnative aquatic species and 4) implementation of flow recommendations. Implementation of these recovery management actions had led to increased adult numbers for both Colorado pikeminnow and razorback sucker. In addition, Colorado pikeminnow and razorback sucker young-of-year have been captured in recent years. The success of razorback sucker in the San Juan River has contributed to the recommendation to downlist the species from endangered to threatened.

Impediments to recovery for Colorado pikeminnow and razorback sucker in the San Juan River Basin

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ABSTRACT: The San Juan River Basin Recovery Implementation Program (SJRRIP) was established in 1992 with the goal of recovering federally listed Colorado pikeminnow (*Ptychocheilus lucius*) and razorback sucker (*Xyrauchen texanus*) while water development proceeds in accordance with federal and state laws and interstate and tribal compacts. Prior the establishment of the SJRRIP, Colorado pikeminnow and razorback sucker populations were nearly extirpated from the San Juan River. The SJRRIP has implemented recovery management actions for almost 30 years in conjunction with ongoing water development. The SJRRIP has and is making progress toward recovery for the two endangered species, but challenges remain. A major impediment to recovery of Colorado pikeminnow in the San Juan River is the slow accumulation of adults because of persistent low survival of juvenile hatchery-reared fish. For razorback sucker, a large adult population has been established through hatchery augmentation, but few adults appear to successfully spawn. For those larvae that are produced, limited survival between the larval and juvenile life stages has been identified as the recruitment bottleneck.

A praxis-based model for cultural resource learning, preservation, and management

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ABSTRACT: The National Park Service has a long history of advancing the practice of cultural resource preservation and integrating that practice across disciplines to protect and preserve natural and cultural resources for the American public. Universities are uniquely situated in that they have disciplinary experts (i.e., faculty) and future professionals (i.e., students), both of whom require models and opportunities for 'learning by doing.' Cooperative Ecosystem Studies Units (CESUs) facilitate and provide a mechanism for such collaborative problem solving to explore current challenges, offer practical solutions, and train the next generation of professionals and leaders. Field-based learning is fundamental to developing critical thinking, of perceiving issues clearly, and generalizing from data. Recognizing the direct and inestimable importance of academic research and praxis-based training for conservation and cultural resource management, the University of Pennsylvania and the National Park Service entered into a collaborative partnership in 1991, to explore the mutual benefits of such a relationship specifically focused on cultural resources. Administering and managing cultural resources has become ever-more complex due to the amount of information needed about resources to understand, protect, and preserve them. Our recent CESU projects have been focused on acquiring baseline information on risks and threats to cultural resources, and developing integrated methods for science-based monitoring, modelling, and evaluation of conditions and interventions. With a huge backlog of deferred maintenance and a poor understanding of building and site

performance and deterioration, especially in the context of aging treatments, limited monitoring, and a changing environment, identifying vulnerability is now a priority concern. These are large and important issues without obvious near-term solutions. A selection of CESU projects in the Intermountain West will illustrate the evolution of the concepts, methods, and practices in the context of Vanishing Treasures parks and the challenges of developing strategic research agendas and applied best practices.

Earthen grouts for the adhesion of painted lime plaster at the mission church of San Jose de Tumacácori, Arizona

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ABSTRACT: The interior decorative painting at Mission San Jose de Tumacácori is a rare survival of late 18th century-early 19th century artistic traditions of northern Sonora and the Kino mission churches. Despite earlier attempts to stabilize these finishes, the original painted lime plaster has continued to detach from the adobe substrate. Previous techniques to stabilize the paintings began with research by J. Rutherford Gettens in 1949-1952 and subsequent attempts in 1984 to reattach detached plaster have proven ineffective. The current research evaluates soil-based injection grouting in order to adhere the loose plaster on the nave and sanctuary walls. Earthen grouts were chosen over the more commonly used hydraulic lime grouts in order to consider a more compatible system with the original construction materials. A well-designed earthen grout must be fluid enough to insure full penetration, exhibit low shrinkage and strong bond strength equal to its own cohesive strength for successful repair. Samples of the original adobe, mortar, and plaster were analyzed and local soils were sampled and tested in order to design a grout displaying optimal properties. The test grout was subjected to several geo-technical tests including injectability, viscosity, density, shrinkage, and expansion/bleeding; as well as its hardened properties such as splitting tensile strength, capillary water absorption, water retention and permeability. The selected grout's performance was finally analyzed within a mock-up assembly composed of friable plaster facsimiles and adobe, simulating 1/2" and 1/4" gaps. Half of the plaster facsimiles were consolidated with nanolime due to their friable nature based on recent parallel research. The research expands current knowledge on the use of earthen grouts for reattachment of earthen and lime plasters on earthen substrates.

Ground-truthing vulnerability: assessing earthen and masonry sites in the arid West

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ABSTRACT: The ruins of many archaeological parks in the American Southwest now face unprecedented challenges as increased cycles of extreme weather challenge prevailing practices of preservation and resource management. This research examines the realities of risk and vulnerability in the context of climate change and the challenge to create a framework for identifying and examining the critical factors of deterioration of adobe and rubble masonry ruins in the arid West. Risk and threat are examined in relation to site 'vulnerabilities' related to factors such as materials and construction, use, environment and weather, orientation and exposure, and past treatment and maintenance. The first phase of the project focused on preparing and analyzing a database inventory of past site records including historical photographs, construction documents, geotechnical and engineering analyses, administrative reports, and weather data as well as the past and current conservation and management strategies. The second phase examined individual vulnerabilities in depth through the creation of rapid assessment surveys or RAS's. Additional metric surveys quantified wall loss, attrition, and wall topography over time compared to original wall mass, surface and profile. Real-time recording of the weather on site was conducted over one year, including monitoring of walls using embedded temperature and moisture probes and time-lapse photography to test monitoring apparatus as well as to record actual weather phenomena and wall responses to those phenomena. Finally, parametric software was employed to dynamically model current and future weather and potential climate-based threats to the site as well as propose smarter responses to these threats in the form of preventive conservation measures.

Warming temperature effect of Megachilidae bee species along the San Francisco Peaks elevation gradient

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ABSTRACT: The San Francisco Peaks in northern Arizona is home to a wide diversity of plants and pollinators, with the elevation spanning from deserts all the way to alpine environments. Along the Peaks there are more than 400 bee species representing all five major bee families that occur in North America. Here we examined the effects of warming temperatures on a key family of bees, Megachilidae, along the San Francisco Peaks. We predict that most bees will successfully move up in elevation, except for habitats above tree-line, which may require over 200 years before nesting substrates become available. We set up nesting blocks along the C. Hart Merriam Elevation Gradient in Arizona, USA. We assessed temperature thresholds for the immature stages of the Megachilidae bees. We placed nest blocks at 4 life zones to accommodate all 57 wood nesting Megachilidae species. Colonized nesting blocks were transferred up one life zone (- temperature), down one life zone (+ temperature), or moved but kept at the originating life zone (no temperature change). Larval and pupal mortality rates were measured to assess viability of these species adapting to warmer or cooler temperatures. We found 2 main results: 1) Individuals that were moved down in elevation, to warmer temperatures, experienced 30% greater mortality at the larval stage than species that were moved up to colder temperatures or species that remained in their native habitat. 2) Mortality rates were species dependent, with *Osmia* having the highest mortality rates among all the Megachilidae genera measured. Consensus opinion is that climate change will open these colder-higher habitats up to bees but could also reduce habitat suitability for bees where they already occur along elevation gradients.

Large-scale forest restoration stabilizes carbon under climate change in Southwest U.S.

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ABSTRACT: Higher tree density, more fuels, and a warmer, drier climate have caused an increase in the frequency, size, and severity of wildfires in western U.S. forests. There is an urgent need to restore forests across the western U.S. To address this need, the U.S. Forest Service began the Four Forest Restoration Initiative (4FRI) to restore four national forests in Arizona. The objective of this study was to evaluate how restoration of ~400,000 ha under the 4FRI program and projected climate change would influence carbon dynamics and wildfire severity from 2010 to 2099. Specifically, we estimated forest carbon fluxes, carbon pools and wildfire severity under a moderate and fast 4FRI implementation schedule and compared those to status quo and no harvest scenarios using the LANDIS-II simulation model and climate change projections. We found that the fast-4FRI scenario showed early decreases in ecosystem carbon due to initial thinning/prescribed fire treatments, but total ecosystem carbon increased by 9 – 16% over no harvest by the end of the simulation. This increased carbon storage by 6.3 – 12.7 million metric tons, depending on the climate model, equating to removal of carbon emissions from 55,000 – 110,000 passenger vehicles per year until the end of the century. Nearly half of the additional carbon was stored in more stable soil pools. However, climate models with the largest predicted temperature increases showed declines by late century in ecosystem carbon despite restoration. Our study uses data from a real-world, large-scale restoration project and indicates that restoration is likely to stabilize carbon and the benefits are greater when the pace of restoration is faster.

We must either protect him or destroy him

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ABSTRACT: John Wesley Powell developed a unilinear evolutionary theory in the field of anthropology. It underpinned Powell's advocacy for assimilation of Native American tribes within the Colorado River Basin and elsewhere into mainstream U.S. society. While distinguishing Powell's assimilationist viewpoint from an "annihilationist" counterpart, the theory nonetheless outlined purported stages of savagery, barbarism, and civilization through which all human cultures were bound to evolve. One can guess where Native American and Euro-American cultures were respectively placed along this progression. In short, Powell believed that "he could save the lives of Indians by forcibly converting them into facsimiles of white people." Just as cultural anthropology would eclipse unilinear evolutionary theory, however, so too would tribal self-determination supplant assimilation in federal Indian policy. Moving further into the contemporary "Great Unknown," what actions should be taken to promote tribes' self-determination and to

surmount the diverse challenges they face within the Colorado River Basin? A host of ideas warrant consideration, all of which stem from a common premise: Native Americans are a permanent, not vanishing, part of the basin's fabric.

Connecting science and land management to enhance Southwest ecosystems – examples from the USGS Restoration Assessment and Monitoring Program for the Southwest (RAMPS)

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ABSTRACT: Public and private lands across the Colorado Plateau and Southwest region can be degraded by invasive species, catastrophic wildfire, and prolonged drought. Restoration actions work to reverse degradation to maintain productivity, habitat, and conservation of threatened and at-risk species. Restoration in water-limited ecosystems of the Southwest is challenging because of unreliable precipitation within and across seasons, disturbances that are growing in intensity and frequency, resource limitations, and a lack of information for scientifically-informed decision making. Managers and scientists can greatly benefit from collaborative, innovative, and dynamic approaches to transmit and receive information on effective and resource-efficient approaches to enhance land condition. Restoration is typically implemented at small spatial scales, but by expanding knowledge of strategies and outcomes at a cross-site level, RAMPS facilitates comparison of challenges and solutions across arid Southwest ecosystems. During this talk, we will share examples of how we are connecting science and management strategies to improve restoration outcomes. Examples include approaches to improve oil and gas reclamation on BLM lands, creation of the RestoreNet field trial network, support for the National Seed Strategy with training and demonstration gardens on the Navajo Nation, and mitigating drought impacts in southeast Utah national parks. Through these efforts, RAMPS is matching cutting-edge science with the most pressing land management problems.

The Escalante River Watershed Partnership: partnering with conservation corps to restore riparian ecosystems

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ABSTRACT: The Escalante River Watershed Partnership (ERWP) was created in June 2009, and is composed of federal and state agencies, local government representatives, non-profit organizations, businesses, and local landowners. This partnership's mission is "To restore and maintain the natural ecological conditions of the Escalante River and its watershed and involve local communities in promoting and implementing sustainable land and water use practices." The major reason for forming the ERWP was to control Russian olive and other woody invasive species that have overtaken the ecosystem and habitats in the watershed. Russian Olive is a highly invasive species that has moved rapidly into the Escalante River Watershed in the last 25-30 years. Infestations of Russian olive and the other invasive species that currently occupy the watershed have altered a number of components in the natural systems, including but not limited to food webs, nutrient cycling, fire regime and wildlife habitat. Reduction and control of these invasive species to minimal levels in the Escalante River watershed is critical to maintaining naturally-functioning riparian ecosystems. To restore this riparian ecosystem the partnership has deploy a number of tactics guided by science to meet its mission. One of these tactics has included using a cost effective workforce. Most of this work has been done by the combined effort of conservation corps crews. These crews are based in Utah, Colorado, New Mexico, and Arizona. Conservation Corps specialize in youth engagement and serving the needs of land management agencies. While serving a national term of service, conservation corps members gain professional skills related to land conservation, get hands on experience in a variety of disciplines in preparation for becoming the next generation of land stewards. By partnering with the conservation corps the ERWP has been able to engage thousands of youth and guide them in best practices on riparian habitat restoration and offered them a meaningful experience where they are making a difference.

A proposed interdisciplinary framework for assessing and managing landscapes with significant historical and natural values

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ABSTRACT: Cultural landscapes offer the National Park Service (NPS) a potential platform and opportunity for better and more integrated natural and cultural resource protection. As defined by the NPS, a cultural landscape is a place of human adaptation to a specific environment, with natural systems and features acting as the framework from which a specific place has evolved. While the cultural landscape method as currently applied by the NPS may result in sometimes nebulous, subjective, and binary outcomes, a closer look at the NPS method and origins, which focused not only on features but also processes, may give the NPS an opportunity to understand landscape systems and their evolving conditions better. Using the cultural landscape characteristics (the primary analytic tool of a cultural landscape study) as a comprehensive guide or set of thinking tools coupled with data and strategies from the Inventory and Monitoring Program (I&M), the Exotic Plant Management Team (EPMT), and Wildland Fire, the NPS is working with partners to create a framework for integrated resource assessment and management. Applied to specific cultural landscape case studies (PECO and FOUN), the framework results in a 'shared vision' between cultural and natural resources systems for each landscape. The shared vision is the result of robust qualitative and quantitative data application, finding areas of data interface, and creating well-defined wording and concept sharing (through a glossary, semantic crosswalks, and other operational definitions). The goal of this project is to reduce landscape management strategy and data redundancy, conflicting treatment goals, and to involve an interdisciplinary team in landscape management. Application of this work may also assist in our understanding of resource vulnerability and threats.

Cultural landscapes and technology – three case studies to enhance integrated resource protection, education, and interpretation

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ABSTRACT: While the cultural landscapes concept as defined by the NPS offers a multi-scalar method of understanding the evolution of both spatial and temporal systems in a specific place of historic importance, the NPS has struggled with full utilization and comprehension of the concept as a tool to better integrate resource protection/management goals (cultural and natural) and enhance visitor experience. Due to the complex systems that cultural landscapes attempt to study, this paper argues that use of advanced spatial technologies can enhance the way the NPS applies this concept to a specific landscape, including staff training and comprehension, resource documentation and analysis, integration of cultural and natural resources issues, and enhanced visitor experience and interpretation. Three case studies involving NPS CESU partnerships will be examined to better understand opportunities using enhanced technologies as applied to cultural landscapes. The case studies are: 1) Carlsbad Caverns National Park – LiDAR of the cave system for an underground cultural landscape study; 2) Bandelier National Monument – cultural landscapes visualization training film; and 3) Manhattan Project National Historical Park – Tech Area 18 3D site evolution model. Technologies discussed will be LiDAR – Leica Cyclone to AutoCAD, GIS to gaming software, and 3D modeling.

Wilderness rock climbing indicators and climbing management implications in the National Park Service

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ABSTRACT: This study addresses the need to characterize the health of the wilderness climbing resource—composed of biophysical and recreational resources as well as visitor experiences—as a part of wilderness character assessments in National Park Wilderness. This is accomplished through assessment of climbing use patterns and associated biophysical and administrative indicators. Research includes a critical review of The Wilderness Act, The Organic Act, National Park Service (NPS) 2006 Management Policies, NPS Director's Order #41: Wilderness Stewardship, and academic research on recreation in Wilderness. Grand Canyon and Joshua Tree National Parks serve as pilot study areas for wilderness climbing monitoring. Monitoring is designed to be repeated on a five-year cycle with wilderness character monitoring and will utilize similar frameworks. This research will estimate baseline information about climbing in parks and identifies climbing associated changes to the landscape, such as increased erosion, fixed anchors distribution, and loss of vegetation along travel routes (both cliff and trail). Land managers can utilize this research to make informed decisions about management actions because it will enhance understanding the effect of climbing activity on the wilderness landscape and the value of wilderness climbing activities to wilderness character. Baseline climbing condition assessments will be completed for pilot study parks and can be used in wilderness management decisions. This thesis will develop wilderness climbing indicators and a simple and adaptable monitoring program for application in park units and will propose standards for management decisions regarding climbing use in National Park Wilderness.

Floodplain restoration in the Middle Rio Grande

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ABSTRACT: Active channel modifications and decreased water availability have significantly reduced geomorphic complexity and floodplain inundation regularity and extent along much of Middle Rio Grande (MRG). These hydro-geomorphic changes have been a principal cause in the loss of native riparian, wetland, and aquatic habitats and associated fish and wildlife species. Rehabilitation efforts along the MRG are increasingly focused on expanding the availability of suitable spawning and breeding habitat for the federally endangered southwestern willow flycatcher (flycatcher; *Empidonax traillii extimus*) and Rio Grande silvery minnow (RGSM; *Hybognathus amarus*), plus the federally threatened yellow billed cuckoo (cuckoo; *Coccyzus americanus*). It is generally well accepted that RGSM nursery habitat attributes include inundated sites with low flow velocities and relatively warm, shallow water that provides food resources and safe zones for larvae. If dense woody vegetation colonizes these sites, they can also mature into desirable habitat conditions for the flycatcher and cuckoo. Since 2003, the MRGESCP has created or restored about 1600 ha of habitat under a water depletion-neutral framework that mechanically modifies banklines, islands, and historic floodplains to create new backwaters, channels, terraces, and swales designed to inundate at discharges of 500 cfs to 3500 cfs. More than 450 features ranging 0.1–8 ha in size have been constructed in the MRG as habitats designed to seasonally inundate and entrain eggs and larvae of RGSM in spring and to restore floodplain dynamics and native vegetation. Numerous challenges, both expected and unexpected, were faced prior to, during, and after project implementation. This presentation includes an overview of implementation techniques utilized during previous projects and a synopsis of challenges and lessons learned with recommendations for improving project success.

Responses of southwestern willow flycatchers to tamarisk defoliation

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ABSTRACT: Tamarisk leaf beetles (*Diorhabda* spp.), released in the western U.S. as biocontrol for tamarisk (*Tamarix* spp.), began defoliating breeding areas of the federally endangered southwestern willow flycatcher (*Empidonax traillii extimus*) in 2008 along the Virgin River around St. George, Utah. Beetles then expanded their range downstream, affecting multiple flycatcher breeding sites along the Virgin and Muddy Rivers in subsequent years and arriving at additional breeding sites along the Lower Colorado and Bill Williams Rivers in 2017. Flycatchers consistently had poor reproductive success when they attempted to nest in stands with a significant component of defoliated tamarisk. Breeding sites varied in the prevalence of tamarisk, the timing and duration of defoliation, and the degree of subsequent tamarisk mortality, and the trajectories of the local flycatcher populations varied in accordance with the amount and quality of the remaining habitat. Tamarisk beetles are continuing to expand farther into the flycatcher's breeding range and are expected to arrive at several large flycatcher sites, some of which consist primarily of monotypic tamarisk, in the next few years. Active restoration of native riparian woodlands in watersheds where flycatchers currently nest primarily in tamarisk is urgently needed to provide flycatchers with alternate nesting sites. Although flycatchers are selective in choosing breeding sites, showing an affinity for areas with dense vegetation in proximity to surface water, sites do not need to be large to support breeding flycatchers. Flycatchers have persisted for several years in small (<0.5 ha) patches of native vegetation within large expanses of defoliated and dead tamarisk. Careful selection of restoration sites and implementation of restoration in advance of or immediately following the arrival of beetles may provide the best chance for flycatcher populations to persist post-beetle in areas where breeding sites are dominated by tamarisk.

Spring diets of antelope and black-tailed jackrabbits

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ABSTRACT: Jackrabbits are a key prey species in the Southwest; many populations of mammals and birds rely on jackrabbits as a food source. Over the past 50 years, populations of black-tailed jackrabbits (*Lepus californicus*) have declined, whereas the sympatric antelope jackrabbit (*Lepus alleni*) has remained abundant. The reason for this is unknown. One hypothesis to explain the dissimilarity is that competition for limited forage resources is negatively impacting black-tailed populations. Based on preliminary studies, we

hypothesized that antelope jackrabbit diets consisted of more exotic, and potentially more abundant, plants than black-tailed jackrabbit diets. To investigate this, we characterized the spring diets of the jackrabbits by identifying the plants found in the scat of both species using Next Generation Sequencing. We sequenced the plant DNA found in scat samples, and matched those sequences to a database of sequences of plant species suspected to be consumed by jackrabbits. Our results show that the spring diets of the two jackrabbit species differ. The antelope jackrabbit consumes a higher diversity of plants, but both species' first and second most frequently consumed plants (*Populus* and *Cynodon dactylon*, respectively) are the same. Notably, we found that the majority of sequences for both jackrabbit species match nonnative plants, a finding that contrasts with previous studies. Given that both jackrabbit species consume native as well as exotic plants, the hypothesis that limited forage drives the differential decline is not supported by this analysis. Other factors, such as habitat loss, might explain the decline in black-tailed jackrabbits. This study provides a foundation for further studies to explore differences in the diets of jackrabbits in response to season or exotic plants.

A case study of the application of an interdisciplinary approach to managing complex landscapes

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ABSTRACT: Fort Union National Monument (FOUN) provides an ideal setting for recent efforts by McGilvray and others to create an interdisciplinary framework for managing landscapes with significant historical and natural values. Fort Union is a small park (approximately 720 acres) with significant cultural resources such as the fort remnants, Old Santa Fe Trail, and "traditional" cultural landscapes all in the natural setting of short grass prairie. The framework seeks to bridge the art of cultural landscapes with the science of natural resource assessments by using landscape characteristics from Cultural Landscapes as a universal thinking tool. The landscape characteristics can serve as a lens through which to assess features and determine the attributes of those features that give rise to its character-defining qualities and provides a point of focus for assessing condition and management. An integrated approach to assessment and management will make resource stewardship stronger. A sample feature assessment is presented using the Old Santa Fe Trail Ruts at FOUN to illustrate the use of qualitative natural resource data in the landscape characteristic process. The ability to utilize robust, park specific data creates the opportunity to guide management strategies, treatment options, and desired future condition. The use of quality data may also assist in our understanding of resource threats and vulnerability.

Desert fire: assessing vegetation recovery using fire chronosequences from five deserts of the southwestern United States

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ABSTRACT: Concern about wildfires across the southwestern United States has increased over the past half century and with predictions of more recurrent intense droughts and elevated temperature, risk of larger and more frequent wildfires is also increasing. We know wildfires can have dramatic, lasting effects on the landscape, however, our understanding of those ecological effects is less well developed in drylands than many other systems. In turn, this limited understanding provides challenges for land managers attempting to effectively manage landscapes experiencing changes in fire regime. There is a need for research focusing on the differences in fire recovery times and state changes of ecosystems following wildfire. Here, we describe the results of a study which looked at fire chronosequences, or time-since-fire, (containing a ~15-year old fire, ~30-year old fire, and an unburned control) in five deserts of the southwestern United States (Colorado Plateau, Great Basin, Sonoran, Chihuahuan, and Mojave) with replicate plots in individual deserts and associated time-since-fire year, or unburned control locations. Within each plot a vegetation survey was completed using the Bureau of Land Management's Assessment Inventory and Monitoring (AIM) methods of line-point intercept, gap intercept, and species inventory, as well as a survey examining canopy and ground cover. The findings from this study show dramatic differences in vegetation dynamics within each desert after fire, including near complete removal of sagebrush (*Artemisia spp.*) cover and subsequent invasion of exotic plants within the Great Basin, long lasting reductions to blackbrush (*Coleogyne ramosissima*) cover within the Mojave, and more subtle changes of species composition within the Chihuahuan Desert. These results highlight that fire does not act equally across dryland ecosystems and further emphasizes the need for continued improvement of our understanding of how fire affects the U.S. Southwest, including evaluation of where and how to prioritize fire management efforts.

Hydropower dams and urbanization in the Brazilian Amazon – a regional analysis

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ABSTRACT: Urbanization in the Brazilian Amazon has intensified in recent decades, with urban population rates surpassing 70% and over 400 new municipalities created in the past 40 years. While acknowledging that urbanization has numerous drivers, this work analyzes the impact of hydropower on population growth in Amazonian municipalities. The region's abundant hydropower generation potential along with public policies oriented towards regional integration and energy generation are bringing about significant change as hundreds of new dams are planned and constructed. This work seeks to understand the diversity and spatial organization of urbanization drivers across the region with a particular focus on the role of hydropower development in spurring urban growth relative to other drivers. To do so, I used spatial socioeconomic and hydropower development data from 1980 to 2010 to assess similarities and differences in the urbanization process across all Amazonian municipalities. Results showed that urbanization was higher in regions closer to hydropower development. A division of the Amazon into quadrants also allowed me to detect a spatial concentration of higher correlations in the southwestern Amazon. Although urbanization is a widespread process across the Amazon, it is happening at different intensities in different regions and is manifesting as a function of multiple drivers, including investments in hydropower systems. This work contributes to our understanding of the heterogenous urbanization process that is reshaping the Amazon and provides an updated assessment of this globally important and dynamically evolving social-environmental system.

Do biocrusts influence arid-land plant community assembly?

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ABSTRACT: Biocrusts are photoautotrophic soil surface communities consisting of cyanobacteria, algae, moss, lichens, fungi, and bacteria. Biocrusts influence vascular plant species performance by modifying soil stability, hydrology, and fertility. Multiple studies suggest that biocrusts have species-specific effects on plant species performance depending on plant characteristics and ecological context. Therefore, by promoting the performance of some plant species, but inhibiting others, biocrusts may influence vascular plant community structure. In this study, we are investigating the effects of biocrusts on plant community assembly using a greenhouse experiment. Specifically, we are comparing emergence and establishment of C_3 and C_4 perennial grasses and annual and perennial forbs grown in biocrust inoculated versus bare soil mesocosms. We hypothesize that the moderate-water treatment plots containing biocrust will support a greater level of community assembly with a mixture of forbs and grasses due to the added modifications to the soil hydrology and fertility of the plots. Additionally, we hypothesize that the biocrust inoculated plots will support greater recruitment and increased survival. A seed mix containing all five plant species will be sown into 32 mesocosms containing full factorial crosses of two soil treatments (biocrust inoculated versus bare soil) and two watering treatments (moderate-water versus low-water). To accept or refute our hypothesis, the following parameters will be tested: germination (%), growth, root to shoot ratio, soil nitrogen (N) content, soil moisture content over the period of the experiment and ending mesocosm community composition. All analyses will be completed by August 2019. Biocrusts may be more important to community assembly in desert ecosystems than we yet know. Biocrusts may decline by 40% within several decades from now, a situation that could drastically alter arid landscape's structure and biodiversity. Understanding biotic interactions such as these will determine if biocrust inoculum can be used to increase restoration success.

Gene flow among net-spinning caddisfly population in the Colorado River Basin

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ABSTRACT: Gene flow among populations is constrained by dispersal ability, habitat connectivity, and time. For aquatic organisms that disperse along stream corridors, habitat connectivity of a river network can thus define the boundaries of gene flow. In this study, we investigated the genetic diversity of a strong-dispersing caddisfly, *Hydropsyche oslari*, using mtDNA (CO1 gene) in the topologically diverse Colorado River Basin. We expected to find less genetic distance among *H. oslari* within the Upper Basin, which has a dense dendritic network of perennial tributaries, than among populations within the arid and sparse river network of Grand Canyon in the Lower Basin. The two basins are divided by Lake Powell, a >300 km long reservoir on the Arizona-Utah border in the

southwestern United States. Consistent with predictions, we found that *H. oslari* within the Upper Basin shared more genetic similarities than *H. oslari* within Grand Canyon. Additionally, we found that populations in the Upper Basin and Grand Canyon were entirely genetically differentiated, indicating that these two populations were isolated thousands of years before the 1963 closure of Glen Canyon Dam and subsequent filling of Lake Powell. We discuss the interactions of network topology and environmental conditions in determining population genetics of this common and important indicator species.

Analysis of change in woodland canopy cover on the San Carlos Apache Reservation, Arizona (1935 vs. 2017)

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ABSTRACT: Since the late 1800's, pinyon-juniper woodland across the West has increased in areal extent and density and encroached into former grassland areas. Reasons for this expansion and infilling include decreases in fire frequency, historical livestock overgrazing, and climate conditions. Woodlands containing varying mixtures of juniper (*Juniperus* spp.), pinyon (*Pinus* spp.) and evergreen oak (*Quercus* spp.) cover a significant portion of the San Carlos Apache Reservation and are important culturally to the Tribe. To provide the Tribe with information on historical and current woodland canopy cover, we developed new image analysis techniques to document change in the tree and large shrub cover over an 82-year interval using 1935 and 2017 aerial imagery. The digital scans of the panchromatic 1935 photography pose challenges in processing and analysis due to their lack of geometric information and metadata, poor dynamic range, shadowing, topographic shading, coarse spatial resolution, and geographic mis-registration. Four spectral bands in the high-quality 2017 digital imagery helped make delineating tree canopies and quantifying the percent cover of woodlands more successful than with the 1935 data. We generalized the higher spatial resolution 2017 data to the resolution of the 1935 data (0.60 to 2.70 m) to gain information on the effects of the resolution difference on canopy cover estimates but found little overall effect. Our results show a substantial increase in the canopy cover of the woodlands, with encroachment (mostly juniper) into former grasslands. For example, percent cover estimates increase from 18.3% to 38.5% in the Bee Flat study area, and 28.3% to 43.3% at Bloody Basin. The Tribe is currently engaged in converting higher density juniper woodland into an open savanna more characteristic of pre-reservation conditions. This analysis provides evidence that the Tribe's active management efforts on a portion of Bee Flat has resulted in canopy cover roughly analogous to 1935.

Mechanisms of *Ranavirus* transmission and its impacts on amphibian and reptile conservation

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ABSTRACT: Mathematical disease models are valuable tools for identifying the mechanisms of divergent epidemic trends. In the amphibian-*Ranavirus* system, after four months of transmission, we see 100% prevalence of frog virus 3 (FV3) in larval wood frog populations of the northeastern USA. In stark contrast, data from several populations of larval tiger salamanders in the southwestern USA show that the related *Ambystoma tigrinum* virus (ATV) burns out after three months, with peak prevalence below 60%. We hypothesize that these divergent patterns are linked to: (1) differences in transmission and kill rates, (2) variable host susceptibility, and (3) the effects of seasonally fluctuating water temperature on viral shedding rate. We construct disease models that represent our competing hypotheses, we estimate model parameters from published data, and we compare the fits of our models to the epizootic data. This routine allows us to identify the mechanisms that most strongly influence these ranaviral epizootics. Model comparisons reveal that the divergent epizootic patterns are driven by substantial differences in transmission rates and kill rates of the two viruses. In addition, wood frog populations are more consistently susceptible to FV3, while tiger salamander populations have high variability in susceptibility. This higher heterogeneity drives lower cumulative infection rates in the ATV system. Although we detect a putative effect of temperature on viral shedding rate in experimental data, we could not detect this effect in the epizootic data. Our analysis identifies key areas of future research and demonstrates how mathematical models can evaluate environmental drivers of disease.

Which environmental variables should one use to select sites for species representation?

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ABSTRACT: One goal of systematic conservation planning is to identify sites for protection that represent the largest number of species in relatively few sites. Environmental data, specifically topographic and soil variables, may be useful for this goal because they are slow-changing, easy to acquire remotely, and can act as a coarse filter strategy for biodiversity conservation. However, areas

selected to maximize environmental diversity can fail to represent species if they are selected based on non-relevant variables, and outcomes can be hard to interpret if included variables are superfluous. We compared two methods of variable selection (a k-means clustering-based filter approach and a random forest recursive feature elimination wrapper approach) that selected environmental variables that are most relevant to beta diversity and least redundant. We applied both methods to 32 biodiversity inventory data sets using 78 environmental variables. We compared the variables selected by the two procedures and identified which selected set better predicted species turnover using generalized dissimilarity modeling. The two procedures selected broadly overlapping sets of variables, but for most data sets covariates selected by recursive feature elimination produced better predictive models, while the k-means clustering approach selected sets with fewer variables. We make recommendations for how both procedures should be considered when selecting informative environmental variables for conservation planning.

Persistence of *Pinus edulis*-associated ectomycorrhizal fungi in New Mexico

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ABSTRACT: Populations of *Pinus edulis* are declining with ongoing climate change. Previous studies have demonstrated the importance of *P. edulis*-associated ectomycorrhizal fungi (EMF) for seedling establishment and resistance to drought. There have been few studies that have examined the persistence of EMF in the absence of a plant host, yet the persistence of these fungi may be paramount to the resilience of *P. edulis* and other mycorrhizal plant species. Seven sites were selected in northwestern New Mexico with known dates of *P. edulis* extirpation and a lack of regeneration. Age classes included: two sites extirpated 10-15 years ago, two extirpated 55-65 years ago, two extirpated 500+ years ago, and one extirpated 11,000+ years ago. At each site, two plots were paired: an extirpated plot and the nearest live adult *P. edulis* stand. Soil samples were collected from each plot at 0-5 cm and 20-25 cm depths from four locations. *Pinus edulis* seedlings were inoculated with field soils to measure inoculum potential of EMF. It is hypothesized that inoculum potential will decrease exponentially with time since extirpation. Additionally, it is predicted that seedlings with higher colonization by EMF will have significantly greater shoot biomass and higher EMF diversity. Ectomycorrhizal fungal diversity and abundance will likely be significantly greater at the 20-25 cm depth. The shallower depth from 0-5 cm will have a lower abundance and diversity because of erosion, deposition, and exposure to variable temperatures. The results of this study will help guide restoration efforts for *P. edulis* and other EMF tree species.

Soil microbial responses to altered precipitation regimes across a southwestern United States elevation gradient

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ABSTRACT: Microbes play an important role in soil carbon (C) cycling. Future microbial activity patterns may be affected by climate, given predictions for warmer temperatures and altered precipitation regimes in the next century. Little is known about the short- versus long-term soil microbial community responses to altered precipitation in dryland systems. Soil organic carbon (SOC) is a critical component of the global C cycle, accounting for several times more C than plant or atmospheric pools. Assessing microbial biomass and C respiration rates under current and potential future precipitation patterns will help understand how SOC pools might change with climate change. We investigated how soil microbial communities are influenced by changes to both long- and short-term precipitation patterns across a 1000 m elevation gradient in northern Arizona, where precipitation increases with elevation. We manipulated precipitation (50% addition and 50% exclusion of ambient rainfall) at five sites across the gradient. We extracted microbial biomass carbon (MBC) from soil and used a portable gas exchange system to measure soil CO_2 flux at each site. MBC and respiration rates were greatest at the three highest elevation sites and lowest at the two lowest elevation sites. Within sites, precipitation treatments did not change MBC, but respiration rates differed among the precipitation treatments at the lowest elevation site with higher respiration rates in the precipitation addition plots. Our results suggest that soil C cycling in drier systems may be more sensitive to short-term precipitation change than wetter systems.

One hundred years of range research in northern Arizona's ponderosa pine-bunchgrass ecosystems

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ABSTRACT: The American Southwest has a long history of range resource abuse, management and research. Range damage during the late 1800s from livestock overstocking on public lands is well documented, and led to the establishment of research experiments on the oldest US Forest Service experimental stations (Jornada, Santa Rita, Sierra Ancha, and Fort Valley), which are some of the earliest and longest running ecological studies in the United States. The objectives of the original range studies at Fort Valley Experimental Forest (FVEF) were to isolate the agents responsible for range deterioration and aid in the grazing management of the ponderosa pine (*Pinus ponderosa*)-bunchgrass ecosystems of the Southwest. Here, we profile two of these experiments at FVEF in northern Arizona. The Hill plots were established in 1912 by Robert R. Hill, a Grazing Examiner on Coconino National Forest. To isolate livestock grazing impacts, Hill and others built ~0.7 ha livestock exclosures at five sites along livestock runways spanning a range of soil types and elevations. Vegetation was measured inside and outside the exclosures using permanently marked 1-m^2 chart quadrats. A second study, the Wild Bill plots (aka Cooperrider-Cassidy study) were established in 1927 using exlosures and chart quadrats spread across ~12,000 ha northwest of Flagstaff, Arizona. Chart quadrats provide a means to quantify herbaceous vegetation cover and composition over time. The individual plants on each quadrat were identified and mapped periodically between 1912 and 1940s, then abandoned. We relocated most of the original quadrats in 2002 and, copying the original methods, remapped the vegetation annually from 2002-2018. These temporal and spatial data provide unique opportunities to examine the effects of climate and land-use variables on plant traits, demography, population, and community processes. We illustrate some of the insights provided by these long-term studies and discuss implications for ponderosa pine-bunchgrass restoration and management.

Partnerships for monarch research in remote southwestern locations

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ABSTRACT: The iconic monarch butterfly population is declining across North America and particularly so in the West. The vast magnitude of challenging and isolated terrain in the Colorado Plateau and Southwestern States presents a challenge for data collection of the utilization of breeding habitats and migratory corridors of *Danaus plexippus*, the monarch butterfly, in the region. Forging a partnership with NGO's, citizen scientists and state, county and federal government agencies offers a team response solution. The Southwest Monarch Study is researching the breeding habitats and tagging monarchs at Grand Canyon National Park South Rim, North Rim and throughout the Colorado River corridor. Partnering with the National Park Service in 2017, we jointly offered monarch biology education and monitoring training for river guides leading expeditions along both the Green River through Dinosaur National Monument and the Colorado River through Grand Canyon National Park. In summer, we offered similar educational opportunities including tagging monarchs to monitor their migration destination at Dinosaur National Monument and the nearby Vernal City Library. During the winter season managers of nearby public lands formed a coalition to further pollinator and monarch awareness in the region including a family passport program through the library. In 2018 in Utah, the Southwest Monarch Study partnered with Dinosaur National Monument, Ouray National Wildlife Refuge, Bureau of Land Management, and Utah Division of Wildlife to offer monarch monitoring and tagging education for public land managers. After training Ouray interns to identify monarch habitat, the interns led managers into the field to tag and monitor monarchs in the area. Managers and staff then held a public tagging event at Dinosaur National Monument the following morning. This multi-year effort resulted in a new understanding of monarchs through the Grand Canyon through Dinosaur National Monument corridor.

Arthropod communities in restoration of slash pile burn scars

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ABSTRACT: Forest insects serve a number of critical ecological functions, such as seed dispersal, soil nutrient cycling, control of invasive plants, and pollination. Previous invertebrate exclusion experiments in healthy, unburned systems indicate that insects influence plant dispersal and post-wildfire soil composition, which is vital for recovering forest ecosystem functions after large-scale thinning projects. Hundreds of burn piles occur throughout ponderosa pine forests in the Southwest, and thousands more are scheduled with the prescribed increase in thinning activity. These burn piles affect both plant and invertebrate biodiversity and are avenues for invasion by exotic species. We hypothesize that the diverse ecological roles of native insects may enhance recovery of these small, severely burned pile sites and enhance overall forest health through small habitat patch restoration. We are using recently-burned pile scars as experimental units for observation, monitoring and manipulation. To better understand how fire has affected insect biodiversity and the role that insects play in habitat restoration, we have installed standard landscape edging on each pile scar and a

matched control plot nearby to exclude walking insects such as ants and ground beetles. Over the past year, we have monitored insects using pitfall traps, recorded vegetation, and collected soil samples. These initial data will allow us to determine the most common insect guilds returning to experimentally burned plots as compared to the community on unburned plots. This will allow us to determine if there is a significant shift in the arthropod community and biodiversity after small-scale high-intensity fire, and how it continues to change over time.

Birds species composition in riparian habitat invaded by Russian olive

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ABSTRACT: The establishment and naturalization of non-native Russian olive (*Elaeagnus angustifolia*) in southwestern US riparian habitats is hypothesized to have negative implications for native flora and fauna. Despite the potential for Russian olive establishment in new riparian habitats, much of its ecology remains unclear. Arid river systems are important stopover sites and breeding grounds for birds, including some endangered species, and understanding how birds use Russian olive habitats has important implications for effective non-native species management. We compared native bird use of sites that varied in the amount of Russian olive and mixed native/non-native vegetation along the San Juan River, UT, USA. From presence/absence surveys conducted in 2016 during the breeding season, we found 1) fewer bird species and functional groups used Russian olive habitats and 2) the composition of species within Russian olive habitats was different from the composition of species in mixed native/non-native habitats. Our results suggest Russian olive may support different bird compositions during the breeding season and as Russian olive continues to naturalize, bird communities may change. Finally, we highlight the paucity of research surrounding Russian olive ecology and stress the need for rigorous studies to improve our understanding of Russian olive ecology.

Modeling the infection dynamics of tick-borne relapsing fever in a community of wild hosts

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ABSTRACT: Tick-borne relapsing fever (TBRF) is a debilitating zoonotic disease that is thought to be endemic in high-elevation forest within the Colorado Plateau and much of the western United States, yet the true dynamics of infections in the environment are poorly understood. Ecological niche models predict that climate change will increase habitat suitability for the pathogenic spirochetes and their tick vectors and potentially increase risk to humans in some areas. Compartmentalized Susceptible-Infectious-Recovered (SIR) models can be helpful in predicting disease dynamics, but they are challenging with TBRF because of its complexity which includes but is not limited to, relapsing infections, host heterogeneity, and vector-obligate transmission. We built upon previous models for TBRF to develop a more comprehensive theoretical framework for the force of infection through a community of wildlife hosts. We then incorporated laboratory and field-collected data into various models to test our ability to explain and predict transmission dynamics. Our research will help inform the public and health officials about this disease that may emerge as a greater concern throughout the western United States.

Active scientific integrity: beyond process and products

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ABSTRACT: The topic of scientific integrity typically focuses on the execution of and adherence to the scientific process, data stewardship, inference scope and strength, and how one outwardly represents one's work. Today, factual information and traditional sources of knowledge have diminished standing in society. Fact is confused with belief, and weight of evidence is often cast aside in favor of "gut feeling." Scientists must prepare to actively engage as civil actors supporting and promoting the scientific process, and doing so will be aided by thinking of contemporary scientific integrity as more than process and products, but as also including engagement of scientists in public discussions of all kinds. External obstacles (those that reside within our audiences) abound, yet I also consider internal obstacles (those that science professionals self-impose, often subconsciously). We, as science professionals, are well prepared for this challenge if we capitalize on three particular skills and processes that we already have: (1) *Do Our Thing* –

emphasize public presentation of the behaviors and thinking that make us scientists; (2) *Network Out* – look for conversations and debates to proactively join, rather than focusing on contacts that may pay immediate dividends; and (3) *Have the conversations that seem small, but aren't* – look for teachable moments outside our comfortable and usual social circles.

Climate drivers of increasing wildfire in the southwestern US from 1984 to 2015

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ABSTRACT: Over the last 30 years in forest and woodland ecosystems of the southwestern United States, wildfire size and severity have increased, thereby increasing the vulnerability of these systems. A combination of land use history and climate change are widely thought to be contributing to the changing fire regimes. We examined climate-fire relationships in forest and woodland ecosystems from 1984 – 2015 in Arizona and New Mexico using 1) an expanded satellite-derived burn severity dataset that incorporates over one million additional burned hectares when compared to MTBS data, and 2) climate variables including temperature, precipitation, and vapor pressure deficit (VPD). Regional climate-fire relationships were assessed by correlating annual area burned, area burned at high and low severity, and percent high severity with fire season (May-August) and water year (October-September) climate variables. We also analyzed relationships between climate and high-severity fire at the scale of the individual fire using a hurdle model. We found that increasing temperature and VPD and decreasing precipitation were associated with increasing area burned, and that area burned at high severity had the strongest climate relationships. VPD-fire correlations were consistently as strong as, or stronger than, temperature or precipitation variables alone, both regionally and at the scale of the individual fire. Notably, at the scale of the individual fire, temperature and precipitation were not able to significantly predict fire activity. Thus, our results support the use of VPD as a more comprehensive climate metric to forecast future fire activity, and using this relationship between VPD and fire activity, we can assess the likelihood of high severity fire occurrence. The link between increasing aridity and increasing wildfire suggests a future with more fire in Southwest forests and woodlands with projected warming, which emphasizes the urgency of restoration in dry forests to reduce the likelihood of uncharacteristic, large high-severity fires.

Plant materials development for effective restoration of native plant communities

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ABSTRACT: New Mexico supports a remarkable array of native plant species. Diverse landscapes and an elevation range of over 10,000 feet give rise to the fourth highest floristic diversity in the country. The New Mexico Bureau of Land Management (BLM-NM) manages over 13 million acres of land and has a robust Plant Conservation Program. One important component of plant conservation on BLM public lands is native plant materials development. The process of developing reliable, native plant materials for eventual use in restoration projects is collecting wildland, native seed. In 2015, the BLM-NM joined the Southwest Seed Partnership (SWSP) in collaboration with the Institute for Applied Ecology (IAE) and other stakeholders to improve the supply and diversity of native plant materials in the Southwest. The SWSP develops target species lists and collects wildland seed throughout the 8 ecoregions of New Mexico. Before seed can be effectively used in restoration, the seed goes through evaluation and development in order to research the biology of the species, seed transfer zones, and the most effective way to produce the seed. SWSP then works with farmers to increase the native seed stock in seed production fields. Seed that comes off of production fields will be made available for restoration projects. This poster will discuss impetus and impacts of the BLM's Native Plant Materials Development Program in New Mexico.

Long-term rangeland monitoring reveals grazing and climate effects vary by ecological site

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ABSTRACT: Managers of rangeland ecosystems require methods to track the condition of natural resources over large areas and long periods of time as they confront climate change and land use intensification. We demonstrate how rangeland monitoring results can be synthesized using ecological site concepts to understand how climate, site factors, and management actions affect long-term vegetation dynamics across landscapes. Forty-six years of rangeland monitoring conducted by the Bureau of Land Management on the Colorado Plateau reveals variable responses of plant species cover to cool-season precipitation, land type (ecological site groups), and grazing intensity. Dominant C_3 perennial grasses (*Achnatherum hymenoides*, *Hesperostipa comata*), which are essential to support wildlife and livestock on the Colorado Plateau, had responses to cool-season precipitation that were at least twice as large as the dominant C_4 perennial grass (*Pleuraphis jamesii*) and woody vegetation. However, these C_3 perennial grass responses to precipitation were reduced by nearly one-third on grassland ecological sites with fine- rather than coarse-textured soils, and there were no detectable C_3 perennial grass responses to precipitation on ecological sites dominated by a dense-growing shrub, *Coleogyne ramosissima*. Heavy grazing intensity further reduced the responses of C_3 perennial grasses to cool-season precipitation on ecological sites with coarse-textured soils and surprisingly reduced the responses of shrubs as well. By using ecological site groups to assess rangeland condition, we were able to improve our understanding of the long-term relationships between vegetation change and climate, land use, and site characteristics, which has important implications for developing monitoring strategies.

Updates on the Restoration Assessment and Monitoring Program for the Southwest

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ABSTRACT: Recovery from drought, wildfire, invasion by non-native species, and other disturbances represents a substantial challenge to Department of Interior and other agencies that manage large tracts of land in the water-limited southwestern U.S. The Restoration Assessment and Monitoring Program for the Southwest (RAMPS) strengthens restoration and rehabilitation outcomes by providing stakeholder engagement, science, and decision-support on effective strategies. As a growing collaborative effort of over 40 federal and state agencies, tribes, universities, and private organizations, RAMPS provides a hub of information and tools to serve land manager needs. RAMPS conducts syntheses of historical restoration treatment outcomes across the Southwest to provide new insight on strategies to accelerate ecosystem recovery. RAMPS builds new tools to identify appropriate native seed mixes for current and future climate conditions. RAMPS hosts RestoreNet, a field trial network that allows land managers to experimentally test new methods to accelerate plant establishment and soil stability across broad environmental gradients. RAMPS will continue to prepare information briefs and guidance materials, organize workshops, trainings, and field trips, and help facilitate land manager-scientist communication to identify critical ecosystem recovery needs and develop innovative strategies to improve restoration practices.

Creating and managing land cover types in a highly managed river system in support of the Lower Colorado River Multi-Species Conservation Program

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ABSTRACT: A major component of the Lower Colorado River Multi-Species Conservation Program (LCR MSCP) is the establishment and management of four specific land cover types; (1) 5,940 acres of cottonwood-willow, (2) 1,320 acres of honey mesquite, (3) 512 acres of marsh, and (4) 360 acres of backwater. For terrestrial and marsh land cover types, trees, shrubs, marsh plants, and ground cover are typically planted or seeded to create the desired land cover. Once established, the land cover types are managed for multiple species and mature into habitat over time. For backwaters, which includes open water and associated emergent marsh, portions of the floodplain are excavated and/or dredged to a target depth in accordance with an engineered design. Backwater habitat is defined by the evaluation of the physical, chemical, and biological conditions suitable for the establishment and maintenance of healthy populations of native fish and can either be connected or disconnected to the main river channel. Management of these land cover types in a highly altered and regulated river system poses both challenges and opportunities. Understanding how the river system currently functions is essential to creating and sustaining these habitats. Since 2006, over 6,000 acres of land cover types have been created on 18 conservation areas, stretching 276 river miles from Davis Dam to the International Boundary with Mexico. These conservation areas individually range in size from 30 acres to 2,150 acres and are located within Arizona, California, and Nevada.

Climate and bark beetle-caused mortality in the Coconino National Forest over the past 15 years

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ABSTRACT: From 2001 to 2004, Arizona experienced a widespread drought that caused extensive ponderosa pine (*Pinus ponderosa* Dougl. ex Laws.) mortality associated with increased bark beetle (Coleoptera: Curculionidae, Scolytinae) activity. Tree mortality resulted in significant reductions in basal area, tree density, stand density index, and mean tree diameter for ponderosa pine and for all species combined in the Coconino National Forest. Most of the observed pine mortality was in the 10–35 cm diameter class, which comprise much of the increase in tree density over the past century as a result of fire suppression and grazing practices. During the summer of 2019, we reexamined the plots in the Coconino and recorded stand conditions and physiographic factors associated tree mortality. We present results of our sampling and discuss trends in tree mortality and potential causes of climate warming and bark beetle activity over the last 15 years.

Characterizing evapotranspiration dynamics in the riparian zone of the Colorado River Delta to evaluate ecosystem changes in response to the Minute 319 environmental pulse flow to Mexico

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During the spring of 2014, about 105,000 acre-feet (130 million cubic meters) of water were released from the Morelos Dam in the United States into the delta of the lower Colorado River in Mexico, allowing water to reach not only the Colorado River's delta but also the Gulf of California for the first time in 13 years. Our study assessed the effects of ecological environmental flows from one nation to another, using remote sensing. Remote sensing is used for water resource evaluation in vast and often inaccessible areas because these approaches can provide answers for binational, integrated water resources management and help to inform planning for the Colorado River, which includes seven states in the U.S. plus two states in Mexico. Our study examined the effects of the 2014 historic binational experiment (the Minute 319 agreement of a water treaty between the U.S. and Mexico) on vegetative response along the riparian corridor. We used two satellite-based instruments, the 250 m Moderate Resolution Imaging Spectroradiometer (MODIS) and 30 m Landsat 8 OLI satellite imagery to track evapotranspiration (loss of water through evaporation from the soil and through plant transpiration; ET), and several vegetation indices to estimate the greenness of vegetation (e.g., NDVI, scaled NDVI, EVI, EVI2). Our time-series analysis from 2000-2018 showed an overall increase in VIs (higher greenness) and ET (more water loss) in the year of the 2014 pulse and following the 2014 pulse in 2015. The higher VI and ET indicate that there was enough water in the riparian zone to generate a positive response from plants, and these results reversed a decline in VI and ET since the last major flood in 2000, but the effect did not last after the first couple of years. The Minute 319 Pulse Flow produced a 17% increase in VI ("greenness") as detected with Landsat throughout the riparian corridor in 2014. The significant greening up was observed across reaches within the riparian zone, as well as in the non-inundated outer parts of the riparian floodplain, where groundwater supported existing vegetation. However, after just two years (by the end of 2016) there was a 22% decrease in VI throughout the riparian corridor (by the end of 2016). In 2017, an overall increase of 2% in greenness was calculated, before falling again, by 8%, in 2018. From 2015-2018, the initial post-pulse greenup and ET using both Landsat (30m) & MODIS (250m) steadily declined, falling below pre-pulse levels in all reaches. The VI and annual phenology signal becomes bimodal and disintegrates after 2016 in all reaches except for in Reach 4, the restoration zone. Our results support the conclusion that these environmental flows from the U.S. to Mexico via the Minute 319 "pulse" had a positive, but short-lived (one year), impact on vegetation growth in the delta.

Field scale soil and ecological maps for adaptive land management

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ABSTRACT: Soil is a fundamental resource governing ecosystem responses to drivers of change via regulation of water storage, nutrient availability, and soil chemical constraints. Maps that predict variation of basic soil properties that control higher-level functions, such as soil texture, salinity, pH, depth to bedrock, among others, can streamline resource planning and adaptive land management strategies. Although conventional soil maps, like the soil survey geographic (SSURGO) database, provide these parameters and ecological behavior groupings [i.e., ecological site descriptions (ESDs)], they are not derived with a validated

statistical method, and are generally mapped at a scale not suitable for providing estimates of soil properties at a field scale. For example, oil and gas well pads are generally 1 to 4 acres in size, and conventional soil survey polygons seldom can distinguish that level of spatial detail. To address this need in the Upper Colorado River Basin, we have created new digital soil maps of 18 soil properties and ESD groups to address pressing land management issues including: 1) reclamation of oil and gas, 2) surface water salinity, and 3) wind erosion. These new digital soil maps provide a consistent basis to better address these and other resource management priorities as well as develop mitigation actions. In this presentation, we will show how these new maps can be used to facilitate adaptive land management actions. The process for creating these maps is based on reconstructing the regional soil survey using both laboratory and original field transect data and is scalable to all of the United States.

Monroe Mountain wants to grow aspen, so how are we doing? Eight years of complementary and collaborative research

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ABSTRACT: In 2011, the 19-member, multi-constituent, multi-agency Monroe Mountain Working Group (MMWG) assembled as a consensus-based collaboration to examine and recommend options for restoring aspen throughout the 176,000-acre Monroe Mountain of Fishlake NF. Two-thirds of the aspen are seral (many stands are overtopped by conifer); one-third of the aspen stands are persistent (i.e., aspen-dominant; many stands have lacked recruitment for decades). In 2016, the Fishlake began a ten-year restoration project based on MMWG data and recommendations and other public input. Since 2011, more than eight distinct research studies have been answering questions raised by the MMWG. Five belt transects with motion cameras, tree-ring counts from 100 persistent aspen stands, 36 transects of persistent aspen recruitment and understory species; three 4-way post-fire exclosures, five livestock-free exclosures; five all-ungulate exclosures surrounding persistent aspen stands that have lacked recruitment for decades; and numerous restoration methods have been established and studied by MMWG subgroups, Grand Canyon Trust, Whitman College students, USFS Rocky Mountain Research Station, Fishlake NF, and Brigham Young University (BYU) researchers. Several of the BYU studies include identical investigations on two additional southern Utah national forests. These studies, from simple to complex, and single-season to multiple year, are yielding complementary information that includes the comparative contributions of cattle, elk and deer to browse of aspen suckers; years since recruitment in Monroe Mountain persistent aspen stands; percent browse with varying abundance of ungulates; capacity of depleted aspen stands to resume recruitment; plant species beneath persistent aspen; chemical defenses against herbivory; and the comparative success of restoration methods in seral or persistent aspen.

Mapping agriculture in the Southwest USA using Landsat imagery, automated cropland mapping algorithms, and cloud computing

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ABSTRACT: Using satellite remote sensing to determine the spatial extent of cropland production enables accurate and politically non-biased maps useful for assessing food availability and security. The study used imagery collected by Landsat 7 and 8 which have a nominal 30 m spatial resolution and collect imagery every 8 days (from both satellites) and MODIS which has a 250 m – 1 km resolution and collects imagery twice daily. The Southwest United States and the Colorado Plateau are particularly suited to remote sensing due to the mostly clear cloud free skies of the region which enable the majority of the satellite imagery collected to be analyzed. By combining imagery collected by these over a period of time, multitemporal time series analysis can be performed which are extremely useful for modeling, mapping and monitoring a suite of cropland products such as cropland extent\areas, croplands versus cropland fallows, irrigated or rainfed, cropping intensities, crop types, crop productivities, and yield. The study will use knowledge-base such as the US Department of Agriculture Cropland Data Layer and other available ground data or ancillary data to train algorithms and to validate products. Novelty in this work involves building automated cropland mapping algorithms (AMLA's) that can produce these products year after year based on the big-data computing on the cloud on platforms such as the Google Earth Engine (GEE), Amazon Web Services (AWS), and regional supercomputer clusters.

Glen Canyon Dam Adaptive Management Program - the next 20 years

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ABSTRACT: In response to the 1992 Grand Canyon Protection Act, the Glen Canyon Dam Adaptive Management Program (GCDAMP) was established to provide an adaptive management approach to evaluating the impacts of Glen Canyon Dam operations. The GCDAMP includes a Federal Advisory Committee, the Adaptive Management Work Group, which consists of a diverse group of stakeholders responsible for making formal recommendations to the Secretary of the Interior, in accordance with consultation requirements of the Grand Canyon Protection Act (GCPA). These recommendations are designed to assist the Secretary to operate Glen Canyon Dam "in such a manner to protect, mitigate adverse impacts to, and improve the values for which Grand Canyon National Park and Glen Canyon National Recreation Area were established" (GCPA 1992) while also complying with water delivery laws and requirements. In 2016, after 20 years of operations under a 1996 Record of Decision, the Long Term Experimental and Management Plan (LTEMP) Final Environmental Impact Statement and Record of Decision were completed. These documents used scientific information gained to better inform Glen Canyon Dam operations and provide a comprehensive framework for adaptively managing Glen Canyon Dam over the next 20 years. Operations under the LTEMP include important refinements and new tools to better comply with the GCPA. Implementation of the LTEMP ROD is expected to 1) result in an improvement in conditions for humpback chub, rainbow trout, and the aquatic food base; 2) have the least impact on vegetation, wetlands, and terrestrial wildlife; 3) improve sandbar building potential and conserve sediment; 4) sustain or improve conditions for reservoir and river recreation; 5) improve preservation of cultural resources; 6) respect and enhance tribal resources and values; and 7) have limited impacts on hydropower resources.

An ecohydrological framework for riparian restoration in the American Southwest

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ABSTRACT: We have developed and implemented an ecohydrological riparian restoration planning approach for systems in the arid and semi-arid regions of the Southwestern United States that links key physical attributes of a river and its watershed—such as climate, hydrology, and geomorphology—with the ecological responses of vegetation, birds, and other wildlife to those conditions. This integrative approach provides a functional framework for implementing successful restoration by using our understanding of key ecosystem linkages to identify appropriate and feasible restoration approaches, including both passive and active revegetation, and suitable locations for river-floodplain conservation and riparian restoration actions. This talk will discuss cases studies from ongoing restoration efforts in that were initiated primarily to enhance and restore habitat for the endangered southwestern willow flycatcher (*Empidonax traillii extimus*) (SWFL) and other native species of interest. The overarching goals of the restoration planning and implementation projects on the Virgin River (UT, AZ, NV) and the upper Gila River (AZ) were to: (1) prepare for observed (Virgin) and anticipated (Gila) alterations to the existing riparian system following colonization by the tamarisk beetle (*Diorhabda* spp.) introduced for the biological control of tamarisk (*Tamarix* spp.); (2) support recovery of native riparian habitat through active (e.g. replanting of native species) and passive revegetation (where natural or managed hydrology is suitable for natural recruitment of native woody riparian plants) to promote local increases in SWFL population size; (3) facilitate implementation of a comprehensive approach toward riparian restoration by a collaborative group of stakeholders, resource managers, and scientists; and (4) provide recommendations to be incorporated into the restoration plans developed by local stakeholders, such as the Clark County Desert Conservation Program (Virgin) and Gila Watershed Partnership (Gila). This approach has widespread applicability to the SWFL conservation plan and associated habitat restoration currently being developed by USDA-APHIS.

Powell as unwitting godfather of outdoor recreation in the great unknown

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ABSTRACT: Did John Wesley Powell view the Colorado River Basin's lands and waters solely through a utilitarian lens? Emilene Ostlind aims to undercut that notion. Drawing attention to Powell's craft in penning adventure stories like *The Exploration of the Colorado River and Its Canyons*, Ostlind suggests Powell actually might be characterized as the "unwitting godfather of outdoor recreation in the Colorado River Basin." As reflected in the *Arid Lands Report* and other writings, recreation was plainly not what Powell had in mind when composing his public-lands classification scheme. Equally clear, however, is the prominence recreation has attained across the basin's landscape and waterscape since Powell's time. Despite these distinctions between past and present, Powell's vision for the Arid Region's public domain nonetheless might serve as a guide in our collective navigation of the contemporary "Great Unknown." The timely topics of overcrowding, diversity, and access are all worth exploring from this angle.

Decadal influence of a high severity wildfire on microbial communities in Southwest ponderosa pine

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ABSTRACT: Southwest ponderosa pine (*Pinus ponderosa* Dougl. ex Laws) ecosystems have received great attention due to fuel conditions that resulted in large-scale wildfires. In 2002, extreme fuel load conditions at the Jemez District of the Santa Fe National Forest, New Mexico resulted in a large-scale wildfire with severe fire behavior (Lake Fire Complex 08/26/02 to 09/01/02), which consumed the overstory canopy and forest floor. Within that wildfire one complete replicate block of the nationwide Fire/Fire Surrogate (FFS) project was consumed. This event provided an opportunity to investigate wildfire effects on soil, and associated microbial populations. Pre-treatment sampling completed prior to the wildfire allowed resampling of the exact sites to investigate immediate post-fire effects. Fire/Fire Surrogate blocks at two unburned replicate sites were used as new controls for this study. We predicted that the immediate direct impact of heating would reduce the size of the microbial biomass and possibly favor bacteria over fungi and the quantity of available C would be altered, along with a change to the quality of C remaining in the soil. Laboratory estimates of C and N transformations suggest a large change in the function of the soil microflora following this high-severity burn and a reduction of the microbial biomass. We have now revisited the burned FFS block in 2016 to determine the impacts on microbial community and function over a decade later. Functional and structural composition are still different than existing controls. These high intensity fires may be novel in a historical sense as are their consequences. Our current knowledge of the role of fire in shaping forest soils comes from sites with intact historical fire regimes or from experiments that mimic historical fire conditions. When wildfires occur outside of historical norms, do we need to anticipate novel recoveries?

Glen Canyon Dam High Flow Experiments at powerplant capacity: history, considerations and opportunities for experimentation

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ABSTRACT: Completed in 1964, the Glen Canyon Dam was authorized for, among other things, water storage and electrical power generation. In recent years, the operation of Glen Canyon Dam has been adjusted to reduce downstream impacts to the Colorado River in the Grand Canyon. High Flow Experiments (HFEs) have been implemented several times since 1996 to reintroduce some of the natural dynamicity that existed in the Colorado River prior to the construction of the dam. Many of these HFEs have required water flows that bypass the powerplant. However, some evidence exists that HFE releases at powerplant capacity may also have beneficial effects. Conceptually, powerplant capacity HFEs are easier to implement, may be implemented more frequently, and come at a lower cost in terms of the use of water and electrical power. In this paper, we describe several possible applications of powerplant capacity HFEs, summarize the ecological effect of those that have been tested, and describe new experiments that may yield informative results. We conclude that powerplant capacity HFE experiments, on their own or combined with the "standard" HFE, would produce a more robust understanding of how Glen Canyon Dam operations can be used to improve downstream conditions while minimizing adverse impacts on water storage and electrical power value.

Genetic structure and gene flow in woody riparian plants: a case study in the Grand Canyon

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ABSTRACT: Current restoration initiatives emphasize the utility of selecting local genetic stock for reestablishment of native plants. The limits of what is "local", however, vary by species, geography, and availability of source populations. Most studies on appropriate transfer zones for plant restoration materials have been conducted using non-riparian species, but species in riparian systems will likely exhibit different patterns of gene flow and genetic structure due to the influence of river corridor connectivity and differing

instream flow regimes on gene flow and local adaptation. Using simple sequence repeats (SSRs) in common woody riparian species (*Populus fremontii*, *Salix gooddingii*, *Salix exigua,* and *Prosopis glandulosa*), we examine the genetic structure and gene flow within the complex riparian landscape of the Grand Canyon region. Results indicate that genetic structure is species dependent and correlated with geographic distribution along rivers. Cottonwoods (*P. fremontii*) are restricted to relatively small stands in tributaries and are strongly differentiated among geographic regions that correlate with temperature gradients. Goodding's willows (*S. gooddingii*), which occur in relatively small stands in tributaries and in a few places along the Colorado River, exhibit genetic structuring related to geography, but have more gene flow among them than cottonwoods. Coyote willows (*S. exigua*) and honey mesquites (*P. glandulosa*), both of which occur extensively along the Colorado River, have high connectivity and gene flow across the Grand Canyon region. Implications of these patterns of genetic structure are compared and discussed within the context of riparian restoration.

The root race: does stream type affect belowground architecture of a riparian tree species?

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ABSTRACT: To understand how rooting architecture influences the biomass and survivorship of Fremont cottonwood (*Populus fremontii*), we conducted an experiment to measure differences between perennial and ephemeral stream adapted genotypes. Differential rooting strategies may be genetically driven, as such it is imperative to understand the impacts of architecture on tree success. To quantify architecture, we collected cuttings from eight natural populations of Fremont cottonwood from paired ephemeral and perennial streams. These cuttings were grown in one of three drought treatments one meter from a mock water table for six weeks then analyzed for biomass and architecture. Three patterns emerged: 1. Ephemeral adapted trees allocated 4x more biomass to root tissue under high drought stress compared to perennial trees. 2. Fine root mass and complexity was greatest in perennial trees under low drought stress, and conversely, ephemeral trees under high drought stress. 3. The length of the longest roots at the end of the experiment revealed that ephemeral adapted trees were superior at reaching a mock water table under drought conditions. We conclude that the rooting structures of perennial and ephemeral stream adapted trees may be controlled by a gene-by-environment interaction. These findings suggest that Fremont cottonwood trees may be locally adapted to a specific hydrological regime. As such, root dynamics and architecture may be an essential consideration for future restoration projects as rivers and streams transition to a more ephemeral state with the progression of climate change.

Skyglow Estimation Toolbox: utilizing NASA Earth Observations to detect changes in nighttime sky brightness using hemispherical visualizations

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ABSTRACT: The expansion of cities and infrastructure networks has raised concerns regarding the impact of growing artificial light pollution on wildlife and human well-being. In addition to degrading night skies for aesthetic viewing, this 'skyglow' interferes with ecosystems by disrupting plant life, animal behavior, and human circadian rhythms. Historically, many natural areas in the Colorado Plateau and the Southwest have been a refuge for those seeking dark night skies. Created in partnership with the National Park Service (NPS) and various non-profit organizations, including the International Dark-Sky Association, Wyoming Stargazing, and the Colorado Plateau Dark Sky Cooperative, the Skyglow Estimation Toolbox (SET) was developed to estimate and identify sources of light pollution in national parks. SET is a Python tool that utilizes Falchi et al.'s (2016) light propagation models and data from Suomi National Polar-orbiting Partnership (Suomi NPP) Visible Infrared Imaging Radiometer Suite (VIIRS) Day/Night band to generate artificial sky brightness maps and a 3D hemisphere of light pollution throughout the night sky at any latitude and viewing angle. Project partners at the NPS Natural Sounds and Night Skies Division provided *in situ* sky brightness measurements at park service units across the country, including Arches National Park in Moab, Utah to demonstrate the utility of SET in a variety of geographic locations. *In situ* data were used to validate skyglow estimates derived from satellite observations and will allow for further calibration of the model output. The use of this tool will help managers make informed decisions regarding local nighttime sky brightness conditions and equip them with tools to identify where further mitigation is needed to reduce light pollution in the future.

Advancing social equity and ecological sustainability in IWRM: lessons from the Wild and Scenic Rivers Act

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ABSTRACT: Integrated Water Resource Management (IWRM) was conceived to promote coordinated efforts for the development and management of water and land resources to equitably maximize social and economic well-being while ensuring sustainable ecosystems. More broadly, IWRM is encouraged across the developing world for countries seeking to establish human water security for the first time while preserving biodiversity. Thus, successful IWRM strategies strike a balance between human resource use and ecosystem protection. Nonetheless, compromise between social equity, ecological sustainability, and growth is seen as a problematic reality in IWRM decision making as water intensive economic development initiatives threaten to subjugate water needs to land-use decisions. Though IWRM is seemingly based on parity, today there is a perceived lack of commitment to addressing the socio-ecological impacts of large dam development, canal and irrigation diversions, and other water development projects with negative repercussions on watershed integrity and local populations. This fact complicates the application of IWRM principles as emerging economies are faced with balancing social, economic, and environmental water needs in the face of climate change. What is more, panacea policies designed for universal implementation often exclude consideration of place-specific variables found from one location to the next. Against that backdrop, this paper shows in places where IWRM practices are desired for socio-ecological resilience across sectors, the WSRA provides a flexible policy framework to address these concerns. Through its eligibility and suitability study design for Outstandingly Remarkable Value (ecosystem service) identification, as well as the three-tiered classification framework designed to distinguish between river corridors that are Wild, Scenic, or Recreational, this exercise can inform IWRM strategies in the service of place-specific policy creation for resilient river ecosystems around the globe. Incorporating such river conservation policy into IWRM strategies can address inequalities within the social, economic, and ecological aspects of water governance.

10 years of the Colorado Plateau Native Plant Program – successes and future directions

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ABSTRACT: The Bureau of Land Management (BLM)-led Colorado Plateau Native Plant Program (CPNPP) was established in 2009 to address needs for adapted native seed in restoration and reclamation on the Colorado Plateau (portions of Utah, Colorado, Arizona and New Mexico). CPNPP supports and coordinates plant materials development activities among a partnership of federal, state, local, scientific, and non-governmental stakeholders. Projects and partnerships are both formal, using cooperative and interagency agreements or contracts, and informal, sharing seed inventory and data resources. Leveraging partner facilities, skills, expertise, and other resources enables CPNPP progress improving plant materials availability and use. CPNPP goals and objectives correspond to those of the United States' 2015 National Seed Strategy. I'll introduce the CPNPP mission, structure and partners including the complementary mix of scientific and applied partners and activities. I'll present selected accomplishments such as: our seed collection and inventory program; a relational tracking database; the establishment of plant material evaluations, common gardens and materials increase; innovative research on functional traits and landscape-scale genetics to enable development of species-specific seed transfer zones; novel restoration methods; geospatial tools; plant materials releases; a reclamation needs assessment; and an economic market evaluation. Current and future CPNPP objectives and projects comply with national leadership priorities related to wildlife habitat and migration corridors, energy independence, and wildfire mitigation. I'll introduce CPNPP current projects and short-term plans, while other speakers in this session will present more specifically on new research results and on-going non-research activities.

Smart parks: IoT outdoors

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ABSTRACT: Visitor statistics have long been collected for the National Parks system. These visitation numbers are primarily collected by manual and mechanical processes. These current processes can be extremely labor intensive and often consume substantial park resources to maintain and update. The subsequent data gathered from these processes are vulnerable to the nature of manual entry and the delay inherent in such systems. Recent advances in machine learning, Artificial Intelligence (AI), and Internet of Things (IoT) sensors have created opportunities for cities to deploy comprehensive systems to understand human behavior in their jurisdictions. Using the latest technology in advanced communications, power management and ruggedized encapsulations have allowed this technology to transition from urban to outdoor environments. In Zion National Park, Cedar Breaks National Monument and Bryce Canyon National Park this means real time or near real time automated counting and classification of vehicles, visitor counts at entrances and trails, real time parking, shuttle tracking and a suite of application-based tools replacing many manual and time consuming park staff visitor-use management activities. All of this information is then designed to be disseminated using web applications, mobile applications, electronic signage, and dashboards to visitors and park staff. The hardware and software developed in an open source environment may be shared with parks and recreational areas nationwide.

Biological soil crust recovery following climate and physical disturbance: creating a recovery clock for biocrust communities and their function

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We know biocrusts take time to recover from disturbance and that the amount of time depends upon climate and edaphic properties. However, very few studies have tracked the recovery of biocrust communities and their function through time following disturbance. Further, emerging data suggest that, in addition to the physical disturbances we have long known affect biocrust communities, changes to climate could be altering the composition of biocrusts over sub-decadal (i.e., fast) timescales. Tracking biocrust communities and function in the context of recovery from climate change and physical disturbance could provide a "clock" from which we could better understand how biocrust community members and the processes they regulate change over the course of recovery. Here we describe a study at four sites on the Colorado Plateau, USA, where climate change and physical disturbance treatments were applied consistently for numerous years – three sites had a standardized physical disturbance experiment and one had the climate disturbance experiment, which included active warming and altered precipitation treatments. Following the cessation of the strongest disturbance factors (physical trampling and altered precipitation), we assessed the recovery of biocrust community composition and key functions such as the provision of soil stability and fertility (based on comparing treated plots with untreated paired control plots). Some of our results were expected, for example, following cessation of disturbance, biocrust communities did transition from lightly-pigmented cyanobacterial communities (e.g., *Microcoleus* spp.) toward darkly-pigmented cyanobacterial biocrusts common in the absence of disturbance. Other results were unexpected. Recovery rates were faster than anticipated and showed strong spatial and temporal variation that pointed to interactive drivers of recovery. These data lend key insight into how biocrust communities will change with continued, interactive anthropogenic drivers and have important implications for predicting

Sand dropseed and drought: an outdoor experiment to test plant plasticity and the role of seed source in seeding success under varying precipitation regimes

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ABSTRACT: Identifying genetically appropriate seeds for current and future restoration projects is a key goal for successfully restoring Colorado Plateau plant communities and the services they provide. However, confidently prescribing the right seeds for the right place and the right time can be challenging, particularly against a backdrop of an increasing frequency and severity of drought. Nevertheless, establishing a predictive understanding of how native plant responses to environmental variability scale from individuals to populations, and across populations, will enable much improved projections of which seed sources should be prioritized for restoration and seed increase efforts. Here we will describe an outdoor experiment where we're growing sand dropseed (*Sporobolus cryptandrus*) plants from seeds collected in multiple climates across the West. Sand dropseed is a promising restoration candidate across a range of ecosystem types, as research suggests that the species is extremely drought tolerant and often able to respond positively to stressors, including severe drought and overgrazing. We are growing sand dropseed outside but under an experimental rainfall gradient, with the rainfall provided to the plants varying from severe drought to uncommonly wet conditions. We are assessing germination and growth rates, as well as plant physiology and forage quality, to determine responses among these different populations each grown under different climate conditions. Assessing these plant responses will allow us to ask questions such as "do seeds of a single species from drier places have higher survival and/or growth under drought conditions?" and "is there a seed source location more likely to provide successful seeds for restoration or seed increase efforts?" Results from this study will offer insight into how plastic this target restoration species can be in its response to large variation in rainfall, as well as if certain populations are more likely to succeed with drought.

Sympatric pairings of dryland grass populations, mycorrhizal fungi, and associated soil biota enhance mutualism and ameliorate drought stress

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ABSTRACT: There is evidence that the distribution of ecotypes of plants and their symbiotic arbuscular mycorrhizal (AM) fungi and other associated soil biota may be structured by the availability of essential soil nutrients; and locally adapted partnerships most successfully acquire nutrients that are in limited supply. Much less is known about how water availability may influence the geographic structure of symbioses among plants and soil biota. We grew *Bouteloua gracilis* ecotypes from wet and dry sites, with either sympatric or allopatric soil inoculum under moderate and extreme soil drying treatments to examine 1) how varying degrees of water limitation influences grass responses to soil biota, and 2) the relationship between AM fungal structures and these responses. Under extreme soil drying the dry-site ecotype tended to perform better than the wet-site ecotype. Both ecotypes performed best when inoculated with their sympatric soil biota. Sympatric pairings produced more AM fungal hyphae, arbuscules, and dark septate fungi. In contrast, allopatric pairings produced more vesicles. Extreme soil drying tended to accentuate these patterns. As water became increasingly limited, sympatric partnerships produced more resource harvesting and exchange structures than allopatric ones.

Mosses under stress: morphological changes in dryland moss *Syntrichia* under climate disturbances

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ABSTRACT: Biological soil crust communities are commonly and frequently dominated by drylands mosses *Syntrichia caninervis* and *Syntrichia ruralis* in the southwestern USA. These major biocrusts components contribute to ecosystem functions, playing a role in dust capture, water retention, soil surface temperature regulation, carbon fixation and soil stability. Some of these roles can be linked to measurable structures of *Syntrichia* morphology that face changes to adapt to more extreme environments and consequently affecting ecosystem functions. We investigated the effects of two climate disturbances on the morphology of *Syntrichia* species in southeast Utah. (1) A 1-year reciprocal transplantation to warmer and cooler environments (± 1°C and 2°C). (2) An 8-year experimental rainfall reduction using passive rainfall interception shelters. In our reciprocal transplant experiment, we observed the local adaptation of *S. caninervis* and *S. ruralis* having distinct characteristics according to their site. The changes of *S. caninervis* to warmer or colder environments did not show a clear pattern after one year of transplantation. However, into a warmer climate *S. ruralis* changed into populations with wider stems, bigger leaf hairs (awns) and greater aboveground biomass. Multivariate analysis revealed that in a natural aridity gradient from semi-arid to arid environments, populations have characteristics that made them distinct of their own site. The eight-year rainfall reduction created populations of *S. caninervis* with thinner stems, shorter rhizoids and smaller awns, these characteristics correspond with populations of the most arid climates in the sample. Our findings suggest that morphological changes due to climate disturbances have distinct patterns in *Syntrichia* species and that populations are adapting to warmer and dryer environment at a fast pace. With the potential of losing the extent of their ecological services in the process, this fast adaptation of moss populations to warmer climates could enhance biocrust restoration efforts in a changing climate.

Developing management tools for Great Basin ecosystem restoration

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ABSTRACT: Landscape scale research involving multiple disciplines often necessitates co-production. In the Great Basin the need for such cooperation has been long-recognized and the Great Basin Native Plant Program (GBNPP), a multi-agency research cooperative was formed in 2001. A major emphasis of the GBNPP has been focused on ecological genetics, understanding intraspecific adaptation or demographic histories, which is enhanced by co-production. In this presentation, I discuss the pros and cons of co-production at the different stages of genetic research. The initial stage of ecological genetic studies involves sample and seed collections, which can be greatly augmented by co-production. However, precise instructions and communication is needed to ensure partners understand the data needs, protocols and goals of the research. These principles also apply to the data collection from common gardens, which are often located some distance away from each other and can be augmented by building partnerships. Building co-produced studies can attract diverse research interests. A common garden study of sagebrush has seen numerous diverse research projects from chemical ecology to hyperspectral remote sensing. Co-production and communication have been most needed at the application phase of these studies. A major goal for ecological genetic research has been the development of a seed transfer mapping tool, the Climate Smart Restoration Tool. Development of this tool requires input from various disciplines including

genetics, climate, GIS, web programming and resource managers. I will discuss the lessons learned from the Climate Smart Restoration Tool.

Forecasting the winners and losers of a riparian herpetofauna in response to habitat invasion and xerification

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ABSTRACT: In many southwestern riparian systems, native gallery forest has been, or is actively being, replaced by invasive saltcedar or encroached by xero-riparian shrubs. Amphibians and reptiles are the two most threatened vertebrate taxa and, in the Sonoran Desert, are often reliant on riparian habitat. The link between amphibians and water availability, as well as the association between lizards and habitat structure, make herpetofauna useful organisms for which to examine the effects of riparian habitat change. Our objective was to relate capture rate of a fossorial toad and lizard abundance to aspects of native, invaded, and shrub-encroached riparian habitats to forecast the potential winners and losers of riparian habitat invasion and xerification. We measured habitat and monitored herpetofauna at sites near the confluence of the San Pedro River and Gila River in Pinal County, Arizona in 2016 and 2017. Sites occurred across three riparian forest types based on dominant tree genus; cottonwood-willow, mesquite, and nonnative saltcedar. Habitat measurements indicated that sites varied significantly in structure and that dominant tree species was a useful descriptor of habitat physiognomy. Herpetofauna trapping results suggested that Couch's spadefoot, a fossorial anuran, are associated with moist, water-retaining soils, and occupy mesquite-dominated sites at a much higher rate than saltcedar sites. We found lizard abundance to be significantly lower in saltcedar habitat, with most captures in invaded habitat attributed to a generalist species. More than half of lizard species displayed a negative association to saltcedar habitat and cottonwood-willow gallery forest supported the greatest abundance of lizards. Based on this study, we conclude that habitat shifts from saltcedar invasion may have a greater negative impact on riparian herpetofauna than those which arise from xerification and shrub encroachment.

Arthropod communities in the pinyon juniper woodlands

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ABSTRACT: Pinyon pine (*Pinus pinyon*) and juniper (*Juniperus* spp.) co-dominate woodlands that cover 19 million hectares in the southwestern United States. The distribution and composition of these woodlands has changed drastically over the last century. Pinyon-Juniper (PJ) woodlands have increased in range 10-fold, encroaching on historical shrub and grasslands, mostly driven by junipers which are more resilient to drought than pinyon. For example, juniper encroachment in Oregon has converted two million hectares of sagebrush communities. While junipers have generally expanded in range, pinyons have recently experienced large drought-related mortality related to anthropocentric changes to climate. The shifting composition of PJ woodlands and their encroachment into other habitats, raises questions about what communities will follow these changes.

Winter rain-on-snow buffers streamflow sensitivity to snowpack losses in the Salt River Watershed in semi-arid Southwest US

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ABSTRACT: Studies that associate recent declines in Colorado River flow with warmer temperatures have received considerable attention because 40 million people rely on water from the Colorado River Basin. However, in other western US river basins, significant warming has not consistently led to declines in streamflow despite losses in snow storage, perhaps due to greater hydrological inputs from winter rain. In winter months, rainfall can potentially generate streamflow more efficiently than snowmelt because flow production occurs before peak sublimation and evapotranspiration losses. The Salt River Basin in central Arizona is a promising location to explore this issue because it has a mixed rain and snow climatic regime that is influenced by large individual events. We examined whether warming has led to changes in precipitation phase and how that influenced streamflow patterns at the annual and event-scales in the Salt River Basin and its gauged sub-basins from 1966-2011. We developed a basin-scale model that

separates snow and rainfall inputs and simulates snow accumulation and melt using temperature, precipitation, and relative humidity. Despite significant warming and simulated snow water equivalent (SWE) losses, annual streamflow did not decline significantly in most sub-basins. Multiple linear regression models showed that Dec-Feb rain-on-snow when combined with peak SWE most consistently explained flow variability, and that flow generation from rain-on-snow inputs was two-fold greater than SWE. At the event-scale, streamflow was significantly higher in winter and fall versus summer seasons, and 40-70% of the largest cool-season events overlapped with atmospheric rivers. Moreover, magnitudes of winter and fall events were significantly higher from 1966-2011 than 1926-1965. We conclude that SWE losses from warming in the Salt River basin are ameliorated by winter rain-on-snow contributions. With continued warming and SWE losses, mean annual flows may decline, but inter-annual flow variability may increase due to intensifying winter rain-on-snow events.

Co-production of science to address short- and long-term challenges of accelerated forest restoration in northern Arizona

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ABSTRACT: After decades of collaborative efforts in forest restoration in northern Arizona, The Nature Conservancy has found that the primary barriers to increase the pace of restoration at a scale that is commensurate with recent wildfires are not scientific in nature, but relate to economic, logistical and institutional challenges. Our approach has been to develop a strategic partnership with the US Forest Service and the wood products industry to accelerate forest restoration by streamlining USFS business practices, reducing industry operating costs, and increasing transparency to interested stakeholders. While off-the-shelf science was not immediately useful, through learning and dialog within the partnership, we have identified several areas where science and technology can address shared challenges. For example, we have leveraged use of remote-sensing, tablet and mapping technologies to provide real-time information on timber resources and harvesting guidelines that are improving operator efficiencies and facilitating rapid monitoring and planning. Additionally, in collaboration with federal agency and academic scientists, we have completed several scientific studies that suggest the Four Forest Restoration Initiative, an effort to restore 600,000 acres of ponderosa pine forest in northern Arizona, could sustain and improve production of ecosystem services, including carbon sequestration and streamflow. In the long term, payment for these ecosystem services could provide additional financial resources as markets and investors emerge and federal funding diminishes. The Conservancy has learned that science products cannot often be applied in a vacuum, but only after investing in long-term partnerships with agencies, private industry and academic partners. These partnerships facilitate communication and iterative problem-solving, allow for pooling of resources to fill key information gaps, and ultimately, help make ambitious natural resource objectives achievable.

Citizen science biocrust restoration

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ABSTRACT: In the Southwest and similar environments, biological soil crust (biocrust) plays an important role in increasing soil stability, water infiltration, and soil fertility in otherwise erodible, dry, and infertile soils. Biocrusts are susceptible to disturbance because they are brittle when dry and crush easily with trampling and biocrust loss can result in soil erosion and loss of soil nutrients. As a solution, researchers are currently exploring how to cultivate ("bulk") soil biocrusts and re-establish them in the field. Based on preliminary successes in higher elevations, we initiated a two-staged experiment in the Sonoran Desert. In 2018 we salvaged biocrusts from two future trailhead development sites on Scottsdale's McDowell Sonoran Preserve and stored them in dry, ambient conditions. In February 2019, we dry sieved the biocrust over a 0.5 mm mesh screen to break up fragments, and then homogenized. We sprinkled the biocrust over the soil surface at 20% of the surface area in the following layering systems: 1) landscape fabric across soil surface to keep vegetation out (not needed in greenhouse setting); 2) jute treatment (to keep soil in place in rain events; jute (homogenized), jute (direct transplant) or no jute); 3) substrate treatments: native soil (soil from biocrust salvage site) or sand; 4) biocrust (at 15%) and 5) environment: "flat" shade cloth (with shade cloth laid on top of the biocrust and stapled to the ground), shade cloth hoop house, or NAU greenhouse. All units were given water to full hydration for 24 hours daily Monday-Friday for four months. We then assessed cover of biocrust by functional group, cover of plants to species and also assessed the chlorophyll a content as a proxy for biocrust biomass. Most treatments achieved good biocrust cover. The highest cover overall was found in native soil in all combinations. We found that cyanobacteria and mosses grew best in the greenhouse, followed by "flat", with poorest growth in the hoop house. Plants grew most in "flat", then hoophouse, then greenhouse. In stage 2, we will apply bulked and stored salvaged biocrust in field plots to compare establishment success of the different cultivation approaches.

Launching a regional effort for regional native plant conservation: IUCN Sonoran Desert Plant Species Specialist Group

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ABSTRACT: The IUCN has recently approved a new IUCN Sonoran Desert Plant Species Specialist Group with the goal to assess the extinction risk of all Sonoran Desert plant species, educate the public about Sonoran Desert species and threats, and implement conservation plans supported by the Red Listing process. The McDowell Sonoran Conservancy will lead this effort by bringing experts across the Sonoran Desert (Mexico, Arizona, and California) to assess the conservation status of nearly 4,000 plant species found in this region. The IUCN Red List of Threatened Species™ is the world's most comprehensive inventory of the global conservation status of plant and animal species. It uses a set of criteria to evaluate the extinction risk of thousands of species and subspecies. These criteria are relevant to all species and all regions of the world. With its strong scientific base, the IUCN Red List is recognized as the most authoritative guide to the status of biological diversity. As assessments are completed, the information will highlight threats across the region and allow us to generate appropriate conservation responses and educational programming. The information generated by the assessments will lead to targeted conservation planning, education, and action across the Sonoran Desert.

Increasing heat and growing visitor pressures on a public recreation treasure: a case study of Fossil Creek

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ABSTRACT: The past two decades mark a period of rapid ecological and social change in Fossil Creek, Arizona. Diverted for hydropower generation for a century, full flows were returned to the creek in 2005. This enhanced valuable aquatic and riparian habitat and the integrity of a landscape that holds deep cultural significance to indigenous peoples. Restoration of flows also greatly expanded a water-based recreation opportunity located in relatively close proximity to one of the nation's fastest growing—and hottest—metropolitan areas. Visitation to Fossil Creek increased rapidly, rising from approximately 20,000 people per year in 2006 to 90,000 in 2015. Also, in 2015, over 43,000 people were turned away because there was simply no more space for parking in the canyon. In 2009, Congress designated Fossil Creek as a Wild and Scenic River. With this designation came a mandate for the USDA Forest Service, which administers Fossil Creek, to develop a management plan that protects and enhances the creek's "outstandingly remarkable values." Managing the burgeoning recreational use in a way that protects the ecological, geological, and cultural values and world-class recreation experience that make Fossil Creek unique is no small task. When combined with the ecological uncertainty brought about by a warming climate, the likelihood of places providing respite from the heat experiencing greater pressure, and ever-decreasing budgets, the Forest Service must develop a management plan that is adaptable and financially sustainable. The draft plan, which was released for public comment in late 2018, relies on a monitoring and adaptive management approach to accommodate uncertainty in how the ecological, social, and cultural environments will change in the future. Additionally, the plan articulates management direction (desired conditions, standards, and guidelines) and actions that are intended to promote resilience of the river corridor and sustainability of management structures.

Growing water: can farmers help resolve our water crisis?

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ABSTRACT: The Western U.S. suffers from increasingly acute water stress, and is also a major growing region for all kinds of irrigated crops- including animal feed. Meanwhile, fallowing programs have proven successful at reducing agricultural water usage without destroying rural farm economies. Recent work from the FEWSION project has mapped agricultural supply chains and tied western farms' water use to streamflow depletion- and to urban consumers of the resulting crops. It turns out that urban beef consumption, and the western irrigated feed crops that support the beef, can be managed through fallowing to dramatically improve western river flows- without serious impact to the agricultural supply chain.

Physiological responses of dominant grass species to precipitation variation in Southwest grassland ecosystems

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ABSTRACT: The US Southwest is predicted to experience longer periods of drought with more intensive monsoonal precipitation during the summer months in the near future. These changes in precipitation may drastically alter grassland ecosystems in terms of community composition, net primary production, and physiological performance of plants. Greater precipitation and increased soil moisture allow plants to uptake more water and open their stomates, allowing for gas exchange. Conversely, lower precipitation results in closed stomates and reduced photosynthesis. The C_4 photosynthetic pathway allows for greater water use efficiency and greater stomatal conductance (a measure of gas exchange) during dry conditions, compared to the C_3 photosynthetic pathway. By experimentally altering summer precipitation in grassland ecosystems ranging from desert scrub to mixed conifer forest meadows, we provide lines of evidence that suggest that changes in precipitation do affect the stomatal conductance and performance of dominant species. Reduced precipitation significantly reduced the stomatal conductance of dominant species, while an increase in precipitation only increased stomatal conductance following an abnormally dry winter. C_3 species were more responsive to treatment effects than C_4 species. C_3 species exposed to reduced precipitation had significantly lower stomatal conductance than C_3 species exposed to increased precipitation. C_4 species showed no significant differences between reduced and increased precipitation. Large year to year differences of stomatal conductance also suggest that winter precipitation played a large role in the physiological performance of species during the summer months, though more research is needed to confirm these results. Our findings demonstrate that C_4 species do not close their stomates and are able to maintain rates of photosynthesis with reduced precipitation, compared to C_3 species.

River resource governance in dam impacted areas – lessons learned from the Brazilian Amazon's Madeira River

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ABSTRACT: The Amazon Dams Network has in recent years built a relationship with the US Geological Survey in an attempt to share lessons learned, especially regarding river resource management and the governance of the impacts wrought by damming. This paper presents a case study from the Madeira River, the largest tributary of the Amazon River, in northwestern Brazil where the Santo Antonio and Jirau dams were recently constructed for the production of hydropower. Both dams are climate change mitigation projects and as such followed plans to ensure environmental, social, and economic sustainability. However, in practice, many of the projects' sustainability goals have fallen short, leaving communities impoverished and without access to the resources on which they are dependent. While many technological and institutional advances have been made since the damming of the rivers of the American Southwest and southern Brazil, many of the same problems persist. Based on a case study of the fishermen and women of the impacted community of Abunã, this paper analyzes evolving governance and resource use after dam construction. This study employed semi-structured interviews with community members and other pertinent governance stakeholders, participant observation at meetings regarding resource use and governance, and document analysis of plans for resource governance and impact management. Drawing on an environmental governance framework, it demonstrates not only the gaps between planning and practice but also how governance plays out in practice, and thus begins to shed light on the *why* behind the gaps.

Designing flows for fish, fisheries and food security

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ABSTRACT: Rivers provide unrivaled opportunity for clean energy via hydropower, but little is known about the potential impact of dam-building on the food security these rivers provide. In tropical rivers, rainfall drives a periodic flood pulse fueling fish production and delivering nutrition to more than 150 million people worldwide. Hydropower will modulate this flood pulse, thereby threatening food security. We identified variance components of the Mekong River flood pulse that predict yield in one of the largest freshwater fisheries in the world. We used these variance components to design an algorithm for a managed hydrograph to explore future yields. This algorithm mimics attributes of discharge variance that drive fishery yield: prolonged low flows followed by a short flood pulse.

Designed flows increased yield by a factor of 3.7 relative to historical hydrology. Managing desired components of discharge variance will lead to greater efficiency in the Lower Mekong Basin food system. This talk will go beyond the results from this published paper and suggest ways that similar algorithms might be developed to improve management of aquatic resources in temperate rivers like the Colorado and Sacramento rivers.

Constraining martian knickpoint retreat and erosion rates at Grand Falls, Arizona

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ABSTRACT: Martian valley networks reflect the paleohydrologic and paleoenvironmental conditions that existed during their formation. While much is known about martian valley networks, major remaining unknowns include the timescales and rates of fluvial erosion, with estimates spanning several orders of magnitude and paleoenvironmental interpretations derived from these estimates ranging from tropical to hypothermal deserts on Earth. The Little Colorado River at Grand Falls presents an ideal terrestrial analog for understanding martian fluvial processes as it is eroding into layered sedimentary bedrock like those observed in many martian landscapes and lacks any significant vegetation within and around the channel at the falls. By measuring the rates and nature of erosion at Grand Falls, along with hydrological data related to these erosion events, we can shed important light on the magnitude and kinematics of fluvial erosion on Mars.

Exploring local adaptation and climate resiliency of priority restoration species in northern New Mexico

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ABSTRACT: The complexity of restoring degraded lands in the Southwest requires a collaborative approach informed by comprehensive research. However, very little research exists in regard to local adaptation and climate resiliency of Southwest plants. Utilizing environmentally diverse native seed resources from the Southwest Seed Partnership, we explore local adaptation and climate resiliency of priority species by analyzing functional traits in the field and in a common garden setting. Field sites are stratified by latitude and elevation to complement a common garden located in Santa Fe, New Mexico. Our initial research subjects include two ubiquitous, perennial species: *Bouteloua curtipendula* and *Heterotheca villosa*. Spurred by the Bureau of Land Management's National Seed Strategy, our research is integral to the management of New Mexico's public lands for the conservation of healthy native plant communities. This presentation will describe the initial steps of this ongoing research and associated management implications.

Salad within: a genetic survey of diet of the endangered New Mexico jumping mouse (*Zapus luteus luteus*)

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ABSTRACT: Endangered due to habitat loss, *Zapus luteus luteus* (previously *Zapus hudsonius luteus*) is specialized to high elevation, riparian zones in the southwestern United States. Jumping mice use streamside vegetation for forage during the summer to accumulate enough fat for a possible nine-month hibernation. Studies of congenerics suggest frequent seed consumption of forbs and graminoids along with a smaller degree of insectivory. However, only seven plant species were known as diet items for *Z. l. luteus* and insectivory was undescribed due to challenges in observing their behavior. A thorough survey of diet can help resource managers promote, maintain, or restore habitat. Towards this goal, we used DNA metabarcoding to identify taxonomic mixtures of plants and insects in the feces of live-captured jumping mice. We detected 109 plant genera in the feces of 128 individuals captured between 2016 – 2018 across the species distribution. These genera were largely of forbs and graminoids (e.g., *Asteraceae*, *Rosaceae*, *Poaceae*) and mirrored the native and perennial vegetation available in the capture sites. Richness of plant taxa significantly increased ($P<0.05$) by the end of summer, potentially as more forbs set seed. This temporal pattern suggests plant phenology may drive dietary selection of plant resources throughout their short summer of activity. We also present the first evidence of insectivory for *Z. l. luteus*. Common moths (*Noctuidae*) and aphids (*Aphididae*) were frequently detected among jumping mice, which along with other detected insect taxa, appear to be associated with vegetation. Our DNA-based survey of diet highlights the importance of promoting jumping mouse

habitat with diverse riparian vegetation that 1) allows herbivory via seed set, and 2) provides habitat for insects jumping mice may opportunistically consume.

Northern Arizona analog sites used for Apollo astronaut training

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ABSTRACT: Every astronaut who walked on the Moon trained in Flagstaff. In 1963, USGS geologist Gene Shoemaker established the newly formed Branch of Astrogeology in Flagstaff to conduct training exercises for the Apollo astronaut crews. Flagstaff was chosen as the base of operations because of its proximity to geologic features that were considered good analogs to what the astronaut explorers might encounter on the Moon. Namely the young cinder cones and lava flows of the San Francisco Volcanic Field and Meteor Crater, the best-preserved exposed impact crater on Earth. They also created some analog sites by detonating explosives in a large flat area of volcanic cinders to simulate a cratered lunar landscape.

Employing NASA Earth Observations to monitor alpine lake algal productivity in Rocky Mountain National Park

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ABSTRACT: Alpine lakes in Rocky Mountain National Park (RMNP) serve an important water source and habitat for wildlife, as well as contribute to the overall aesthetic value of the park. However, since the 1960's, alpine lakes within RMNP have experienced intensified algal productivity as a result of rising temperatures and increased nitrogen and phosphorus deposition. This increased algal productivity may have negative impacts on water quality, ecological function, and park aesthetic. Due to the remote location of many of these lakes, continuous monitoring of algal productivity is difficult. In order to assist in the surveillance of these lakes, NASA DEVELOP partnered with the US Geological Survey and the National Park Service to develop a methodology integrating satellite imagery for monitoring chlorophyll-α concentration as a proxy for algal productivity. In 2016, a previous study incorporated Landsat 8 Operational Land Imager (OLI) to predict chlorophyll-α levels, but were limited by spatial and temporal resolution of the available data. This feasibility analysis compared the efficacy of higher resolution Sentinel-2 Multispectral Instrument (MSI) data with Landsat 8 OLI algorithms to detect chlorophyll-α at two focal lakes, Sky Pond and The Loch, in RMNP. With increased understanding of the algal productivity of these lakes, our partners will inform management practices to maintain the resilience and preserve the beauty of these fragile ecosystems.

Values Mapping for Planning in Regional Ecosystems (VaMPIRE): a modernized participatory GIS application for assessing social value substitutability on public lands

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ABSTRACT: Federal lands are managed for multiple uses that can sometimes conflict. For instance, increased grazing or energy development may change recreational opportunities available in a given location. To facilitate management planning in this context, we present the Values Mapping for Planning in Regional Ecosystems (VaMPIRE) Public Participatory GIS (PPGIS) mapping application. VaMPIRE uses GIS tools and mapping interfaces to include local communities, user groups, and other interested stakeholders in planning processes. It will gather spatial data on the meanings people attach to places and activities they do in those places. These data are spatially referenced and can be used to identify landscape values; how proposed management actions might affect use and value; where potential conflicts might occur; and high-performing areas where multiple values already co-exist. In addition, these data can easily be overlaid with biophysical data to predict the impact of management changes on existing uses and values for public lands. VaMPIRE also incorporates a survey designed to assess behavioral changes in land use by the public and the acceptability of substitute resources considering a given change on the landscape. VaMPIRE is a partnership between the USGS and BLM with the objective to develop a transferable tool to help facilitate actionable planning that maximizes multiple land uses while considering possible social tradeoffs. This presentation will provide a discussion of the theoretical foundation for the values and substitutability survey questions; a demonstration of the mapping tool; and an overview of applications.

Determining prescribed fire and fuel treatment compatibility with semi-desert grassland habitat rehabilitation for the critically endangered masked bobwhite quail (*Colinus virginianus ridgwayi*)

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ABSTRACT: Livestock grazing, fire regime disruption, pronounced drought, and altered arid-land hydrology have significantly transformed semi-desert grasslands since the late 1800s. 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 an emphasis on the critically endangered masked bobwhite quail (*Colinus virginianus ridgwayi*). Since refuge establishment and grazing cessation, prescribed fire has featured prominently as a management tool to restore habitat. We used a random sample of semi-desert vegetation (n = 239 plots) across fire history and biophysical strata to determine disturbance and environmental factors important to developing quail habitat. Structural equation models (SEM) revealed that soil texture and climate gradients were important to determining fire-effects on habitat. Prescribed fire produced short-term benefits for quail such as increased forb cover, although these conditions were often short-term (<3 yrs.) on sites retaken by the non-native grass *Eragrostis lehmanniana* (ERLE). Leguminous shrubs and subshrubs that are important winter food for quail were in low abundance and negatively affected by frequent fire according to SEM. Subshrubs important for quail hiding cover and food were more abundant on plots ($\bar{x}$ = 5.2%±5.9 cover), but had a significant negative association with fire frequency. Locations with higher plant diversity and habitat suitability for quail were on coarse textured soils with lower moisture holding capacity, that were less suitable to ERLE. Non-linear models comparing fire history variables to masked bobwhite habitat suitability showed a significant negative relationship with fire frequency (F=14.8, P<0.001, r^2 = 0.36) and significantly positive relationship with the number of years since last burn (F=14.6, P<0.001, r^2 = 0.35). Adaptive management approaches that consider site factors and the present abundance of ERLE could likely benefit many aspects of quail habitat rehabilitation and prescribe fire use on BANWR.

Unmanned aerial vehicle radio telemetry (UAV-RT) for wildlife localization

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ABSTRACT: The low cost and widespread adoption of very high frequency (VHF) transmitters for wildlife localization likely ensures their use into the foreseeable future. For many species, these low mass tags are the only option for real-time localization. The time required for VHF tag localization though, can significantly contribute to the overall expense of a study, especially if manned aircraft are required for the search. Over the past three years, our group has worked to integrate a VHF receiver with an unmanned aerial vehicle. The two-fold benefit of altitude and rapid mobility can significantly decrease the time to localize, as well as aid in tag detection. Our system uses a software defined radio and onboard computer to record radio data in flight. The current open-loop operational method relies upon user designed flight plans to dictate the autonomous flight of the vehicle, but closed loop control of the vehicle based on received VHF signals has been tested and shown to provide localization performance similar to the open loop flight plan method. Upon landing, this data can be quickly processed to provide audio and visual representations of the received signal. In this presentation, we will discuss the current state of the system design, the user interface software developed for processing and visualizing the results, and the results of recent testing.

Harnessing landscape genomics to guide seed collection and increase habitat restoration success in a changing climate

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ABSTRACT: Understanding environmental drivers of local adaptation is fundamental to predicting species responses to climate change and effectively applying seed treatments to restore degraded ecosystems. In locations subject to rapid climate change, predictive restoration strategies that prioritize seed sources with favorable adaptations to future climate could promote long-term resilience. Landscape genomics is a cost-efficient approach for assessing spatial patterns in local adaptation and may enable

identification of resilient genotypes. The Mojave Desert Native Plant Program is committed to developing landscape-genomics based seed-transfer guidelines for multiple native species of restoration importance. In a recent study, we genotyped 760 individuals from 64 Mojave Desert populations of the annual *Plantago ovata*. Genome scans identified 38 potentially adaptive genetic loci related to climate and satellite vegetation metrics. A multivariate generalized dissimilarity model attributed spatial turnover in potentially adaptive loci to summer maximum temperature, precipitation seasonality, and variability in NDVI amplitude, a measure of green-up potential. Importantly, we found that summer maximum temperature both constrains the range of *P. ovata* and drives adaptive divergence in populations exposed to higher temperatures at the range margins. Warm-adapted genotypes for this species are likely to experience a six-fold increase in climate niche over the next several decades and may harbor key adaptations to cope with future climate. More broadly, we have now found evidence that higher temperatures are an important driver of local adaptation in three contrasting Mojave Desert species, relating to threshold responses in potentially adaptive genetic loci. Precipitation variability was also more important than total precipitation for two species. Although a network of targeted common garden studies will further resolve these relationships in terms of phenotype, we suggest that prioritizing seed-increase efforts on genotypes with expanding future climate niches could be a promising strategy for native plant restoration involving predictive seed sourcing or genetic admixture strategies.

Seed traits, soil seed bank and above-ground vegetation characteristics in northern Arizona grasslands: implications for restoration

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ABSTRACT: Arid ecosystems worldwide are experiencing losses in ecosystem function and services due to human impacts and climate change. In northern Arizona grasslands, historic grazing practices combined with an arid and unpredictable climate may have caused significant changes to the vegetation community and other ecosystem properties. We evaluated soil seed bank and standing vegetation characteristics along a grazing exclusion chronosequence to explore the potential impacts of historic grazing practices and subsequent livestock removal on vegetation communities in northern Arizona grasslands. Additionally, we analyzed a suite of seed traits for species occurring within the study area to investigate the relationships between seed traits and germination as potential drivers of plant community change and limitations to recovery of desert grassland species. Seed traits are a key factor in species' dispersal, establishment, and persistence in communities; they interface with environmental filters at several critical life history stages including dispersal, seed bank residency, germination, and seedling establishment. In light of increased drought frequency and duration due to climate change, insights about soil seed banks and regeneration traits in relation to legacy and current land use practices will help identify mechanisms by which different species may respond to varying environmental conditions or restoration practices in arid northern Arizona grasslands.

Greater Grand Canyon Landscape Assessment: ambitions, collaboration, and outcomes at the interface of science and management

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ABSTRACT: Management of large parks and protected areas is often carried out in relative isolation from the surrounding landscape, despite the fact that many ecological, economic, and social factors interact across jurisdictional boundaries. As part of the Natural Resource Condition Assessment (NRCA) program of the National Park Service, scientists at Grand Canyon National Park and Northern Arizona University's Landscape Conservation Initiative partnered to conduct an NRCA for Grand Canyon National Park that advances a collaborative, landscape-level assessment of both natural and cultural resources. During this assessment, scientists engaged neighboring landowners, land management agencies, tribes, and communities of interest in participatory analyses addressing the condition of key resources and stressors that threaten these resources. Over 170 experts of various backgrounds joined managers with diverse responsibilities to identify, prioritize, and assess cultural and natural resources in an integrated approach unprecedented in scope and ambition. Numerous benefits emerged from the 3-year effort, including new avenues for cooperation, new perspectives on broad trends affecting natural and cultural resources, and the identification of key areas where high-value resources face impending threats. However, the project also identified areas where resource assessments were limited by a lack of data, difficulties in sharing information, and challenges in sustaining collaborative efforts. Two years after completion, efforts to integrate assessment results into actionable management decisions are proceeding, although far slower than initially intended. Nevertheless, as a result of this project an inclusive, landscape approach is currently being implemented to guide resource management at Grand Canyon National Park.

Lessons learned during preparation of the Greater Grand Canyon Landscape Assessment can help inform similarly challenging landscape-scale efforts that offer a valuable approach for improving the flow of knowledge from research to management.

Utilizing cooperative agreements to work with partners in furthering NPS goals

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ABSTRACT: There are two ways that the National Park Service can spend, or "obligate" money. One is the infamously challenging government contracting system, the other is through cooperative agreements. While both are legal instruments, they vary greatly in both intent and objective. Contracts generally give complete responsibility for project execution to the Contractor - who has specific performance standards - and they provide a direct benefit to the government. Agreements must provide a direct benefit to the public beyond the NPS mission. Agreements have not traditionally been used for cultural resource management, as evidenced by the name of our primary source of Cooperators - The Cooperative Ecosystem Studies Units (CESU). It has only been about a decade since cultural resource managers learned how to effectively use cooperative agreements beyond research and documentation projects. They provide a way to enhance capacity, reach out to the professional community, engage students and youth corps, and access technical capabilities within our partners for both brick-and-mortar work and for science. The challenge was to provide a direct public benefit while also achieving the ancillary benefit of preserving cultural resources. The answer was to execute preservation projects in the context of field schools where students, interns, and volunteers could work side-by-side with preservation professionals to learn the philosophy behind preservation work and develop hands-on skills. This provides the direct public benefit. The ancillary benefit is the preservation of cultural resources in the parks. These partnerships allow us to accomplish programmatic goals, and to assist parks in addressing needs related to documentation, assessment, training and project implementation. Vanishing Treasures has helped many parks develop and execute preservation-related agreements including: DEVA-UV Protectant for Redwood, CARE-Reconstruction of Collapsed Lime Kiln, ARCH-Fort Bottom Cabin/Stone Cabin, FOBO-Non-destructive Evaluation of Adobe Walls, GRBA-Johnson Lake Cabins, JOTR-Eagle Cliff, ORPI-Gachado, and ZION-Cable Draw Works.

A snapshot of pioneer women scientists on the Colorado Plateau

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ABSTRACT: Women scientists have helped shape our understanding of Colorado Plateau ecosystems, making lasting contributions to numerous fields of science, technology, engineering, and mathematics. This work has had wide reaching impacts, ranging from cataloging plant life in the Grand Canyon to helping Colorado's fight against polio and tuberculosis. People in the Southwest have a deep appreciation of the women scientists who have pioneered advancements of science and who have improved the understanding of the consequences, challenges, and opportunities of our changing world. Women scientists studying the Colorado Plateau have and continue to be trailblazers for others to follow. Here I highlight a snapshot of the many scientific achievements of women working on the Colorado Plateau.

The role of conservation policy in protecting New Mexico's Gila River network: assessing public support for a wild and scenic river designation

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ABSTRACT: The Gila River in New Mexico is the last major free-flowing river network in the arid Southwest United States. Despite several layers of conservation policy bestowed upon the greater Gila region, this river system and the ecosystem services it provides are vulnerable to development that could exacerbate effects of a warming climate and compromise the river's wild condition. The river network, however, is eligible for additional protections under the National Wild and Scenic Rivers Act (WSRA). If implemented, the WSRA would restrict future damming or diversions on designated river reaches and would seek to improve water quality and specific Outstandingly Remarkable Values, or ecosystem services, recognized within the management plan. However, some stakeholders fear that increased federal regulation may not result in effective management and could threaten local control of the river's resources as well as future development opportunities. Thus, this research seeks to identify the ecosystem services most valued in the river network and the public perceptions of potential designation under the WSRA. The deployment of surveys and semi-structured interviews with stakeholders within the Gila River region show the majority of respondents value the cultural ecosystem

services provided by the Gila River network and welcome WSRA designation. However, themes that surfaced during interviews revealed that there exists widespread misunderstanding of what the WSRA has the potential to preserve and how it may impact the Gila River network. This research aims to inform decision-making for river conservation policy within the watershed and greater national Wild and Scenic River System.

Climate migrants, climate refugees and the future of the Colorado Plateau

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ABSTRACT: Climate change is disrupting both natural and agro-ecosystems on the Colorado Plateau and in surrounding regions. These changes are affecting human populations in a number of ways. Increases in the number of days of extreme high temperature in central and southern Arizona are increasing the number of climate migrants in Flagstaff. Reduced water availability and associated losses in agricultural productivity in Central America are projected to increase the number of climate refugees from those areas. Rise in average temperatures in Flagstaff are driven primarily by the loss of low temperature days and this will continue to affect snow amounts and seasonality. This has already affected river rafting businesses in northern Arizona. Drying springs and other water sources and increased winds in the fall are increasing costs for ranchers in northern Arizona. Socioeconomic costs of climate change are projected to increase in every county of the Colorado Plateau in terms of energy costs, violent crime, property crime, and loss of high-risk labor force before the end of the century. Sea level rise along US coastlines is projected to result in 50k to 200k additional climate refugees per county in Coconino, Navajo, and Apache counties by 2080. Climate refugees from hurricane Katrina and hurricane Maria have been documented on the Colorado Plateau and as storm frequency and intensity continue to increase more can be expected. Incoming climate migrants and climate refugees will put additional pressure on housing availability and prices and on already dwindling water resources.

Climate interacts with grazing to alter diversity and composition of a semiarid grassland

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ABSTRACT: In semiarid grasslands, the effect of grazing on native plant diversity has been equivocal; some studies suggesting that grazing reduces diversity, others that grazing increases or has little impact on diversity. One impediment towards generalizing grazing effects in this region is that high levels of inter-annual variation in precipitation may obfuscate vegetative response patterns. By analyzing a long-term dataset collected over a 20-year period, we explicitly evaluated the role of climate in regulating the effect of cattle grazing on plant communities. Native species richness was low in plots that were intensively grazed relative to ungrazed and moderately grazed plots. Following a severe drought in 2002, exotic species richness and cover rapidly increased in the high-intensity grazing plots. While this pattern was mirrored in the other treatments, exotic species richness and cover increased to a greater extent and was slower to return to pre-drought levels in the high intensity grazing plots. Moreover, the 2002 drought event altered plant community taxonomic and functional composition, resulting in a persistent shift towards annual species in the high intensity plots. Overall, moderate grazing, even compared to grazing cessation, stabilized grassland communities through time, increased resilience to drought, and maintained the highest levels of native plant diversity and lowest levels of exotic diversity. These findings suggest that grazing, at moderate levels, may support grassland resilience to climate change in semiarid regions. However, grazing that exceeds tolerances, particularly in combination with extreme climatic events, like drought, can alter plant composition over relatively long timescales and possibly increase invasibility by non-native species.

An evolving partnership between Arizona tribes, the Forest Service, and researchers to ensure the availability and sustainability of culturally important plant species on federal lands

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ABSTRACT: The Emory Oak Collaborative Tribal Restoration Initiative (EOCTRI) is currently in the early stages of treating 13 Emory oak groves located on the Coconino and Tonto National Forests with the purpose of ensuring the sustainability of subsistence

foods for Arizona tribes. The Yavapai-Apache, Tonto Apache, San Carlos Apache, and White Mountain Apache Tribes direct the project, while the USFS, under the leadership of the Tonto National Forest Tribal Relations Program, manages the project execution and coordination. Research is integrated throughout the project, informing the restoration treatment protocols and quantifying treatment effects, in order to export best practices for restoration and management of Emory oak to other forests and oak stands. During our presentation, we will describe the importance of Emory Oak to Apache peoples, the origins and status of the EOCTRI project, the challenges and rewards of conducting research on a restoration project conducted across multiple Forest Service districts, and the projected future of this dynamic and evolving collaboration.

Grassland vegetation collapse following long-term drought on relict mesas in Glen Canyon National Recreation Area

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ABSTRACT: On the Colorado Plateau there are numerous mesas that support relict soil and vegetation undisturbed by human activities. In 1987, via helicopter, The Nature Conservancy surveyed the vegetation of several relict mesas in Glen Canyon National Recreation Area using 50 m x 2 m belt transects along which plant cover, density and frequency were recorded. In 2014, the NPS resampled transects on four of these mesas, 5381, Horn, Monument and Mazuki Point. The original transects were relocated on three of the four mesas, while the fourth transect was matched as best as possible using available photographs as the transect rebar monuments could not be located. The transect data show that the original grasslands on three of the mesa tops experienced significant declines sometime between 1987 and 2014. The cool season bunchgrasses *Achnatherum hymenoides* and *Hesperostipa comata* showed the greatest declines in cover of up to 95%. Declines in the warm season turfgrass *Hilaria jamesii* also occurred, but were less severe. Monument Mesa, the only super-relict mesa in the study (lacking native mammalian herbivores larger than rodents), showed the smallest overall declines, with the cool season grassland still present and intact. On all mesas shrub cover increased, while herbaceous forb responses were variable. No significant turnover in community composition occurred, although the relative abundance of many species changed. The exotic annual grasses *Bromus rubens* and *B. tectorum* were encountered in both surveys, but no *Salsola pestifer* (Russian thistle) was found on the mesas during the 1987 surveys. This species was encountered on all mesas in 2014. The results have significance for understanding the role of climate change impacts on economically important grasslands on the Colorado Plateau.

Preserving the connection: habitat connectivity in Scottsdale's McDowell Sonoran Preserve

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ABSTRACT: Large, contiguous landscapes are necessary to maintain wildlife species' access to resources, movement routes, and gene flow. Human development can fragment these landscapes and cut off wildlife movement. The McDowell Sonoran Preserve in Scottsdale, Arizona, is uniquely situated to connect Tonto National Forest with McDowell Mountain Regional Park, providing nearly 3 million acres of protected habitat. A narrow corridor connects the northern and southern sections of the Preserve. Development is rapidly filling in around, and a road cuts through that linkage. We used wildlife cameras to assess the mammalian community within the corridor and other areas of the Preserve. We placed 20 cameras approximately 1 km apart in Preserve washes from 2017–2019, and trained citizen scientists regularly processed captured images. Results indicate that a robust mammalian community occupies all sections of the study area, including the narrow corridor. Although species richness is similar in each area, community composition differs. Urban exploiters are the most likely species to occur in the corridor, whereas species such as deer and javelina are rare compared to other parts of the Preserve. We will continue to monitor the wildlife cameras to determine how the mammalian community may change in the future with increased development pressures. The results of this study will help inform management decisions to maintain connectivity within the Preserve and to potentially mitigate impacts from encroaching development.

Buffelgrass and fountain grass removal experiments

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ABSTRACT: Non-native plant species can wreak havoc on the landscape, displacing native species, altering wildlife habitat, and spreading wildfire. Control of these species can be difficult due to the prolific nature of these plants, which is further complicated by limited resources, including time, money, and workforce. Previous studies investigating control techniques have been short term, included only a partial suite of removal techniques, or did not determine effects on the native plant community. Our objective is to determine efficient, effective control measures for fountain grass (*Pennisetum setaceum*) and buffelgrass (*Pennisetum ciliare*) that best protect the native plant community over the long-term. We established 5x5 m plots in the McDowell Sonoran Preserve in Scottsdale, Arizona, and are testing combinations of cutting, herbicide, and hand pulling for both species. These treatment plots are compared to uninfested control plots in similar habitat. Once per year, we document plant and ground cover on five transects in each plot, which allows us to compare treatment effects on native and non-native species. We record cost and effort for each treatment application. We have conducted two years of treatments and plant sampling. Initial results indicate that fountain grass responds favorably to all treatments, whereas multiple herbicide applications are necessary for buffelgrass control. Because plants must be photosynthetically active for most herbicides to work, drought may be a limiting factor in buffelgrass control. Results of this project will help land managers choose the most appropriate means to achieve long-term control of these non-native species in arid regions.

More than just cliff dwellings: survey at Navajo National Monument, Arizona

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ABSTRACT: The Museum of Northern Arizona (MNA) recently collaborated with the National Park Service (NPS) to complete a comprehensive survey of Navajo National Monument in northern Arizona, thereby assisting the NPS in meeting their Section 110 compliance responsibility. The spectacular cliff dwellings of Keet Seel and Betatakin have been known to science since the early 1900s, but no comprehensive inventory had been conducted of the entire monument. Survey in 2016 focused on the mesa top and canyons in the vicinity of Betatakin, resulting in discovery of two late Puebloan habitation sites, two probable Archaic camps, and several historic sites related to Navajo herding and NPS infrastructure development. The probable Archaic camps are particularly significant because no sites of that age had been previously identified in the monument, although Archaic sites are common in the region. Survey in 2016 around Inscription House resulted in the discovery of new petroglyphs and buried cultural horizons. In 2017, survey in the canyon surrounding Keet Seel documented historic inscriptions, prehistoric and historic trails cut into bedrock, and two previously unknown buried sites. Survey on the mesa top above Keet Seel primarily revealed logistical sites dating prior to the occupation of the large cliff dwelling, suggesting a shift in activity and resource procurement areas over time. In total, the MNA-NPS survey documented 25 previously unknown sites, a 54 percent increase of cultural resources known in the monument. The survey results will allow managers to interpret the human history of the monument in greater detail, and promote the development of research goals specific to the types and temporal span of the prehistoric and historic resources.

Strange resurrection: the fall and rise of John Wesley Powell

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ABSTRACT: Wallace Stegner's publication of *Beyond the Hundredth Meridian* in 1954 helped bring John Wesley Powell from posthumous obscurity to renewed fame. Stegner proclaimed Powell the "*genius loci*" or guardian spirit of "all the canyons of the Green and Colorado." Can this characterization be reconciled with Powell's vision for Western rivers? To the contrary, it appears that if the Colorado River Basin had taken shape as Powell imagined it, there would not only have been no wild rivers, there would have been no rivers at all. Past portrayals of Powell, as well as the paradoxical nature of his character, deserve attention. At the same time, no historical construction (or arguable misconstruction) of Powell should stand in the way of our gleaning valuable lessons from his life and work in modern times. Such lessons include the importance of climate science, pragmatism and civic discourse, and commitments to social justice.

Proposed changes in endangered species classification of two Colorado River fish: part II - U.S. Fish and Wildlife Service proposes downlisting the razorback sucker (*Xyrauchen texanus*)

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ABSTRACT: The USFWS uses species status assessments (SSA) as the basis for a variety of decision-making processes [e.g., Endangered Species Act (ESA) Section 7 consultations; species recovery plan revision; and ESA Section 4 species classification decisions]. SSA's review the best available information on a species' needs, its current condition, and future condition. The SSA is not a decision-making document. An SSA for razorback sucker was completed in September 2018. The USFWS relied on the findings of the SSA to develop a 5-Year Review for the species. A 5-Year Review is a decision-making document; in this case, the USFWS - Mountain Prairie Regional Director has decided to propose: 1) reclassification of razorback sucker from endangered to threatened status, i.e., downlisting, and 2) revision of the species recovery plan. We will review the major findings of the SSA, which serve as the basis for the USFWS's Proposed Downlisting Rule (PDL; scheduled for publication in the *Federal Register* in 2020). We will also review the content of a proposed 4(d) rule that will be published with the PDL. The authors will host a 15-minute Question and Answer session with the audience to discuss this proposed listing action and a similar action for humpback chub (*Gila cypha*).

Biocrust optimization of net carbon to varied precipitation pulses

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ABSTRACT: Research has shown that Southwest desert vascular plants respond to varied precipitation event sizes and frequencies but far less is known about the responses of non-vascular autotrophs such as mosses and cyanobacteria, collectively known as biocrust. In fact, the size and frequency of precipitation events that favor biocrust survival and growth are still largely undetermined. Nevertheless, understanding how these important ecosystem members respond to alterations in precipitation is necessary to effectively manage and restore southwestern drylands. In this experiment we explored how changes in precipitation size and frequency affect biocrust growth and functional responses. We asked two main questions: (1) How do (*Synthrichia caninervis*) moss and darkly-pigmented cyanobacterial biocrusts respond to different precipitation pulse sizes? (2) Are there optimal pulse sizes and frequencies for biocrust growth and function? To answer these questions, we applied five different watering treatments over a three-month period, with incrementally larger and less frequent rainfall events, while keeping the total overall precipitation added the same. We measured biocrust surface temperature and moisture, light and dark CO_2 measurements and photosystem II efficiency at the beginning, middle, and end of the experiment. Building from previous studies, we predicted that moss and darkly-pigmented cyanobacteria would respond more favorably to larger but less frequent precipitation events, and that a threshold would exist above which biocrusts would respond positively to increased precipitation sizes and below which increased frequencies would be detrimental to biocrust. Through these findings, we can help predict the response of these important biocrust community members to altered precipitation regimes and inform management of soils in semi-arid environments into the future.

A cost-effective and reliable method to genetically fingerprint horses using degraded scat

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ABSTRACT: In Central Arizona, feral horses challenge land managers responsible for mitigating grazing impacts. Research on their population structure and dynamics is limited because the collection of tissue samples for molecular analysis is difficult. Difficulties in sample collection are diminished by the use of non-invasive techniques to collect DNA from scat. Such a technique generally exists, but in places such as Central Arizona where sunlight can quickly damage environmental DNA, refinement is necessary. The purpose of this study was to develop a cost-effective and reliable fingerprinting method to use with degraded DNA from feral horse scat obtained using non-invasive techniques. We compared amplification success of DNA obtained using two DNA extraction methods, and we evaluated the effect of sample degradation on DNA amplification across 10 microsatellite loci. Our findings suggest that a commercial extraction method had more amplification and genotyping success, but the less expensive lab standard yielded comparable

results while producing more DNA for half the cost. Our results will make available a technique that will allow the analysis of population structure, genetic diversity and inbreeding in a Central Arizona population of feral horses.

Social-ecological systems and climate migration across the western US

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ABSTRACT: Climate change is impacting human and non-human systems in complex and interconnected ways, and in response, people are on the move. In the western United States, news reports describe the role of climate in human migration across the Southern border, permanent displacement of residents from their communities after events such as fires in California or coastal erosion in the Arctic, and affordable housing shortages in mountain towns impacted by amenity migrants. We conducted a literature review of human climate migration in the West. We found that published research on the environmental and social impacts of human movement in response to climate change in the western United States is limited, and focuses primarily on issues of amenity migration and displacement due to coastal erosion, while research outside the western US addresses a broader set of issues and impacts, including those of urban-rural movement. We offer a framework for considering the spectrum of reasons for and impacts of climate-driven human movement, and discuss what can be learned from studies in other geographies that might apply to this region. We also explore opportunities for regional inter-organizational collaboration and research to generate sustainable and just policy responses to these social and environmental pressures.

Developing science with management in mind: stories of participatory analysis and collaborative planning

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ABSTRACT: Decision making for land management on the Colorado Plateau requires sound science and responsiveness to social values. Collaborative, multi-stakeholder groups are often convened to provide guidance to agencies or collectively make decisions regarding land management issues. In these sometimes high-conflict situations, science can be a point of tension and disagreement, or a source of common ground, providing a tool for deliberation and helping parties find a path forward that meets common interests. We will discuss guiding principles from the collaborative planning and conflict resolution fields that provide a framework for effective co-production of actionable science, and share research outcomes and experiences from several case studies on the Colorado Plateau.

Risk and vulnerability assessment of adobe and masonry ruins at Pecos NHP

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ABSTRACT: The National Park Service has a long history of advancing the practice of cultural resource preservation and integrating that practice across disciplines to protect and preserve natural and cultural resources for the American public. Administering and managing cultural resources has become ever-more complex due to the amount of information needed about resources to understand, protect, and preserve them. Critical baseline information, especially focused on integrated science-based monitoring, modelling, and real time evaluation of conditions and interventions has been the focus of developing a Vulnerability and Risk Assessment framework for several parks in the Intermountain and Desert Southwest Regions, especially in the wake of changing climate. With a huge backlog of deferred maintenance and a poor understanding of building and site performance and deterioration, especially in the context of past aging treatments, limited monitoring, and an uncertain future, identifying vulnerability is now a priority concern. The focus of this study is Pecos National Historical Park where an integrated methodology has been developed to assess past and current conditions using a variety of coordinated data sets including legacy site records, time lapse photography, rapid assessment survey, material studies, and weather data to develop the first phase of a site wide preservation conservation and management plan.

Grand Falls Dune Field, a Mars analog on the Colorado Plateau

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ABSTRACT: In this talk we will discuss seven years of monitoring at the Grand Falls Dune Field with a focus on what aspects of the dune field qualify it as a Mars analog. We will review the equipment used at the site and discuss lessons learned in the field. *Any persons wishing to conduct geological investigations on the Navajo Nation including visiting the stops described in this guidebook, must first apply for and receive a permit from the Navajo Nation Minerals Department, P.O. Box 1910, Window Rock, Arizona 86515, telephone # 928-871-6588.*

Leveraging long-term data sets to address land management issues

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ABSTRACT: The Inventory and Monitoring (I&M) Division of the National Park Service supports the mission of preserving and protecting our national parks by providing science to inform natural resource management. Each of the 32 nation-wide networks embarked on a thorough planning process with a bottom up approach, working in conjunction with park staff and regional researchers to select indicators and design monitoring programs that would be highly applicable to park management. This is the primary way that I&M seeks to integrate science and management - meeting the needs of individual parks through place-based science. I&M data have been used to support planning strategies for climate adaptation, fire, livestock grazing, and overall resource stewardship at a park or group of nearby parks. A secondary way that I&M seeks to integrate science and management is by incorporating I&M datasets into regional research and monitoring programs. By partnering with researchers from universities and other federal agencies, large I&M datasets can be leveraged to spatially broaden understanding of the natural resources monitored and to compare the impacts of management strategies used within national park units with more intensive management practices on other federal lands. Two regional networks, the Northern and Southern Colorado Plateau Networks, are now more than a decade into collecting long-term data on upland vegetation and soils across the Colorado Plateau. They will share examples of how they have leveraged I&M datasets to inform science-based land management at both the park-level and across the landscape, and highlight successes and lessons learned along the way.

Impacts of drought and seed source climate on survival in southwestern white pine seedlings

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ABSTRACT: The western United States is predicted to experience earlier onset of spring and increased drought, which could disrupt the synchrony between environmental cues and growth. Early snowmelt and late frosts exert pressure on cold tolerance physiology, and trees that grow too early in spring are at risk of mortality. Additionally, early snowmelt lengthens the growing season in forests that rely on summer monsoon precipitation thus increasing exposure to drought. Southwestern white pine (*Pinus strobiformis*), which grows on isolated high-elevation sky islands across the southwestern United States and Mexico, is an ideal species for investigating the impacts of drought and variable climate on survival. Through a common garden experiment with 22,154 seedlings (from maternal trees across the species' range) planted in three consecutive years at three different elevations, our research group has studied the impacts of precipitation and temperature extremes on seedling phenotypes and survival. For two growing seasons a drought treatment was applied to half of the individuals at each garden. To investigate the possible impacts of local and seed source climate on survival, we assessed the impact of the drought treatment on survival after two years of implementation. Preliminary results suggest that *P. strobiformis* seedling survival was influenced by both local and seed source factors. An interaction between the gardens where the seedlings were planted and the drought treatment significantly impacted overall survival. Additionally, seed source climate variables, related to precipitation and temperature, were significantly associated with seedling survival. Our results will help identify populations and families of *P. strobiformis* that are putatively drought tolerant and more likely to survive under future climate extremes.

The Lower Colorado River Multi-Species Conservation Program

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ABSTRACT: The Lower Colorado River Multi-Species Conservation Program (LCR MSCP) is a multi-stakeholder, Federal and non-Federal partnership that seeks to balance the use of 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 long-term (50 year) program that provides the ESA compliance for covered activities such as the delivery of 9 million acre-feet (maf) of water to Arizona, California, Nevada, and Mexico; the generation of power from 6 facilities; operations and maintenance activities along the river; and change in point of diversion for up to 1.574 maf. The partnership is comprised of 6 Federal and 51 non-Federal agencies including water users, powers customers, state agencies, municipalities, Native American Tribes, and non-governmental organizations. The Bureau of Reclamation is the lead implementing agency. Incidental Take Authorization is obtained through the implementation of a Habitat Conservation Plan, which contains conservation measures to meet the biological needs of 27 covered species and to benefit 5 evaluation species.

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

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ABSTRACT: The Lower Colorado River Multi-Species Conservation Program (LCR MSCP) is a long-term (50 year) program that provides the Endangered Species Act compliance for covered activities such as water delivery; power generation; operations and maintenance activities along the river; and change in point of diversion for water deliveries. The Bureau of Reclamation, as the lead implementing agency, is responsible for completing conservation measures listed in a Habitat Conservation Plan (HCP) designed to meet the biological needs of 27 covered species and to benefit 5 evaluation species. Two major focus areas of the HCP are the creation of new habitat for 21 covered species and the augmentation of native fish populations within the lower Colorado River. Since implementation began in 2005, the LCR MSCP has established over 6,000 acres of cottonwood-willow, honey mesquite, marsh, and backwater habitat. This represents almost 75% of the required acreage; this habitat has been established twice as fast as the planned scheduled allowed. Many targeted covered species have been detected using this new habitat. Almost 300,000 native fish have been raised and stocked as part of the fish augmentation program with an additional 126,000 razorback suckers stocked in Lake Mohave to maintain the genetic diversity of this important population. Still, challenges exist. While razorback sucker populations have been established in multiple areas, bonytail stockings have not been as successful. Stocking is required to keep both species present in the river. Administrative issues, such as ensuring hatchery capacity for the fish augmentation program and securing land and water for habitat creation in California, are continuing concerns. Unanticipated challenges, such as the 19-year drought and new invasive species, have added to the complexity of meeting HCP requirements; however, the flexibility built into the program documents has allowed us to meet these challenges.

Collaborating with tribes: Lessons learned from developing the Diné Native Plants Program

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ABSTRACT: The Navajo Nation (Diné Bikéyah) is the largest reservation within the United States, covering 27,000 square miles of the Colorado Plateau. Because of its scale and unique geologic features, the Navajo Nation is home to a diverse array of ecosystems and species, many of which are endemic to the region. However, a large proportion of Navajo ecosystems are in a degraded state due to decades of overgrazing by livestock and feral horses, oil and gas development, mining, invasive species, and will likely be further impacted by climate change. Recognizing the need for restoration, the Navajo Nation Department of Fish and Wildlife recently initiated the Diné Native Plants Program (DNPP) to develop native plant material production for re-vegetation on Navajo land. We conducted a feasibility study in 2018 to assess the native plant needs of official Navajo Nation (and affiliated) agencies and Navajo community members to ensure the operations of the DNPP are meeting the needs of all potential stakeholders, while also respecting the cultural beliefs of the Navajo People. The results of the feasibility study showed overwhelming support for the mission of the DNPP, identified priority species, and illuminated concerns regarding seed collection and propagation of culturally important plants. We are currently using the feasibility study to guide seed collection/propagation for our seed bank and forthcoming restoration projects. Further, we are able to use feedback from the feasibility assessment to highlight barriers to collaboration between outside organizations and the Navajo Nation, and suggest guidelines on successfully working with the Navajo Nation on research and restoration.

Ecosystem restoration on the Hopi Reservation, Arizona

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ABSTRACT: This talk will familiarize the audience with the cultural link that the Hopi Tribe of Arizona has to water, the hydrology of the Hopi Reservation, and the efforts of the Tribe to restore important ecosystems in a changing climate. Surface water is a scarce and valuable resource with great cultural and ecological significance to the Hopi people. Almost all surface water of the Hopi Reservation issues from springs, creating groundwater dependent ecosystems or GDE's. With seven aquifers and a variety of water qualities the hydrogeologic framework supporting the springs is complex. Climate change can affect the springs differently according to which aquifer they issue from. The funding framework supporting restoration will be discussed, the development of a robust tribal Wetland Program utilizing EPA's Core Elements Framework will be examined, and we will discuss funding restoration and erosion control via Clean Water Act 319h Nonpoint Source grants. Mr. Taylor will highlight several restoration projects on springs and watersheds and the challenges, successes, and failures Hopi Water Resources Program has experienced in years of working on high desert ecosystems. Examples of projects at Keams Canyon, Polacca, White Ruin Canyon, Shungopovi, and Hotevilla will be presented. With a variety of hydrologic environments and problems, the Hopi Tribe's experiences in dealing with its water issues may prove relevant to other water managers.

Urban striped skunk ecology and rabies management in Flagstaff, Arizona

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ABSTRACT: Wildlife populations are the major reservoirs for the rabies virus in North America and each year, approximately 55,000 people across the USA require post-exposure prophylaxis due to suspected contact with a rabid animal. Rabies on the Colorado Plateau is maintained by a variety of wildlife reservoirs, with species specific variants of the virus found in several bat species, striped skunk and gray fox. Spillover and potential host shifts from big brown bats to striped skunks and gray foxes has been the primary driver for rabies in and around Flagstaff, Arizona since 2001. We review our studies of the ecology of urban skunks in Flagstaff and address several hypotheses about the transmission and maintenance of the disease, including the influence of winter denning and torpor, the potential for artificial urban waters to increase transmission from bats to mesocarnivores, the ecological potential for transmission via scavenging dead carcasses, and the potential for seed spilled from bird feeders to act as foci for disease transmission and vaccination.

Survey and monitoring of the endangered Arizona hedgehog cactus: can we do it better?

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ABSTRACT: The Arizona hedgehog cactus (*Echinocereus triglochidiatus* var. *arizonicus*) is endemic to central Arizona and has been federally listed as endangered since 1979. Mining, mineral exploration, and highway development have resulted in habitat degradation and loss of plants. Compilation of survey data is essential for evidence of the cactus' population size, distribution, and range extent. Systematic surveys for the Arizona hedgehog cactus began in the late 1970s and early surveys were usually anecdotal. Precisely georeferenced records of cactus occurrence came only with the advent of global positioning systems. Contributed survey records have been compiled by the Arizona Game and Fish Department, but contributions of these data by various consultants and agencies may be incomplete, and the reported attributes vary. Monitoring data, in contrast to survey data, comprise repeat observations of cactus individuals. Demographic monitoring further involves marking individual cacti in consistently defined plots and recording the fate of each through time, including birth, growth, reproduction, and death. We used existing demographic monitoring data to calculate survival and population growth rates for the cactus. Resulting models indicate larger cacti, as measured by number of stems, have greater survival rates. Larger individuals also had higher probability of producing more flowers. Small cacti had the lowest survivorship, with potentially only 15–20 percent reaching large size. Most of the populations monitored were stable to increasing; however, there were differences in the growth rates among plots and some plots had negative population growth rates. Previous analyses with cacti suggest at least 10 years of data are necessary to accurately forecast long-term population trajectories. The monitoring intervals we evaluated were shorter and represent short-term dynamics only. Several suggestions are made in this presentation to improve collection of survey and monitoring data to support evidence-based input to recovery planning for the Arizona hedgehog cactus.

Investigating the potential for effects from breccia-pipe uranium mining on regional water resources in the Grand Canyon region

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ABSTRACT: The Grand Canyon region in northern Arizona is an international tourist destination and home or sacred place of origin for many Native Americans. It also hosts some of the highest-grade uranium deposits in the U.S. and has subsequently experienced varying levels of uranium mining activity since the 1950s. Beginning in 2005, the price of uranium increased from about $20 per pound to $136 per pound in June 2007, prompting thousands of new uranium mining claims in the Grand Canyon area. In January 2012, then-Secretary of the Interior Ken Salazar withdrew 1,006,545 acres of federal land near Grand Canyon from new mining activities for a 20-year period, citing scientific uncertainties in potential impacts from uranium mining on cultural, biological, and water resources in the area. In cooperation with land managers in the region, the U.S. Geological Survey developed a multidisciplinary science plan to address data and knowledge gaps identified in the withdrawal record of decision. Data collection and interpretive studies are being conducted to better understand how breccia-pipe uranium mining may impact water resources, what impacts might look like, where the impacts might be observed, and when those impacts might appear. Current water studies include developing a conceptual model of groundwater flow in the region, investigating groundwater chemistry in the region to increase understanding of baseline conditions, and monitoring water chemistry in the Colorado River as well as water and sediment chemistry in major tributaries in the region. Results from these and other studies will provide policymakers and land managers with objective, unbiased scientific information so they can make informed decisions about how to manage resources in the Grand Canyon region.

Restoration planning with simulations using southwestern willow flycatcher fine scale (1m) habitat models incorporating riparian woodland species aerial imagery classification

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ABSTRACT: Optimal restoration site planning for habitat of the federally endangered southwestern willow flycatcher (*Empidonax traillii extimus*, flycatchers) requires data on the size and configuration of riparian woodland species patches with respect surface water, and incorporation of risks from tamarisk beetle (*Diorhabda* spp.) defoliation and fire. Vegetation at a flycatcher occupied site on Tonto Creek, Arizona was mapped using classification of multi-temporal high resolution (1 m) aerial imagery from USDA National Agricultural Imagery Program and Google Earth. Habitat suitability index (HSI) and GLM niche models incorporating riparian vegetation mapping were compared for projecting flycatcher habitat suitability at the site. Four variables were included in the baseline flycatcher habitat models, including percent cover of tamarisk/willow/cottonwood at 2-10 m height, patch area, vegetation height, and distance to water. Nest tree defoliation susceptibility from tamarisk beetles was included in habitat model simulations. Flycatcher habitat simulation scenarios were also developed for tamarisk beetle-induced defoliation and dieback, and restoration of willow habitat patches. Spatial models of fire canopy removal and fire mortality for the study area were based on an expert model incorporating riparian fire data. Riparian vegetation was classified to 87% accuracy using random forest in conjunction with feature selection for a large number of spectral indices. Both HSI and GLM flycatcher habitat models had high accuracy (AUC = 0.98), and the HSI model provided a more conservative estimate of suitable habitat. Three-year simulation scenarios projected how many hectares of willow patches and surface water pools were needed to mitigate for flycatcher habitat suitability lost to tamarisk defoliation and dieback from tamarisk beetles. Fire simulations highlighted the greater risks for flycatcher habitats in tamarisk stands. The flycatcher habitat suitability simulations can guide planning of willow restoration activities to improve flycatcher habitat suitability in tamarisk beetle affected habitats.

Intra-annual measurement of drought relief in *Pinus ponderosa* radial growth near the northwest edge of the North American Monsoon region

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ABSTRACT: The 2012-2015 drought in Nevada and California was one of the most severe droughts in recent history. The termination of this drought in southern Nevada began in the late warm season of 2015 with precipitation from an unusual hurricane (Dolores) that recurved into the area. Subsequently, an exceptionally larger snowpack deposited in the mountains of southern Nevada by Pacific Ocean storms during the 2015-2016 cool season. We sampled precipitation, stem water, and microcores (2 mm width) on a biweekly interval at a highly-instrumented ponderosa pine forested site in the Sheep Range of southern Nevada. A sharp depletion in $\delta^{18}O$ was detected in precipitation and stem water samples associated with the late warm-season precipitation events of 2015, which was followed by a depleted $\delta^{18}O$ stem water signal for the entire 2016 growing season. We used a microtome to slice the 2015 and 2016 tree rings into quartiles and calculated the date of when each quartile finished cell wall thickening using xylogenesis results. A depletion of $\delta^{18}O$ and $\delta^{13}C$ indicative of drought-relief was measured in the latewood α-cellulose of small trees in the 2015 tree ring. The continued depletion pattern of $\delta^{13}C$ in the earlywood and sharp depletion of $\delta^{18}O$ in the last quartile of the α-cellulose in the 2016 tree ring in small and large trees was linked to the depleted $\delta^{18}O$ soil water from the large snowpack of the 2015-2016 cool season. Small trees were more sensitive to the depleted $\delta^{18}O$ late warm-season precipitation in 2015 after the drought, while both small and large trees radial growth appear to be driven by snowmelt in 2016. Intra-annual radial growth, stable isotopes, and meteorological measurements provide insight into the mechanisms of radial growth response to severe drought in threatened montane forests of hyper-arid regions.

Can assisted migration improve biocrust restoration outcomes in the face of accelerating climate change?

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ABSTRACT: Current approaches to restoring biological soil crusts are largely focused on using local biocrusts communities because they are adapted to the local environment, and because of the importance of preserving ecological integrity. However, warming experiments and global modeling studies suggest that some biocrust communities may be poorly suited to grow in parts of their current range under future warming. One potential solution to this problem has been variously called “assisted migration”, “climate-smart restoration” or “prestoration”, wherein species or genotypes are transferred from a warmer site to the target site anticipating a warmer future. Here we evaluate growth and climate sensitivity of moss-lichen biocrusts harvested from multiple sites across western U.S. drylands spanning wide bioclimatic gradients. Community composition along these gradients supported the hypothesis that the proportion of moss, lichen and cyanobacteria in biocrusts is in part a function of bioclimate. Biocrusts from these sites were used in paired greenhouse and field restoration trials, evaluating the response of biocrusts to shading, altered wetness, and warming. Under cooler and wetter conditions mosses from cooler sites grew rapidly in both the greenhouse and field, but fared poorly in the absence of shading and with warming. Lichens, especially those from the Mojave, were inhibited by shading, but grew best under warmer, drier conditions. Concurrently, we have been pioneering an approach to salvaging large amounts of biocrusts from areas slated for development, and cultivating these in an outdoor nursery to provide an inoculum source for restoration. In this outdoor nursery, we find a similar pattern, in which lichen-rich biocrusts from the Mojave showed the most promise as restoration inoculum at our site on the Colorado Plateau. While there is some promise for assisted migration, geographic transfers pose numerous potential pitfalls, which remain to be comprehensively evaluated.

Development of silvicultural objectives managing high elevation mesic coniferous forests in southwestern Colorado

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ABSTRACT: After a period of extensive management from approximately the 1950s through early 1980s, high elevation spruce-fir and mixed-conifer forests have been a low priority for vegetation management on public lands in the Southwest until recently. Over the last decade, active management of high elevation coniferous forests in Southwest Colorado has resumed in response to broad scale forest health concerns and a renewed demand for wood products from these forests. The climate, composition, structure, succession and disturbance processes in these forests differ dramatically from lower elevation frequent-fire-adapted forests which have been a top priority for management for past few decades. Several silvicultural approaches have been applied in the management of these forests on the San Juan National Forest over the last several years. These efforts demonstrate the application of principles of ecological forestry to develop economically viable and ecologically compatible silvicultural objectives and management practices in these forests. We discuss the challenges and opportunities associated with the development and implementation of these approaches and

highlight key differences between the objectives guiding management of these forests and those guiding management of lower elevation, frequent-fire-adapted forests.

Climate and vegetation effects on ant communities

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ABSTRACT: Despite hundreds of studies showing that terrestrial animal communities are largely driven by both vegetation and climate, we still don't fully understand their relative and/or interactive effects. Our study investigates the role of climate and vegetation in shaping ant communities by observing community changes along elevational gradients in northern Arizona. We tested and compared weather, climate, and vegetation predictor variables, finding that average annual precipitation and temperature, and vegetation composition best explained observed ant patterns. Structural equation modeling was then used to test the relative effects of climate and vegetation on ant communities. We found that ant composition was driven mainly by temperature and precipitation, while ant richness and abundance were driven by temperature, precipitation, and vegetation composition. Our results highlight the strong direct role that climate and vegetation composition plays in shaping ant communities, and suggest that indirect effects of climate through vegetation are relatively weak.

Importance of Middle Rio Grande floodplains to the endangered Rio Grande silvery minnow

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ABSTRACT: The abundance and diversity of native fishes in the Rio Grande have declined over the last few decades as flood control and river regulation have reduced the frequency and magnitude of overbank flooding and delinked much of the floodplain from the mainstem. The endangered Rio Grande silvery minnow (*Hybognathus amarus*, RGSM) is a native broadcast-spawning species that has been reduced to 5% of its historical range, with the only remaining wild population in the Middle Rio Grande (MRG). A positive relationship between spring river discharge and October catch-per-unit-effort (CPUE) suggests that the RGSM is floodplain-dependent, but the mechanisms behind this relationship are poorly understood. Natural and restored floodplains of the MRG were sampled April−June 2016−2019, with a focus on spawning, egg incubation, and larval development of RGSM. A large proportion of adult RGSM were gravid or spent females and ripe males, indicating that substantial spawning and egg incubation is taking place within inundated floodplains. RGSM were the most abundant larvae of ten fish species found in floodplains, and their residence time in this nursery habitat appears to be related to developmental phase, where the larvae become increasingly mobile with fin and fin-ray development in the postflexion mesolarval and metalarval phases at 14−22 days post-hatch. These studies show that timing of floodplain inundation affects the availability of nursery habitat for the newly-hatched larvae and the synchrony of food production; magnitude of inundation affects the amount of floodplain habitat available; and duration of inundation is necessary for larval development. The RGSM appears reliant on floodplain habitat for spawning, egg incubation, and larval nursery, and coordinated water management, as hydrological conditions allow, can enhance floodplain inundation and promote reproductive success and recruitment of RGSM.

Tamarisk Defoliation and Restoration: The Influence on Birds along the Dolores River in Southwestern Colorado

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ABSTRACT: The tamarisk leaf beetle (*Diorhabda carinulata*), introduced as a biological control agent for the invasive plant *Tamarix ramosissima*, has spread throughout the western USA. With *D. carinulata* now very abundant, scientists and restoration managers have questioned what influence this introduced arthropod and habitat restoration activities might have upon the avian component of riparian ecosystems. From 2009 through 2012 we studied the consequences of tamarisk leaf beetles on avian diets and habitat restoration activities on bird density along the Dolores River in southwestern Colorado, USA. We documented *D. carinulata* abundance, plant species where the beetles occurred, and the degree to which they were consumed by birds compared to

other arthropods. We hypothesized that if *D. carinulata* is an important new avian food source, birds should consume beetles at least in proportion to their abundance. Despite *D. carinulata* being the most abundant arthropod in the environment, these invasive beetles were infrequently consumed by birds and seem not to provide a significant component of avian diets. We also assessed the effects of tamarisk restoration and defoliation by monitoring defoliation rates, changes in vegetation composition following restoration activities, and changes in density of six obligate riparian breeding bird species at two sites along the Dolores River in Colorado. Avian point counts were undertaken from 2010 to 2014 and we modeled bird density as a function of native vegetation density and extent of defoliation using hierarchical distance sampling. We found that maximum annual tamarisk defoliation by beetles decreased throughout the study period, peaking at 32–37% in 2009–2010 and dropping to 0.5–15% from 2011–2014. Density of all bird species declined concomitantly throughout most of the study, with Blue Grosbeak and Yellow Warbler densities negatively related to defoliation, while Lazuli Bunting exhibited a positive relationship with defoliation. These findings suggest that tamarisk defoliation and removal may have short-term negative impacts on some riparian bird species, but potentially positive effects on others.

How the addition of nesting platforms influences nest parasitism by (*Protocalliphora parorum*) on Cordilleran flycatchers (*Empidonax occidentalis*): consequences of a newly introduced parasite

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ABSTRACT: The Cordilleran flycatcher (*Empidonax occidentalis*) is a neotropical migrant bird species that nests on the Colorado Plateau, and is nest-site limited. The species is a nesting riparian obligate of the mountainous regions of the western US, and migrates to southern Mexico for an 8-month nonbreeding period. The blow fly *Protocalliphora parorum* is known to only parasitize cavity-nesting birds and is not known to kill nestlings. From 2007-2018 we studied breeding of the Cordilleran flycatcher, adding nesting platforms in 2012 with a goal of enhancing breeding productivity. From 2012-14 Cordilleran flycatcher reproductive success increased, with similar developmental periods and nest predation rates in natural and platform nests. However, in 2015 we recorded the first known case of nestling death caused by the *Protocalliphora parorum* blow fly larvae, and this impact escalated each year through the end of our study in 2018. In this presentation we will discuss: 1) How development of a nesting platform enhanced nesting density and productivity of the Cordilleran flycatcher on the Colorado Plateau in SW Colorado, 2) how the blow fly *Protocalliphora parorum* changed egg-laying location, thus greatly impacting a naive avian host, and (3) the consequences to Cordilleran flycatcher productivity of a newly introduced wildlife disease factor. This information is important for understanding potential consequences of human assisted wildlife enhancement activities, as related to changing epidemiology of host/parasite interactions, especially when working to conserve Neotropical migratory bird species of the Americas.

A long-term partnership between the Colorado Plateau Research Station and the National Park Service enables scientist-manager collaboration and informs stewardship of natural resources

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ABSTRACT: Since its formation in 1989 at Northern Arizona University (NAU), the Colorado Plateau Research Station (CPRS) has closely collaborated with the National Park Service (NPS). CPRS was originally an NPS Cooperative Park Studies Unit, with the mission to provide actionable science to the mangers of the region's national park units. Dr. Charles van Riper built this unit from one individual to a team of 42 researchers, who, as an integrated research team, solved natural resources problems throughout the Colorado Plateau and the southwestern United States. These ties continued when CPRS was merged into the United States Geological Survey (USGS) in 1996 and later, when CPRS became an NAU research center. The establishment of the Colorado Plateau Cooperative Ecosystem Studies Unit (CPCESU) in 1998 further facilitated collaboration among CPRS and resource scientists and managers, including the NPS Southern Colorado Plateau Inventory and Monitoring Network (SCPN). Since 2005, CPRS has worked closely with SCPN, monitoring habitat-based bird communities as part of the network's integrated upland monitoring. During this session, we will discuss how CPRS has worked with the CPCESU over the past 21 years and discuss the benefits for NAU, CPCESU partners and natural managers throughout the Colorado Plateau and southwestern United States.

Modeling ponderosa pine mechanical properties to aid restoration efforts in northern Arizona

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ABSTRACT: Land managers in the southwest are responding to overstocked forests by restoring stands to basal area levels within a historical range of variability. In northern Arizona, tens of thousands of acres of mostly ponderosa pine forests have been thinned, resulting in an accumulation of byproducts in the form of tree boles, tops and slash. Without viable markets for this material, the cost of transport from the forest often exceeds its value. Ponderosa pine wood could be used in higher-valued structural applications, but more research is needed on its fundamental properties. Strength (Modulus of Rupture, MoR) and stiffness (Modulus of Elasticity, MoE) are the most important structural properties of wood, and are known to vary tremendously both within a single tree and across a landscape. The goal of this study was to quantify the variability in MoE and MoR of ponderosa pine in northern Arizona and develop models to predict these properties from stand inventory data. Across three national forests in northern Arizona, we destructively sampled 103 trees from 18 sites. From each tree, we collected multiple samples to capture within-tree variability, resulting in 546 total samples. We prepared and tested samples (following ASTM International standards) in three-point static bending to determine MoE and MoR. To link multiple scales of variability, we integrated within-tree variability models into landscape-scale prediction models. Results show that MoE and MoR in mature wood compares favorably with other commercial western species used in structural applications, indicating that separating mature wood from juvenile wood could allow for higher-value products. At the landscape scale, the most important factors determining mechanical properties are crown base height, tree height, and wood density. This can be used in conjunction with inventory data to help inform end-uses of material during the planning stages of a restoration project.

Sagebrush restoration success on the Colorado Plateau depends on soil texture and depth

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ABSTRACT: Restoration success in drylands is strongly influenced by climate conditions, particularly those related to moisture availability for plants. Soil properties, including texture and depth, mediate soil moisture availability and thereby contribute to heterogeneous restoration success within a climate zone. Big sagebrush (*Artemisia tridentata*) is an important component of native plant communities in the Colorado Plateau, but experimental data on how soil texture and depth influence sagebrush restoration plantings is lacking. We experimentally planted sagebrush seedlings across a range of soil textures and depths in sagebrush sites in San Juan County, southeastern Utah. First, we investigated effects of annual climate cycles by repeated plantings across twenty study plots in a wet vs. dry year at one site. We found that sandier, less deep soils were advantageous for sagebrush survival, but only during wet years. Caging of seedlings also improved survival, likely due to improved moisture conditions associated with shading. Second, we examined broader patterns of sagebrush seedling survival during a dry year in 56 study plots distributed across four sites. We found that, in contrast to wet year results, finer textured soils improved sagebrush survival at some sites, and the effects of caging were variable across sites. Overall, our results suggest that, in wet conditions, soils that are well-drained but shallow enough to facilitate plant access to water are advantageous for sagebrush seedling survival. In dry conditions, however, increased water storage provided by finer-textured soils may provide better conditions for seedling survival at some sites. This work illustrates the importance of incorporating information on soil texture and depth into restoration planning to maximize restoration success under increasingly variable climatic conditions.

Effects of temperature on mites and fungi associated with bark beetles

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ABSTRACT: The evolutionary success of tree-infesting bark beetles and wood-boring beetles can often be attributed to a variety of symbionts. Many beetle species form complex mutualisms with wood- and phloem-invading fungi that provide a nutritional resource for the beetle larvae. These mutualistic fungi are introduced into the tree environment via specialized pockets or 'mycangia' present on adult beetles. Similarly, beetles also introduce phoretic mite species into the tree environment, affecting both beetle larvae and their associated mutualistic fungi. These effects may be antagonistic and/or mutualistic with beetles. Mountain pine beetles (*Dendroctonus ponderosae*) are bark beetles native to the American southwest where they are associated with a variety of host trees which include high elevation five-needle white pines. Over the past few decades, they have gained increased attention due to large-scale outbreak

events responsible for tree mortality, particularly in Colorado and British Columbia. Climate, particularly temperature, plays an integral role in the success of these bark beetles. Beetle fitness has been known to fluctuate with temperature. However, few studies have examined the effects of temperature on the symbiont communities of these beetles, nor how they might vary across different populations. Our objective was to determine the effect of warm and cool climate (i.e., temperature) regimes on the symbiotic composition of the mountain pine beetle. We found that some species of mites and fungi favored warm temperatures while others favored cooler temperatures. Thus, the geographic location of the beetle population (i.e., past exposure to particular climates) likely influences the initial symbiotic community with in the tree and the beetle's relative fitness. Temperatures experienced by the symbiotic community within the tree during beetle development will influence beetle population growth via changes in the mite and fungal species.

Summary of effects of breccia-pipe uranium mining in northern Arizona to soil trace-element content, dust flux, and flux of elements into the unsaturated zone across the mine life cycle

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ABSTRACT: One objective of studies of uranium breccia-pipe deposits in northern Arizona is to understand how environmental effects vary across the mine-life cycle. Monitoring of soil, dust, and the unsaturated zone has been occurring at sites representing conditions before mining (EZ2 Mine), during mine development (Canyon Mine), during active mining (Pinenut Mine), after mining and before reclamation (Arizona 1 Mine, Kanab North Mine) and during and after mine reclamation (Kanab North Mine). Results indicate soil concentrations of uranium and uranium-ore related elements, including arsenic, generally increase in surface and shallow soils surrounding and within mine yards (where data are available) while progressing from pre-mining through active- and post-mining conditions. In the Kanab North Mine yard, uranium and arsenic concentrations generally decreased after reclamation, relative to before, and were generally greater than in the soils surrounding the mine. Just over one percent of soil samples exceeded the Arizona non-residential soil remediation level (SRL) of 200 parts per million (ppm) for uranium whereas about 40 percent exceeded the 10 ppm SRL for arsenic. Monitoring of dust transport around the mine sites show that horizontal aeolian flux is elevated in dust collectors located immediately downwind from mine sites relative to collectors located upwind from the same mines and in areas having no mines. Studies of the unsaturated zone quantify the movement (flux) of water and uranium into the subsurface. Preliminary results indicate that movement of uranium into the unsaturated zone increases across the mine-life cycle. Together these studies show that during the mine-life cycle of uranium breccia-pipe deposits, trace elements and dust are mobilized into areas surrounding the mine, and some trace elements (represented by uranium) are moving into the unsaturated zone beneath mine sites. This information may help inform strategies to reduce trace-element transport during mining activities and (or) design more effective reclamation techniques.

Successes and pitfalls in research and land management partnerships

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ABSTRACT: At the Ecological Restoration Institute at Northern Arizona University, there is a history of working with federal and state land managers to establish research and long-term monitoring to advance ecological restoration and conservation in frequent-fire-adapted forests. These experimental sites are located on US Forest Service, Bureau of Land Management, National Park Service, and Arizona state lands. Many of these partnerships and experiments are at or approaching 20-year re-measurement site visits. We share examples of lessons learned and recommendations for long-term project initiation and maintenance. Academic long-term partners contributed scientific support, including project design, consistent data collection and management, and research and monitoring findings applicable to land management decisions. Land management practitioners contributed funding and staff time, including work for the project's environmental compliance review, implementation design, contracting and any prescribed fire application. In addition, agency partners were invaluable to provide real-world policy interpretation to allow application of best available science even under 20-year old management guidelines. Pitfalls of long-term collaboration included staff change, loss of institutional knowledge, and a continuous need for information sharing and re-education across multiple partners. Key characteristics needed for successful partnerships included personal relationships, long-term commitments, and leveraged funding. Continuous coordination, regardless of funding availability, was also critical for long-term experimental maintenance and awareness. Anecdotally, projects were more successful when there was a "champion," or single personality, that maintained momentum and enthusiasm for the project through time. This champion was either from the academic or practitioner side.

Modeling fire trends within the range of the spotted owl

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ABSTRACT: Fire size and severity have increased in the western United States in recent decades and are expected to continue to increase with warming climate. Many species are under threats of large and high-severity fires. We evaluate relationships between spatial patterns of burn severity and changes in habitat suitability across different spatial scales following the Wallow Fire – the largest wildfire in the history of Arizona. We also apply non-stationary area burned projection models and high-severity fire probability models to evaluate recent and future climate-driven trends of fire across the ranges of the three spotted owl subspecies in the western United States. Results suggest that fire effects on habitat suitability were spatially variable and the strength and direction of relationships were scale-dependent. Spatial patterns of burn severity mosaic resembled the patterns of habitat suitability change. High burn severity reduced nesting habitat suitability and the relationship was strongest at large scales. Pre-fire habitat suitability was positively related to burn severity at fairly large scales but the relationship was weak. Low-severity fires showed little negative effects on habitat quality. Current area burned and risk of high-severity fire vary among the three spotted owl subspecies. Future area burned and risk of high-severity fire are expected to increase under climate change within the ranges of all three subspecies. The Mexican spotted owl is expected to have a 13-fold increase in percent area burned within its range by 2080. The combination of increased climate-driven fire extent and risk of high-severity fire suggests a potential for large-scale future loss or modification of spotted owl habitat. Fire studies without the consideration of scales, or conducted at inappropriate scales, may underestimate true fire impacts on species and their habitats.

Structuring science and assessment to inform policy and management within regulated and complex ecosystems

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ABSTRACT: Complexity in systems ecology, water and resource management, politics, and changing dynamics of watershed hydrology require expanded and integrative approaches to river management. Many of the world's large aquatic ecosystems are severely stressed due to population growth, water quality and quantity problems, vulnerability to floods and droughts, the loss of native fauna, invasive species, inadequate and aging infrastructure and challenges of sustaining cultural and social expectations. The consequences of climate change further increase uncertainties in planning and predicting future resource responses. Over the last four decades resource managers, the courts and political forums have embraced various concepts to address the increasing complexity of decision-making and resource allocation. Adaptive management, integrated river basin management, watershed plans, and expanded reservoir operations have emerged as tools. Adaptive management has been used to support the use of science and predictive/conceptual models in the decision framework. Often adaptive management is part of a collaborative approach which brings both agency and non-agency stakeholders together so that goals and management objectives can be developed and embraced. To be of value to the decision process, the science must be credible, legitimate and relevant to the issues and the goals. Reviews of many programs has yielded a rich body of information regarding the success of alternative management approaches. To be relevant, especially in complex applications, the approach embraced must have three factors clearly defined from the beginning: (1) program authority, (2) definitive program governance, and (3) committed funding for science. Science has advanced during the past decades with new technology, data synthesis, modeling and predictive capacity. Severe challenges persist as science discovery does not occur on the same timeframe as management or policy actions. Decisions must often be made in the face of considerable uncertainty and risk. Management approaches in complex systems require innovative and collaborative thinking and cooperation.

Integrating listed species habitat restoration and long-term genetics studies of cottonwoods and willows that can survive climate change at the Cibola National Wildlife Refuge

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ABSTRACT: Riparian areas along the Lower Colorado River support many sensitive and listed species including the southwestern willow flycatcher. With the support of the National Science Foundation, the Cibola National Wildlife Refuge, and the Bureau of Reclamation, we planted native trees and shrubs to provide critical habitat for these species. We overcame challenges of collaborating institutions with the very different mandates (research emphasis for the National Science Foundation and restoration emphasis for the National Wildlife Refuge and Bureau of Reclamation). Because of the expense of such long-term projects no one agency can generally afford to do both and it is crucial for future efforts to solve common problems at local to global scales. Three major goals were addressed: 1. Restore habitat for sensitive and listed species to provide short- and long-term critical habitat, which was successfully accomplished in the short term. 2. Identify the importance of the genetic differences of source populations of species used in restoration. We found major differences in genetic effects on productivity among populations that have been documented among species in different forests across the planet; i.e., genetics is very important for land management and climate change mitigation. 3. Identify populations that can survive current conditions and most importantly, identify those that can survive projected climatic conditions this century when local populations will no longer be expected to survive. We identified plant populations and genotypes from non-local populations that are expected to best survive future conditions. However, as these cottonwoods and willows are near the edge of their geographical and physiological limits, it is imperative that future water stocks essential to their survival be maintained and that extreme temperature events not exceed critical thresholds; i.e., the southwest riparian habitat is very vulnerable to climate change and land managers need to incorporate genetics approaches into long-term management practices to ensure the survival of this threatened ecosystem. Our findings argue that the integration of restoration, adaptive land management, and genetics research is providing real solutions to help mitigate climate change challenges.

Collaborative rare species monitoring with environmental DNA sampling

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ABSTRACT: Characterizing biodiversity at ecologically-relevant scales requires coordinated sampling across landownership types using methods that are cost-effective and informative across a broad suite of taxa. Environmental DNA (eDNA) sampling - the inference of species presence from genetic material in the environment - is a powerful, sensitive tool for rare species detection in aquatic systems. The sampling approach requires little technical skill, is non-invasive, and effective across a large number of divergent taxonomic groups. Further, collected samples can be archived and interrogated to answer new questions in the future. With funding from the Department of Defense (SERDP Project RC18-1348) we are expanding application of a public database to facilitate eDNA monitoring partnerships; the eDNAtlas. To date, this database represents thousands of georeferenced samples and their analysis results. Focusing on military installations and their neighboring lands in the Southwest, this project works with partners to facilitate eDNA sampling on their lands to address local data needs and also to integrate those data into the eDNAtlas to build up more comprehensive, regional biodiversity data resources for the benefit of all partners.

Drought monitoring using quantitative precipitation estimation over northeastern Arizona

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ABSTRACT: The intent of this research effort is to determine the standard precipitation index (SPI) for measuring drought severity using radar derived rainfall measurement products. The National Weather Service Multi-Radar Multi-Sensor (MRMS) quantitative precipitation estimation (QPE) system provides a radar-only rainfall product used in this analysis. The SPI is calculated over a domain that extends over northeastern Arizona. Much of this region exists on the Colorado Plateau, such that it is prone to drought conditions due to orographic effects along the Mogollon Rim as storms move from west to east. Reliable QPE is a challenge to obtain in this area due to the distance from the individual radar locations. The surrounding NWS WSR-88D radars are KFSX located near Flagstaff, AZ, KICX near Cedar City, UT, KGJX near Grand Junction, CO and KABX near Albuquerque, NM. These radar scans are ingested by MRMS to produce QPE over this region. However, at far ranges from the radar sites, beam broadening and terrain obstacles make it difficult to assess the accuracy of rainfall measurements given by MRMS. SPI is generally calculated using the monthly rain gauge accumulation value. This approach is considered due to the lack of rain gauge data over the domain, and thus the SPI is calculated for each radar pixel. The SPI values are such that positive values indicate wetter than normal and negative is drier than normal. The range of values will include rainfall data from 2000 to 2019.

Sparser but larger: phenological shifts compensate for reduced performance after 13 years of warming

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ABSTRACT: Drylands play a dominant role in global carbon cycling and are particularly vulnerable to increasing temperatures that increase evapotranspiration and accelerate drying of terrestrial surfaces. Most warming experiments to date capture only community-level data and fail to track individual plants, potentially leading to divergent patterns. In a 13-year ecosystem warming experiment, we investigated the consequences of rising temperature on the widespread, keystone grass species *Achnatherum hymenoides*. In an effort to make inferences about the likelihood of this species surviving, we tested for shifts in aboveground biomass, phenology, and photosynthesis after 13 years of continuous warming. We also evaluated population cover and recruitment to reveal how changes in population dynamics and individual growth patterns interact. Warming dramatically affected plant growth through large enhancements in aboveground production. However, there were fewer individuals in warmed plots due to lower survival and recruitment over the course of the experiment. As a result, while measured plants are larger in warmed plots, they also represent more of the younger individuals who germinated in our experiment's warmer world conditions. Plants also responded to warming through large changes in phenological cycles, advancing spring green-up by 8.5 ± 2.9 days, date of first flower by 10.8 ± 1.3 days, and senescence by 2.2 ± 1.1 days. No treatment effects were found on photosynthetic optima or temperature optima, but net photosynthesis in the warmed plots was reduced by 30% when soil moisture was not limiting. Overall, our study demonstrates a plastic response of *A. hymenoides* to tolerate 13 years of warming by shifting growth and aboveground allocation strategies and downregulating CO_2 fixation to prevent plant damage. Together, these results suggest *A. hymenoides* may be capable of facing increased temperatures but that the species may not be as abundant nor will the species represent as much of the system's vegetation cover.

The Southwest Fire Science Consortium: the science-management feedback loop

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ABSTRACT: The Southwest is one of the most fire-dominated regions of the U.S. We developed a consortium to make fire science in the Southwest more efficient and inclusive, allowing future issues to be addressed from a broader perspective, with more information, more partners, and more accessible resources. With support from the Joint Fire Science Program, the purpose of the Southwest Fire Science Consortium is to promote communication, build relationships and trust, and to meet the fire knowledge needs of scientists and managers. Fifteen national Fire Science Exchanges now exist across the country. Over the past ten years, the Consortium has provided opportunities for managers, scientists, and policy makers to interact and share science in ways that can effectively move new information to management practices and facilitate new research based on management needs. The Consortium is always looking for new fire science and ways to disseminate that knowledge to the community. The Joint Fire Science Program annually surveyed "consumers" (typically managers) and "producers" (typically researchers) of the national fire science exchanges, the results of which showed primarily positive feedback and a perceived increase in the use and accessibility of fire science. We will also present results of an internal effectiveness evaluation and share these results.

Interactions among scientists and managers in a landscape scale collaborative setting: Retrospection from planning, implementation, and monitoring in a changing world

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ABSTRACT: It is well accepted that there is an urgent need to restore dry forested landscapes for resiliency in the face of large scale, severe disturbances and a multitude of climate change induced stressors. This necessitates that scientists and managers leverage and integrate perspectives and create shared goals. Oftentimes managers are required to ground policy and management decisions in the best available science. However, given time demands on managers, it can be difficult for them to delve deep into existing literature to develop action-based plans that are based on best available science. In addition, determining where gaps in information may exist that

need filled to support management needs can be key to set short- and long-term goals, designing appropriate treatments, and monitoring and adaptive management plans. This is also a chance for managers and scientists to co-develop science to support decisions. Collaborative-based, landscape scale restoration projects, such as the Four Forest Restoration Initiative (4FRI), can provide the opportunity and context for managers and scientists to work together to gather and apply existing scientific information, identify science gaps/needs, and develop stakeholder-derived plans that have scientific foundation. This process can be used to engage and communicate with stakeholders in a collaborative process. In addition, scientists can bring robust concepts and methodologies to monitoring and adaptive management processes that are often required, better setting up managers for success. Examples from 4FRI and other restoration programs will be shared that exemplify successes and difficulties with integrating scientific understanding into collaborative forest restoration and conservation efforts.

Using population models of interacting species to support decisions

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ABSTRACT: Defoliation associated with spreading Tamarisk beetle populations is expected to negatively impact Southwestern Willow Flycatcher (*Empidonax traillii extimus*; hereafter SWFL), a federally listed bird species that typically nests in Tamarisk or native Willow trees. Managers have various potential management activities available to them at a site level to improve SWFL habitat over the long term, however it is unclear how they actions should be sequenced and prioritized to maintain adequate habitat SWFL over time at broad spatial scales. Identifying the best management strategy requires first developing population models that link relevant covariates to SWFL population dynamics followed by formal evaluation of forecasts developed under different alternative management strategies. Here, I discuss how lessons from other complex biological systems with multiple interacting species can inform both population and management models that could be developed to aid decision makers concerned with SWFL. I begin by showing how population and management modelling of three interacting fish species are informing decisions made in the Grand Canyon. Next, I review efforts to quantify the impacts of habitat and negative species interactions on the territorial occupancy dynamics of Northern spotted owl and develop management recommendations. Lastly, I discuss how restoration of native vegetation is optimally timed when a species depends on thick stands of either native or non-native vegetation and restored native vegetation takes many years to mature. I conclude by outlining how such an approach could be applied to identify a restoration strategy, as well as to identify scientific uncertainties that are most critical to address from a management decision perspective.

What about those rare species? Study design implications for multi-species monitoring programs

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ABSTRACT: Multi-species monitoring programs are often designed appropriately for capturing trends with common species, but tend to lack sufficient information to make inference on trends with rare species. These rare species, however, are frequently the species of most concern with large-scale monitoring programs. Bayesian hierarchical multi-species occupancy models can be used to obtain parameter estimates with rare species using assumptions that individual species are governed by community-level parameters, but inference is limited with few detections. This is challenging since most monitoring programs have multiple objectives of determining trends of these rare species from changes in local extinction and colonization, in addition to the overall community trends with changes in species richness or diversity. Our previous work with optimal designs of multi-species community occupancy models with avian monitoring programs indicated rare species occupancy was more influenced by spatial than temporal replicates within a season, while species richness was more driven by temporal replicates (e.g., multiple visits within a season). Our focus for this review is on bird monitoring programs that occur on western National Forests, although results are applicable to other large-scale and long-term multi-species monitoring programs. Our objectives were to (1) summarize current research with study design of rare species; (2) highlight the unique challenges of sampling for rare species in the context of multi-species monitoring programs due to low sample sizes and observational error from false negatives and false positives; and (3) identify potential modifications to study design to maximize accuracy of parameter estimates for rare species while still meeting other community objectives. Special consideration of budget and logistical constraints is important for practical guidance in large monitoring programs; therefore, study design modifications that we propose are within these constraints.

Integrated population modelling of Rio Grande silvery minnow to inform management decisions

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ABSTRACT: The Rio Grande is a heavily regulated river with significant water withdrawals for agricultural and municipal purposes throughout Colorado, New Mexico and Texas. The endangered Rio Grande silvery minnow (*Hybognathus amarus*, RGSM) was once a widespread species throughout the Rio Grande that has been reduced to 5% of its historical range, with the only remaining wild population in the Middle Rio Grande (MRG). Management of RGSM involves a variety of actions including floodplain restoration and modification of spring releases to benefit spawning; however, the flexibility to manage spring flows is modest and often overridden by basin hydrology. Substantial resources have been dedicated to monitoring and research of RGSM populations in the MRG over the last few decades. There is a need for approaches that synthesize results from these activities and provide insights into the effectiveness of management actions and into the management significance of different scientific uncertainties. Here we present results from a model designed to integrate various monitoring and research datasets and summarize understanding of RGSM population dynamics, their response to management actions, and quantify the sources and magnitudes of uncertainty. The goal of this project is to provide a tool that can help managers make decisions about management and future science needs.

Cost-effective restoration: evaluating a decade of land treatments across Utah

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ABSTRACT: Restoration efforts in the southwestern United States have largely focused on the removal of invasive species and the establishment of desirable grasses and woody plants through revegetation initiatives. The specific objectives of individual treatments include enhancing forage availability for wildlife and increasing landscape resilience against drought, fire, and soil erosion. However, poor tracking of economic costs and a lack of systematic, pre- and post-restoration ecological monitoring have made assessments of cost-effectiveness difficult. In this study, we compiled land treatment information from the Watershed Restoration Initiative (WRI) for over 300 different restoration projects across the state of Utah between 2005 and 2017. We evaluated the effectiveness of each effort by comparing treatment costs with vegetation recovery metrics recorded before and after each WRI treatment by Utah's Big Game Range Trend studies. We examined the effectiveness of commonly stated project goals of 1) pinyon-juniper reduction, 2) removal of noxious species, 3) sagebrush enhancement, and 4) increased forage for wildlife, using post-treatment changes in target species. Repeat post-treatment measurements showed varying effectiveness of stated goals; and effectiveness also depended on environmental settings. We conclude that learning from long-term monitoring of restoration costs and outcomes can lead to much needed cost-effective solutions to enhance land condition.

Diné kinship as a framework for conserving native tree species in climate change

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ABSTRACT: Climate change affects all ecosystems but despite increasing recognition for the need to integrate Indigenous knowledge with modern climate science, the epistemological differences between the two make it challenging. In this study, we present how Indigenous belief and knowledge system can frame the application of a modeling tool (Climate-Forest Vegetation Simulator). We focus on managing forest ecosystem services of the Diné (Navajo) Nation as a case study. Most Diné tribal members depend directly on the land for their livelihoods and cultural traditions. The forest plays a vital role in Diné livelihoods through social, cultural, spiritual, subsistence, and economic factors. We simulated forest dynamics over time under alternative climate change scenarios and management strategies to identify forest management strategies that will maintain future ecosystem services. We initialized the Climate-Forest Vegetation Simulator model with data from permanent plots and site-specific growth models under multiple management systems (no-management, thinning, burning, and assisted migration planting) and different climate scenarios (no-climate-change, RCP 4.5, RCP 6.0). Projections of climate change show average losses of basal area of over 65% by 2105, a shift in tree species composition to drier-adapted species, and a decrease in species diversity. While substantial forest loss was inevitable under the warming climate scenarios, the modeling framework allowed us to evaluate the management treatments, including planting,

for conserving multiple tree species in mixed conifer forests, thus providing an anchor for biodiversity. We presented the modeling results and management implications and discuss how they can complement Diné kinship concepts.

Effects of policy change on wildland fire management strategies: Evidence for a paradigm shift in the western US?

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ABSTRACT: In 2009, new guidance for wildland fire management in the United States (US) expanded the range of strategic options for managers working to reduce the threat of high-severity wildland fire, improve forest health, and respond to a changing climate. Markedly, the guidance provides greater flexibility to use naturally ignited fire to meet multiple resource objectives. We use Incident Status Summary (SIT-209) reports to understand how wildland fire management strategies have differed across the western US in recent years and how management has changed since the 2009 Guidance for Implementation of the Federal Fire Policy. Between 2002 and 2016, 87% of large fires (≥40.5 ha) in SIT-209 reports in the western US were managed with a suppression strategy. When controlling for confounding variation within an econometrics framework the 2009 Policy Guidance motivated an estimated 27% to 73% increase in the number of fires managed with expanded strategic options. When comparing like fires, weather revealed counterintuitive influences depending on fire risk and the subsequent application of suppression tactics (e.g., decreased management duration under extreme conditions). The expanded use of strategic options can help increase the scale of fuel reduction in fire-adapted forests and improve fire heterogeneity in the western US.

Best practices for conducting vulnerability assessments for cultural resources in the NPS: workshop description and next steps

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ABSTRACT: In June 2019, the National Park Service in partnership with Boise State University and the University of Arizona conducted a workshop to explore best practices for assessing the vulnerability of cultural heritage resources to climate change. Workshop participants discussed elements of exposure, sensitivity, and adaptive capacity, and conducted a field exercise at Bandelier National Monument. This paper presents workshop results including best practices, data gaps, and future directions for assessing climate change vulnerability of the diverse array of cultural heritage resources under NPS stewardship.

Patterns and themes in climate change vulnerability assessments conducted on NPS cultural resources

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ABSTRACT: Across America, cultural heritage resources under the care of the National Park Service are being impacted by climate change. The National Park Service has therefore conducted an array of vulnerability assessments for archeological sites, historic structures, cultural landscapes, museum property, and more. In 2018 the NPS and Boise State University completed a comparative analysis of 14 vulnerability assessments. The project was designed to learn what has been done, identify data gaps, and improve the practice of vulnerability assessments as well as scientific understanding of cultural resources vulnerability to climate change. This paper presents results of this first-ever analysis along with recommendations.